# USING 3D GARMENT DESIGN SOFTWARE TO CREATE CUSTOM AVATARS FOR WHEELCHAIR USERS: A USER-CENTERED DESIGN APPROACH EXPLORING THE USE OF 3D SOFTWARE TO DESIGN FOR PEOPLE WITH DISABILITIES

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by

MACKENZIE MILLER

Dr. Kerri McBee-Black, Thesis Supervisor

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

USING 3D GARMENT DESIGN SOFTWARE TO CREATE CUSTOM AVATARS FOR WHEELCHAIR USERS: A USER-CENTERED DESIGN APPROACH EXPLORING THE USE OF 3D SOFTWARE TO DESIGN FOR PEOPLE WITH DISABILITIES

presented by Mackenzie Miller,

a candidate for the degree of master of science, and hereby certify that, in their opinion, it is worthy of acceptance.

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Dr. Kerri McBee-Black

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Dr. Li Zhao

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Dr. Song-Yi Youn

## DEDICATION

This work is dedicated to the people who educated me about the importance of disability rights. Thank you to everyone who has ever shared their story with me. While it can be difficult to be open and honest, please know that it has changed my life. Thank you to my friend Arianna, to my grandfather, to my sister, and to my friend Mak who inspired this area of study. Thank you to the essential and difficult work of all disability activists that allow me to even have these opportunities.

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# Chapter I: Introduction

Chapter I contains the following sections: (a) background of the study, (b) purpose of the study, (c) significance of the study, (d) definitions of key terms, and (e) organization of the study.

## Background of the Study

### *People with Disabilities (PWDs)*

Everyday, the majority of the world starts their day by getting dressed. Clothing serves a variety of purposes for each individual. For some, clothing is simply for personal protection, comfort, and security. For others, their dress is a specifically selected set of symbols to represent aspects of their personality, group affiliation, or self-image (Chang, 2014; Lennon et. al., 2017). Having suitable clothing that meets the needs of an individual can help increase their inclusion into societal groups and their confidence (Lennon et al., 2017).

For the over one billion people with disabilities (PWDs) living worldwide, clothing that meets their physiological and psychological needs is simply not available or accessible (Chang et al., 2009; Suri, 2016; Kosinski et al., 2018). Further, the ready-to-wear (RTW) options for people with disabilities (PWDs) are limited in the mass-market apparel marketplace (Carroll, 2015).

### *Adaptive Clothing and PWDs*

Adaptive clothing was created as an option for PWDs, often including design elements like alternative closures (e.g., magnets, snaps, or hook and loop tape), accessible features (e.g., access a medical device), or removal of unneeded features (e.g., eliminating back pockets and rivets on pants for wheelchair users).

However, mainstream apparel brands and retailers have yet to fully embrace the design and production of adaptive clothing in the apparel marketplace (Na, 2007; Sarcone, 2017; Morris, 2019). The few options that are available are evaluated as unfashionable, out of the consumers' intended price range, and lacking in features that are considered useful (Na, 2007; Rutledge, 2017; Sarcone, 2017; Ryan, 2018; Morris, 2019).

Disability is a broad and wide reaching category that includes people who use mobility devices, those with a lack of limb dexterity, people who have sensory sensitivities, and many more potential considerations that can affect garment design (CDC, 2020). Thus, a feature that works for one type of disability may not be beneficial for another disability. While some brands develop items that are considered "adaptive," there are still gaps in the market for many disabilities. Moreover, within the mainstream apparel marketplace, the needs of PWDs are often considered "too specific" to address (Carroll, 2015).

Further, the adaptive needs, the body composition and muscle tone of PWDs is different from non-disabled bodies (Carroll, 2015). This means new blocks and base patterns must be produced to fit the intended consumer group; the development of these necessary solutions is seen as unprofitable and unnecessary within the fashion industry. Thus, PWDs face challenges in finding clothing that fits their body shape and disability type (Chang et al., 2009).

**Apparel Design Education & Training**

Moreover, apparel designers often lack training when designing for PWDs (Kosinski et al., 2018). Currently, there is no standardized apparel design process for

designing products with PWDs as the intended target market (Carroll, 2015). While disability related design projects may be included in some course progressions, apparel design programs currently do not have extensive training for students in designing for people with a variety of functional and aesthetic needs. Without the direct instruction and involvement of course instructors, most students do not consider PWDs as a potential design subject.

In addition, there is a lack of training within the industry on designing for individuals with multiple ability levels (Kosinski et al., 2018). Current industry practices involve designing apparel clothing items based on a strict target market; these targeted consumers are based on contemporary societal ideals of beauty that do not involve PWDs (Carroll, 2015). Adaptive apparel companies are often the only apparel design companies in the industry with PWDs as the intended target market. Still, there is no specific guide for designing for this diverse consumer group; many designers learn preferred clothing features through product testing or personal experiences.

Therefore, it is necessary to explore adaptive clothing design methods in courses and training for apparel design students and industry professionals. Without exposure to the unique fit, function, and performance needs of PWDs, as well as other marginalized consumer groups, most apparel design and product development professionals will lack the necessary knowledge and skills to ensure adaptive clothing continues to expand in the mainstream apparel marketplace.

### *Flat Patternmaking vs. Virtual-Reality Patternmaking*

Traditionally, there are two ways of creating a pattern for a garment–flat patternmaking or draping. These methods can be used separately or in conjunction to

create an ensemble (Joseph-Armstrong & Ashdown, 2022). While both methods are used in the apparel industry, flat patternmaking is utilized more often in mass production (Joseph-Armstrong, 2010). Draping uses fabric manipulated to a dress form to create pattern shapes. These can be traced onto paper and recreated, but are more often used for custom pieces (Joseph-Armstrong & Ashdown, 2022).

Flat patternmaking is a process where a basic (block) pattern is developed to fit a standard set of measurements. This block pattern is then manipulated by adding, subtracting, or substituting design elements to create a desired silhouette (Macdonald, 2019). Thus, all designs are based on an ideal figure with standardized proportions. This allows for an effective and efficient creation of ensembles, as it is all based on the same foundation (Obinnim & AfiPongo, 2015). In addition, standardized pieces can be arranged into a digital pattern marker, allowing for the maximization of the fabric and trim usage for profitable manufacturing (Joseph-Armstrong, 2010).

However, there are some problems with flat pattern design. Since all designs are based on a standardized form, it can be difficult to adapt past designs as the standard form changes. This can cause fit issues with all garments. In addition, it can be difficult to visualize what the pattern will look like until the first draft is sewn. Creating multiple iterations of each product increases production time and labor costs. Unfortunately, this is the primary method that students are instructed on in textile and apparel design studies. Thus, most apparel design and product development students lack the necessary knowledge and skill to transform flat patterns for the unique body formations of consumers such as PWDs.

Virtual reality garment simulation uses 3D software to draw, drape, and pattern clothing designs on 3D avatar bodies. Almost all aspects of the software can be customized; fabrics, avatars, and designs can be manipulated based on purpose and end use (Gill, 2015). Some examples of software are CLO3D, Optitex, Lectra Modaris 3D Fit, Vstitcher, Tuka3D, & Gerber Accumark 3D (Lee & Park, 2017).

Virtual reality garment simulation provides designers with an improved way to create marketable garment designs. They are able to use virtual avatars to drape or draw directly on a standardized form, then have pattern shapes generated automatically to create the silhouette they desire (Volino, Cordier, & Magnenat-Thalmann, 2004). In addition, pattern shapes can be instantly edited to another garment shape or silhouette, for example PWDs.

Further, virtual reality garment development has features that assist with grading, pattern nesting, surface design visualization, and virtual try-on. The software can be utilized to create pattern markers to assist the production staff with pattern layout. Which can help maximize fabric use.

While criticism and limitations have existed for virtual reality garment development (i.e., Issues in realism of the textiles, need for customization in avatars, and user interface issues) the virtual reality software developers have made great improvements to address these issues (Liu et. al., 2020). One significant improvement is the use of customized avatars. Avatars are the virtual fit models used to demonstrate the 3D view of the created garment design.

Currently, there is an integration between CLO3D and Alvanon, the industry standard for dress forms. Digital replicas of the Alvanon mannequins, called Alvaforms,

can be uploaded to the virtual reality garment software to help optimize fit between virtual reality and real life garments (Alvanon, 2023). Furthermore, customized avatars can be created using circumference and length measurements or full body scanning (Luu & Zhang, 2021).

Moreover, kinematic skeleton development of virtual avatars has allowed for adaptations in posture and animation of avatars; this can help achieve a more realistic shape for bodies outside of the standard form (Kozar et al., 2014; Jevsnik et al., 2017). For example, Hobbs & Morris (2020) used a custom 3d avatar to create a custom Paralympic shooting jacket. The results showed that avatar assisted in making a more accurate and usable prototype in the virtual reality garment software.

While there has been progress in research exploring the use of virtual reality software for garment production, s research area, there remains a gap in the literature regarding the use of customized avatars and virtual reality garment software to design for PWDs on a mass market basis. One way to support such research is in the area of user-centered design.

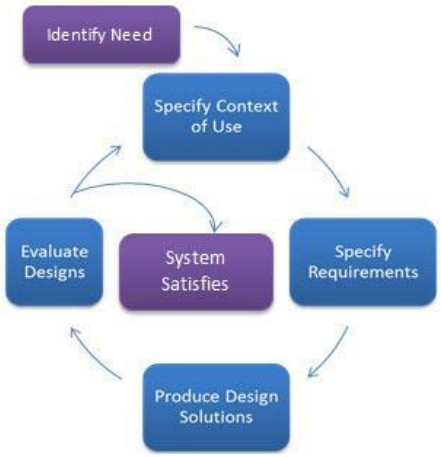
***User-Centered Design***

User-centered design is a design framework focusing on gaining a deep understanding of the person that will be using the product. Originally used in studying technology and user satisfaction (Abras, Maloney-Krichmar, & Preece, 2004). This iterative process focuses on five main stages of design: a) specifying context of use; b) determining the goals of the user; c) creating solutions by centering the user(s) needs; d) evaluating the effectiveness with potential users; and e) assessing whether the product satisfies those predetermined needs. These five stages of design create a feedback loop

that continues until the design problems are solved. At the end of any evaluation with the user, the researchers or designers can return to the previous step or back to the beginning of the process to test a new iteration until the design satisfies the target market users. See Figure 1.1 for the user-centered design feedback loop.

**Figure 1.1**

*User-centered design feedback loop*




*Note.* Figure 1 was taken from User-centered design Basics from usability.gov

With a focus on research on the intended user, focus groups, and wear testing, user-centered design framework is an ideal strategy in designing for users with specific needs, like PWDs. There are multiple studies focusing on creating functional designs for PWDs using user-centered design as the design approach (Morris, Park, & Sarkar, 2017; Sokolowski et. al., 2018, Orlando et. al., 2020; Imbesi & Scataglini, 2021; Shrock & McBee-Black, 2022; Wu & McBee-Black, 2022). However, there are still gaps in the literature about using a user-centered design approach to create designs for PWDs that can be replicated on a mass-market level. In addition, there is a lack of previous research

about incorporating virtual reality garment software to facilitate a more robust user-centered design process.

With the previously stated gaps in the literature, this study is focused on engaging PWDs in the apparel design process to develop a user-centered design approach using virtual reality garment design software that can be utilized in the mass-market apparel industry. The research will compare two types of garment design techniques–traditional flat pattern techniques and 3D virtual reality garment simulation software. Currently, designers are missing knowledge on designing for PWDs because of lack of training, limited experience, and lack of an effective design process (Kosinski et al., 2018). These problems continue to contribute to the gap in available clothing for people who use mobility aids (Chang et al., 2009). As of now, there is more clothing available for pets than PWDs (Ryan, 2018). Therefore, this research intends to provide a blueprint for future designers when designing for the market of PWDs in order to create garments that meet the needs of PWDs that can also be developed using mass-market technology.

**Purpose of the Study**

The purpose of this study is to discover a more efficient and effective way of designing for PWDs through the use of 3D virtual reality garment design software. To achieve this objective, the user-centered design model and the social model of disability will be used to inform a semi-structured interview process. The study will deploy qualitative methods including semi-structured interviews with PWDs and with adaptive apparel designers. The researcher will analyze the traditional flat-pattern garment design methods and the virtual reality garment software using a comparative design process.

## Significance of the Study

### *PWDs*

As previously stated, PWDs lack apparel options in the mainstream apparel marketplace (Chang et al., 2009; Suri, 2016; Kosinski et al., 2018). This is due to a lack of understanding of the needs of PWDs (Na, 2007; Rutledge, 2017; Sarcone, 2017; Ryan, 2018; Morris, 2019), an absence of education and instruction for emerging apparel designers in designing for people with a range of ability needs (Kosinski et al., 2018), and a lack of engagement with intended users with disabilities (Carroll, 2015). The traditional process of apparel design, which includes segmenting users mainly by demographic characteristics, does not work with the need to develop specific design features for clothing intended for PWDs (Carroll, 2015).

Currently, there is no specified design process to create garments for PWDs. However, recent developments in virtual reality garment software show promise in assisting the user-centered design process. Therefore, the significance of this research is to contribute to three main areas: (a) improve garment design options for PWDs, (b) creating a guide for apparel designers who want to create inclusive designs, and (c) developing a strategy to educate apparel design students to utilize virtual reality garment software to design for PWDs.

The research study can benefit PWDs by using their direct feedback, needs, and wants for garment design to develop better apparel products for them. For PWDs, this study is designed to showcase their apparel needs and wants by developing apparel that is specifically designed for them. Further, the PWDs engaged in the study will provide direct feedback to the physical and psychological aspects of the clothing they currently

use, which will allow the researcher to incorporate those dynamics into the design process. Overall, this study aims to provide a voice in a space that PWDs are typically excluded from.

### *Apparel Designers*

Furthermore, the study can benefit apparel designers who have a desire to create garments that satisfy the wants and needs of PWDs. By having a streamlined garment design strategy, apparel designers can have a resource to access as they develop more inclusive designs. In addition, this study will inform apparel designers about the importance of engaging directly with the target market when designing for PWDs. This research can help improve the background research and design evaluation processes for apparel designers. Finally, the study can inform apparel designers about the significance of using virtual reality garment software in apparel design; specifically how it can improve the user engagement process.

### *Apparel Design Educators*

Apparel design educators will also gain the same benefits as apparel designers. Additionally, this study can inform apparel design educators who desire to incorporate more inclusive design practices in their apparel design coursework. With a lack of a standard apparel design process, the results of this research can provide a framework for which to base future product development modules around. With an emphasis on user engagement, it can help students develop empathy for users and encourage them to think in a more inclusive fashion.

In designing apparel for PWDs using 3D technology, students will be engaging with the software in a new way; this can help develop a deeper understanding of the

software's features and functionality. An emphasis on utilizing 3D technology can help students gain a competitive advantage, as its use is increasing within the fashion industry. Finally, students can carry these skills into the industry to influence the creation of future products in a more inclusive fashion.

## Organization of the Study

This thesis is organized into five chapters as follows. Chapter I presents the introduction, justification, and purpose of the research study. Chapter II presents information outlining the disability consumer in greater detail, design frameworks that have been previously utilized to design for people with disabilities, and a background on virtual reality garment design software. Chapter III presents the research methods, recruitment, sample selection, and analysis of the data. Chapter IV presents the major themes of the research findings from the semi-structured interviews as well as the results of the comparative design study.

## Definitions of Key Terms

**Table 1.1**

*Definition of Key Terms*

| | |
|---|---|
| **Flat pattern garment design** | A method of garment design using body measurements to create paper (flat) patterns (Joseph-Armstrong, 2009) |
| **Virtual reality garment simulation** | Uses 3D software to drape and pattern clothing designs on 3D avatar bodies. Some examples of software are CLO3D, Optitex, Lectra Modaris 3D Fit, Vstitcher, Tuka3D, & Gerber Accumark 3D (Gill, 2015; Lee & Park, 2017). |
| **Wheelchair Users** | People who use wheelchairs for mobility purposes. While some use this mobility aid full time, others use it part time. There are a variety of types of wheelchairs, including power wheelchairs, manual wheelchairs, and bariatric wheelchairs (Sellars, 2017). |

| | |
|---|---|
| **Apparel Designers** | People whose occupation is to create clothing for targeted consumers (Joseph-Armstrong, 2009). |
| **Functional Design** | The process of apparel design where the ending product features are dictated by the user's specific needs, like need for flame retardants (in terms of a firefighter's uniform) or need to be hydrophobic and wick water (like in activewear) (Watkins & Dunne, 2019). |
| **Disability** | A physical or mental impairment that substantially limits one or more major life activities (ADA, 1990). |
| **Flat Patternmaking** | Drafting a sewing pattern on paper using human body length and circumference measurements as a guide for creation (Lo, 2021). |
| **2D Vs 3D** | 2D pattern making uses circumference measurements and formulas to create paper pattern designs. These designs can then be sewn into 3D designs. 3D pattern making uses virtual avatars and workspaces to create a 3D rendering of the design while simultaneously generating a 2D pattern of the garment. |

## Chapter II: Literature Review

Chapter II contains the following sections: (a) overview of disability, (b) people with disabilities and the apparel industry, (c) people with disabilities and adaptive clothing, (d) people with disabilities and garment challenges, (e) FEA model, (f) Universal Design, (g) Inclusive Design, and (h) virtual reality garment simulation for people with disabilities.

### Overview of Disability

One is not able to unassociate "disability" from the strong cultural and political roots it holds, or ignore historical and geographical contexts and inequalities (Burch & Patterson, 2013). Under the Americans with Disabilities Act (ADA), the definition of disability is: a person with a physical or mental impairment that substantially limits one or more major life activities of that individual (ADA, 1990). The ADA was passed in July 1990 to protect people with disabilities (PWDs) from discrimination and provide

accessibility accommodations within the environment, the workplace, and education (ADA, 1990). According to the World Health Organization (2001), disability includes three dimensions: impairment in a person's body structure or function, or mental functioning; activity limitation; and participation restrictions in normal daily activities.

Impairment is a condition that results in a difference in a person's physiological or psychological functioning. Disability is a limitation or lack of opportunities to take an equal part in society because of societal and environmental barriers (Oliver, 1983). To be clear, a person's impairments do not cause them to be unable to socially participate. The lack of accommodations provided by those without disabilities prevents them from opportunities to be included in society (Oliver, 1983; Northern Officers Group, 1999).

The Center for Disease Control (CDC) has established six categories of disability: hearing, vision, cognitive, mobility, self-care, and independent living (2016). While these are broad categories, there is a diverse range of disabilities within these categories; each has unique needs that must be taken into account. While some conditions are present at birth, others are developed later in life. These conditions can affect functions during a person's life, including traversing the physical environment, traveling independently, ability to work, learning & comprehension, behavior, or a combination of these (CDC, 2019). Further, a person may experience overlap in these categories related to their condition(s). PWDs require a variety of levels of care; some PWDs are able to live independently, while others need assistance with activities of daily living (CDC, 2019).

## People With Disabilities and the Apparel Industry

In terms of the population of the United States, 85 million (27 percent) have some form of disability. In other words, 1 in 4 people in the US have a disability (CDC, 2023). In terms of mobility related disabilities, this is equal to 40 million (12.1 percent), which is about 1 in 8 people (CDC, 2023). For most of the 20th and 21st century, the fashion industry has focused on a narrowly defined retail customer; one based on contemporary societal ideals of beauty: young, conventionally attractive, and high perceived physical health (Carroll, 2015).

Apparel designers receive extremely limited training (if any) on designing clothing that encompasses many ability levels (Kosinski et al., 2018). Many academic fashion design programs design for a seemingly able-bodied, traditionally female, size 6 ideal customer; they are typically taught the needs of consumers outside of that range (Christel, 2017). Further, the current methods used for designing clothing for PWDs focus on creating a singular functional garment for one person or small focus group of people, which can contribute to the stigma that designing for PWDs is difficult or not profitable (Rosenblad-Wallin, 1985; Stokes & Black, 2012; Menec, 1989).

With this being said, PWDs face significant challenges in shopping for clothing that fits their body shape and need to dress independently (Chang et al., 2009). As a neglected market, PWDs are unsatisfied with the selection of RTW clothing options that are available (Suri, 2016; Kosinski et al., 2018), and feel alienated from the fashion industry due to the lack of apparel options available and the social stigma of disability (Freeman, Kaiser & Wingate, 1985-1986). The combined issues of lack of design

training, stigma around disability, and fashion industry ideals have resulted in more available clothing for pets than for PWDs (Ryan, 2018).

While some brands are trying to create disability friendly clothing (Gallucci, 2018; Klein & Madrid-Han, 2018), there remains dissatisfaction among the disability population with these options as well (Freeman, Kaiser & Wingate, 1985-1986; Rutledge, 2017; Sarcone, 2017; Morris, 2019). Thus, there is a strong need for a more efficient process of designing for PWDs that ensures their voices are included in the creation process.

**People with Disabilities and Adaptive Clothing**

Adaptive clothing is defined as items of clothing specifically designed for PWDs who may have difficulties with dressing independently or traditional features on RTW clothing (Langtree, 2016). Clothing in this category assists with independent dressing, helps caregivers assist in the dressing process, can hold medical devices or monitors, and/or provide a more comfortable experience while wearing the items of clothing (Banks, 2001).

Adaptive clothing features unique design innovations including alternative closures like magnets, snaps, or hook and loop tape, seated position pants for those in wheelchairs, grab loops on closures, shoes with zippers instead of laces, and alternative closure placements for ease of accessing medical devices (Reich & Shannon, 1980; Banks, 2001; Na, 2007; Ruteledge, 2017; Sarcone, 2017; Gallucci, 2018). Many adaptive clothing items were sold as medical devices until 2009 with the introduction of IZ Adaptive by designer Izzy Camilleri (Klein & Madrid-Han, 2018). IZ Adaptive introduced mainstream denim jeans for PWDs, specifically wheelchair users.

Further, the adaptive clothing movement gained significant attention when Tommy Hilfiger launched the first mainstream adaptive apparel line for children. The Runway of Dreams Foundation (RoD) was founded in 2014 as "a nonprofit that works toward a future of inclusion, acceptance and opportunity in the fashion industry" (Everyday Living, 2019). In 2017, RoD collaborated with Tommy Hilfiger to develop the first mainstream adaptive children's wear line.

After the success with the adaptive childrenswear line, Tommy Adaptive was created with "a mission is to be inclusive and empower people of all abilities to express themselves through fashion." (Gallucci, 2018). Other brands, like Target and Zappos have started entering the arena as well, with Zappos partnering with Runway of Dreams in 2019 to create the first fashion show presenting adaptive clothing and models with disabilities (Vazquez, 2020). Even with these forward strides, there is still a gap in the market for fashionable adaptive clothing for PWDs (Morris, 2019). Further, there remains a gap in how best to design with PWDs to ensure their clothing meets their needs and wants.

**People with Disabilities and Garment Challenges**

Overall, PWDs do not find that RTW clothing satisfies their needs (Caroll & Kincade, 2007). Typically, PWDs face fit issues when purchasing RTW which causes issues with overall attractiveness and comfort (Chang et al., 2009; Lee & Jin, 2019). Moreover, the conventional sizing system currently used in the apparel marketplace fails to accommodate PWDs (Thoren, 1997; Li Wang, et. al., 2013). Many PWDs experience anatomical changes, like curved spines, limb differences, or height variations (Ng et. al., 2011). In addition, many PWDs are aging, where height decreases are common (Civitci,

2004). Thus, causing challenges in finding RTW clothes that achieve a desired fit (Wang et. al., 2014; Carroll & Gross, 2010; Sarcone, 2017).

Anatomical changes can also affect the way clothes fit PWDs. For example, curvature of the spine, limb difference, paralysis that causes atrophy or distended abdomens, can cause issues in traditional clothing styles. Further, spinal cord injuries can impact thermal regulation, thus causing an inability to regulate body temperature. Therefore, apparel that accommodates these unique features related to specific disabilities should be considered and addressed when designing apparel with PWDs (Ng, Hui, & Wong, 2011; Civitci, 2004; Li Wang, et. al., 2013).

Further, individuals who use wheelchairs experience specific garment challenges. One of the main issues for those who use a wheelchair in terms of clothing fit is the fit of pants (Abraham-Murali, Kane, & Staples, 2001; Suri, 2016). For people who use wheelchairs, the shape of their body differs when sitting versus when standing (Na, 2007). Muscle tone can also vary from the "typical" person without disabilities (Kidd, 2006; Ruteledge, 2017). For example, protruding stomachs can be common (Chau, 2012), as well as a loss of muscle tone can occur in those with a loss of sensation (Gefen, 2014). Conversely, shoulder or arm muscularity may be increased because of the motion of propelling a wheelchair. Thus, ease in the shoulder and armscye may make the fit more comfortable (Sarcone, 2017). Additional ease should be incorporated to accommodate body changes or mobility devices (Na, 2007; Morris, 2019).

Furthermore, garments can often be inappropriately long in a seated position. This can cause a safety issue, as excess fabric can be caught in mobility aids (Na, 2007; Sarcone, 2017). Thicker fabrics or bulky seam finishes can cause pressure sores or

abrasions to those using wheelchairs (Ruteledge, 2017). Additionally, someone who is consistently in a seated position will not be able to use back pockets. Pockets located on the back are a common location of pockets on jeans and other pants, but are not usable when seated in a wheelchair (Thorton, 1990).

Additionally, a person using a wheelchair may experience a loss of dexterity; this can make donning and doffing apparel independently extremely challenging (Newton, 1976; Stokes, 2010). The size, shape, and location of closures can add additional difficulties (Dallas et al, 1982; Chung, Lee, & Ahn, 2007). Back closures with small pulls or tabs are some of the most difficult to use without assistance (Sarcone, 2017). With these substantial challenges in finding clothing that fits their aesthetic and functional needs, PWDs remain unsatisfied with the selection of clothing available for their consumption (Suri, 2016; Kosinski et. al., 2018).

Therefore, additional research should explore how best to design adaptive clothing which accommodates the needs and wants of PWDs, specifically those who use a wheelchair. Thus, this study aimed to discover a more efficient and effective way of designing for PWDs through the use of 3D virtual reality garment design software.

**FEA Model**

While models such as the Functional, Expressive, & Aesthetic Consumer Needs Model (FEA model) have been used for over two decades, they do not always apply to designing for PWDs. The FEA model was created by Lamb and Kallal (1992) as a conceptual framework that assesses the needs of the user when creating a new apparel product. The key of this model is that it assists in resolving problems related to apparel for consumers. This model works whether the primary use of the garment is functional or

fashionable. It also accounts for the cultural context behind the garment (Orzada & Kallal, 2016).

There are five needs assessed with the model:

a) Target Consumer - This is the core of the model. Designers develop a profile of the user's demographics and psychographics, along with their needs and wants in a garment or product.

b) Culture - Culture is the filter between the user of a product and the item itself. This is the frame that users consider what are acceptable items to wear in a context.

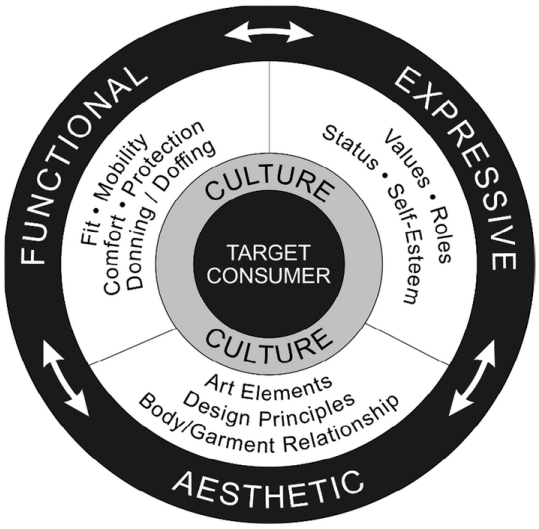
c) Functional - Functional considerations are in regards to utility, like putting on and taking off, fit, and how well a person can move.

d) Expressive - Expressive elements relate to the symbolism an item of clothing communicates about the wearer. Users can choose garments that portray a certain meaning about themselves or that they feel fit into their personal style.

e) Aesthetic - Clothing is fashion as well as function, so the aesthetic element considers elements of art and beauty to create a pleasing design to the intended audience's eye.

**Figure 2.1**

*Functional, Expressive, & Aesthetic (FEA) Consumer Needs Model*




*Note.* Figure 2 was taken from A Conceptual Framework for Apparel Design (Lamb & Kallal, 1992).

Zainea & An (2020) utilized the FEA Model to design three prototypes of vests for individuals with Alzheimers. The researchers found functional needs like thermal protection and ease of closure use, expressive needs like customizable fasteners, and aesthetic needs in attractive colors and design. Thus, the three designs were created using the findings, which applied the FEA model to create a vest that provided sensory stimulation while still providing warmth and comfort.

Hobbs & Morris (2020), using the FEAL model, created a custom Paralympic shooting jacket for a female athlete. Through interviews and interactions with the participant, the researchers recognized the emotional, functional, and appearance needs for the athlete. One interesting finding was how the participant rated aesthetic needs as much higher than functional or expressive. At the end of the interview and coding process, the researchers created a prototype using CLO3D.

While the study by Hobbs & Morris (2020) attempted to address the aesthetic needs of the PWD user, one of the main struggles with using the FEA model for PWDs is

that many designers focus solely on the functional and cultural aspects of the model. Many with disabilities feel that ignoring the aesthetic elements makes them feel more like medical equipment than people (Sarcone, 2017). In addition, much of the research utilizing the FEA model focuses on a single case study or specialized group of individuals. While these are positive developments, these studies do not show the mass market appeal of these clothing adaptations. Thus, this study aims to address this gap in the literature when exploring how to develop adaptive apparel that is scalable and therefore more profitable for apparel brands and retailers.

**Universal Design**

Universal design is the design of products so that they can be understood and accessed by the greatest number of people possible; regardless of age, size, or ability level, the environment or product will be usable (Preiser & Smith, 2011). Applying these concepts to apparel design, universally designed garments allow individuals with or without disabilities to use or wear a clothing item in the same manner (Preiser & Smith, 2011; Park et. al., 2014).

There are seven principles of universal design (Preiser & Smith, 2011):

| | |
|---|---|
| Principle I: Equitable Use | 1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.<br>1b. Avoid segregating or stigmatizing any users.<br>1c. Make provisions for privacy, security, and safety equally available to all users.<br>1d. Make the design appealing to all users. |
| Principle II: Flexibility in Use | 2a. Provide choice in methods of use. |

| | |
|---|---|
| | 2b. Accommodate right- or left-handed access and use.<br>2c. Facilitate the user's accuracy and precision.<br>2d. Provide adaptability to the user's pace. |
| Principle III: Simple and Intuitive Use | 3a. Eliminate unnecessary complexity.<br>3b. Be consistent with user expectations and intuition.<br>3c. Accommodate a wide range of literacy and language skills.<br>3d. Arrange information consistent with its importance.<br>3e. Provide effective prompting and feedback during and after task completion |
| Principle IV: Perceptible Information | 4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.<br>4b. Maximize "legibility" of essential information.<br>4c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).<br>4d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations. |
| Principle V: Tolerance for Error | 5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated,<br>isolated, or shielded. |

| | |
|---|---|
| | 5b. Provide warnings of hazards and errors.<br>5c. Provide fail-safe features.<br>5d. Discourage unconscious action in tasks that require vigilance |
| Principle VI: Low Physical Effort | 6a. Allow users to maintain a neutral body position.<br>6b. Use reasonable operating forces.<br>6c. Minimize repetitive actions.<br>6d. Minimize sustained physical effort |
| Principle VII: Size and Space for Approach and Use | 7a. Provide a clear line of sight to important elements for any seated or standing user.<br>7b. Make reach to all components comfortable for any seated or standing user.<br>7c. Accommodate variations in hand and grip size.<br>7d. Provide adequate space for the use of assistive devices or personal assistance. |

Starkey & Parsons (2013) evaluated the handbag needs of wheelchair users using a universal design framework. The goal of this pilot study was to identify the specific needs of the underserved market segment while applying the principles of universal design. The researchers chose the wheelchair market as part of their initial questionnaire because of their unique needs for a handbag, but felt that the information could be applied to other market segments. The users were specifically interested in a bag that was universally designed–a bag that would not seem different from a bag that a non-wheelchair person would use. Overall, the research concluded that there was a lack of bag

selections for wheelchair users in the current market; the data collected could be used to inform a larger study including prototype bags.

Annett-Hitchcock (2020) utilized universal design to create a jacket that can be used for individuals with upper body immobility. Based on a patent from 1914, this garment was analyzed as an early example of universal design. This garment can be laid completely flat and be manipulated around the body without having to force someone's arms through sleeves. In addition, Annett-Hitchcock used colored snaps to indicate which sections connect, contributing to simple and intuitive use (i.e., principle III). There are also multiple ways to wear the garment. The researcher also suggests that an evaluation of aesthetic properties should be added to the universal design framework as "I believe that a marketable product must have aesthetic appeal" (Annett-Hitchcock, 2020).

Universal design theory can help combat the concept of stigmatization (both internal and external) that can often increase with "specially made" clothing (Freeman, Kaiser, & Wingate, 1985-1986, p. 51). Contrastly, some items may need to be created for specific purposes. For example, a wheelchair user requires a higher back rise in their pants and needs back pockets eliminated, while users with limited dexterity may find back pockets easier to access and require a faux fly front closure.

Moreover, relaxed silhouettes with minimal design details are encouraged as part of the universal design principles (Park et. al., 2014), but this can lead to a lack of innovative designs or interesting apparel details. The focus on the functional inclusion instead of needs centered around specific user groups is a negative aspect of this method. In a study by McBee-Black and Ha-Brookshire (2020), it was found that products marketed as universal design were not marketed specifically for PWDs. This could make

products more challenging to find, thus possibly indicating a need for a more specific set of features for a defined user group.Thus, it is important to consider universal design as a design principle while still considering the needs of specific users.

**Inclusive Design**

Inclusive design is based on the aforementioned universal design. While the end goals are similar, the approaches to each framework are different. Universal design is based on a "one-size-fits-all" concept (Keates & Clarkson, 2002, p. 69). While this strategy may work for the built environment, there are many more factors affecting apparel design that will not work for this approach. Recognizing that one product may not meet the needs of an entire population, inclusive design focuses on dividing the population into multiple segments based on their specific needs (Clarkson et al., 2003; Waller et al., 2013).

The goal of inclusive design is to improve the design of "environments and products by making them more usable, safer, and appealing to people with a wide range of abilities" (Patrick & Hollenbeck, 2021, p. 361-362). Whereas, disability represents a diverse group of needs, inclusive design attempts to serve the unique needs of PWDs using a mindful approach (Carroll & Kincade, 2007).

There are two main criteria to guide the inclusive design process (Cho & Karpova, 2021):

1. *Understanding user diverse capabilities.* It is important for designers to be mindful of all users and not to accidentally exclude a group of people from using the product. If the effort required to use the product exceeds the range of the user's capabilities, it is considered design exclusion.

2. *Responding to user diverse capabilities*. This framework encourages designers to systematically address the needs of the specific target user group while expanding the product usability to anyone with a full range of usability capabilities.

Carroll & Kincade (2009) utilized the inclusive design framework to explore product development strategies for a group of women with disabilities whose impairments were dissimilar to each other. The goal was to help broaden the idea of the "target market" to demonstrate the commercial viability of apparel for PWDs. The researchers utilized a codesign process to involve the intended user group directly. The end product of the study was a jacket. Users had positive reactions to the jacket both aesthetically and functionally, while the product testers felt that there were some features that needed to be more specific towards a users' individual impairments.

Cho & Morris (2018) developed a baseline set of design criteria for men with lower body mobility impairments based on the inclusive design framework. The researchers used both in-person interviews and content analysis to suggest a criteria for producers of mass-produced apparel to create inclusive apparel. It was found that the participants preferred to purchase and wear RTW apparel because of the negative perceptions of "specially designed" clothing. The study suggested that more inclusive features be incorporated into RTW clothing to help reduce stigma and increase availability.

While there are improvements from universal design, there is still a lack of specific criteria to verify that a garment will work for the intended user. In addition, there is a lack of information, within the inclusive design framework, related to an iterative

process to gain additional feedback. Overall, more specific criteria to guide apparel designers could be of benefit, especially at the original generation of adaptive clothing for a brand. If a firm lacks knowledge of a user group, it may be necessary to have a strong base of knowledge rather than a far reaching target consumer that is considered "disabled". Therefore, this study aims to address the gap in literature by including PWDs into the design process to help add to the specific criteria needed to design for the unique needs of PWDs.

**Virtual Reality Garment Simulation and PWDs**

Virtual reality and augmented reality is being utilized in the fashion industry in a variety of ways. From virtual try on services, to augmented reality styling, to digital store layouts, it is becoming increasingly popular to use this technology to help customers visualize what clothing or a store will look like in a more cost effective way (Liu et. al., 2020).

Moreover, virtual reality garment simulation provides designers with an improved way to create marketable garment designs as well as to shorten the lead time from production to market, ensuring more profit for the brand and the retailer (Kamal, 2015). Designers are able to use virtual avatars to drape or draw directly on a standardized form which provides the opportunity to develop pattern shapes generated automatically to create the silhouette they desire (Volino, Cordier, & Magnenat-Thalmann, 2004).

While virtual reality garment simulation is growing and impacting apparel design at significant rates, there are still issues that need to be addressed to ensure the 3D platform addresses the needs of the user. For example, textile realism, the ability to digitize fabrics and materials that drape and handle realistically is still a challenge in

virtual reality. Designers lack the ability to understand the performance of a garment on a virtual body when 3D textiles do not perform realistically (Liu et. al., 2020).

Further, while the avatar simulation has improved significantly, there are still barriers that exist. For example, most 3D simulators lack avatars with body differences. Thus, apparel designers are unable to assess how adaptive clothing will perform on a PWDs. CLO3D recently launched a new update to other 3D software that allows for soft tissue customization on their avatars. This update will allow for more realistic fits and therefore, better performing garments for all users, including PWDs (Ryan Lee-Tang, 2023, June 15).

Virtual reality garment simulation has been used in the past to design for PWDs. Hobbs and Morris (2020) used virtual body scanning and CLO3D software to create a custom paralympic shooting jacket. This case study involved creating a garment for a single consumer. The researchers found importance in both the emotional and functional connection of garment design for someone with a disability. Overall, this study did utilize virtual reality garment simulation to create a specialized piece, but the overall focus was use of user-centered design processes and the application of the FEA model.

Luu and Zhang (2021) pointed out multiple benefits of using virtual reality garment design for PWDs. These included accuracy in product information, lower production costs, reduction of waste and physical samples, and the ability to fit a similar design to multiple body types with ease. Currently, there are seemingly no examples of CLO3D software being utilized for PWDs in the apparel industry. However, there are examples of utilizing virtual reality to improve fit (Wang & Liu, 2020), access (Xu, Yue, & Xiaogang, 2021), and cost (Luu & Zhang, 2021; Wang & Cho, 2021).

Thus, it is safe to assume that virtual reality garment simulation could be used to accommodate the needs of PWDs. In addition, virtual reality garment design software may provide equity in clothing design by using elements of the CLO3D software to better engage with the user. Some of the issues the researchers found with the current use of virtual garment design was lack of appropriate seated avatars, inability to have asymmetrical avatars, and reliance on custom 3D body scanning technology to develop different avatars (Hobbs & Morris, 2020; Luu & Zhang, 2021).

As the disability market is set to reach $400 billion by 2026 (Gaffney, 2019), it is expected that fashion brands can use virtual reality garment simulation to address the clothing needs and wants of PWDs in a more efficient and cost effective way. Therefore, due to the gap in literature the goal of this research is to develop a curriculum module demonstrating the use of virtual reality to create custom avatars to engage wheelchair users in the apparel design process using 3D garment design software and user-centered design approach.

**Theoretical Frameworks**

This study will use a combination of the social model of disability and user centered design to underpin this study. The social model of disability views disability as a restriction in being able to fully participate in home and community activities because of societal barriers (Oliver, 1983; Shakespeare, 2013). These findings align with findings of significant challenges PWDs face in shopping for clothing that fits their needs (Chang et al., 2009). In addition to a lack of clothing options for PWDs, what is available is inaccessible due to physical, social, and financial barriers (Freeman, Kaiser & Wingate, 1985-1986; Sarcone, 2017). In addition, designers are missing knowledge on designing

for people with disabilities (PWDs) because of lack of training, limited experience, and lack of an effective design process (Kosinski et al., 2018).

User centered design will be used to focus on creating solutions with the users in mind. Through wear testing, incorporating their feedback, and iterative design processes, this study will work to ensure a user-focused approach to understanding and resolving apparel challenges for PWDs (The International Organization for Standardization, 1999). A user-centered design framework can be more labor intensive. However, this study will use virtual reality technology to attempt to improve the efficiency of design, testing, and communication with the users.

**User Centered Design**

User centered design is a design method focused on the wants and needs of the user. It engages the user with the design process from design generation to design prototype so the user's needs and wants are incorporated into the design. User-centered design includes an emphasis on background research, focus groups, prototyping, user testing, and interviews and questionnaires to assess user satisfaction at all stages (Karat, 1997).

There are five main stages of user-centered design:

a) Specify the context of use by identifying the users and how they will use the product
b) Determine the goals of the user in order to determine the success of a product
c) Create solutions by using the knowledge of the users and centering their needs in the process

d) Evaluate the effectiveness of the solutions by testing the features with actual potential users
e) Assess whether the product satisfies the users' needs (The International Organization for Standardization, 1999)

The framework was first used when studying technology and the user (Abras, Maloney-Krichmar, & Preece, 2004). Since then, the framework has benefited apparel designers attempting to design for end users with specific needs, especially those within marginalized populations with a lack of literature about their preferences.

With a lack of literature related to the clothing needs and wants for PWDs, several scholars have utilized user centered design to engage with the user to create functional clothing designs. Imbesi & Scataglini (2021) utilized a user centered design approach to create five smart textile items for older adults. Through engagement with the user in a survey process, they discovered comfort and independence were key needs. In addition, they were able to use digital human modeling to virtually prototype and simulate trying on the garments they designed. This allowed for issues in mobility or physical impairments to be mitigated and for prototyping to be efficient. Overall, the researchers found that they were able to communicate with the users effectively and elaborate strategies to satisfy their needs through user centered design.

Morris, Park, and Sarkar (2017) created a sports bra for breastfeeding and nursing women through a user-centered design framework. They used focus groups and wear trials with eight participants. Some of the features they incorporated based on those focus groups were surplice straps, nursing pads and clips, and additional length to add to a full coverage fit. The researchers included feedback from users during each stage of the

design process. This included comparing the bra they created with the participants' favorite owned bras. The honest feedback from the users made the product perform better than the participants' typical favorite athletic bra.

Wu & McBee-Black (2022) utilized the user-centered design approach to create a functional period panty for PWDs. One of the main innovations of this design was the use of high moisture-wicking, antibacterial fabric. The researchers considered the traditional period underwear and added replaceable pad elements to keep a wheelchair user comfortable with sitting on the product for the entire day. In addition, the designers used bonded seams to help with skin fragility and accessible hook and loop tape to help with independent donning and doffing.

McBee-Black (2022) conducted a study utilizing Mindy Scheier's (of Runway of Dreams) design approach to create adaptive clothing and gain support from a mainstream apparel brand. While not specifically following the user-centered design framework at the outset of her project, Scheier's use of home visits, interviews, focus groups, and prototype sessions constitute a user-centered design framework. However, the user-centered design framework had not previously been translated into mass-market appeal for PWDs.

Scheier did have to balance the needs of the users with the scalability of the apparel industry. She was able to focus on three specific categories of adaptive design innovations that would help multiple types of disabilities; this allowed the mass-market organization she worked with to "'understand the PWD that would benefit [from the adaptive design innovations]'" (McBee-Black, 2022, p. 21). Thus, this study is a road

map for how other brands can incorporate adaptive and inclusive designs into their current mass-market lines.

Currently, there is a gap in literature when utilizing user-centered design practices in designing for PWDs. Many of the aforementioned examples also used small focus groups, but the results seemed to have a greater market reach than those using the FEA model, universal design model, or inclusive design model. The user-centered design framework is more time consuming because of the multiple tests required to ensure user needs are met. Despite these limitations, user-centered design is the best design framework for this study as it centers the voice of the intended user while having a structured and iterative process for design.

Therefore, this study will utilize user-centered design to develop an efficient apparel design process for PWDs utilizing virtual reality garment design software. The study will address the potential time and resource consuming nature of user-centered design. By incorporating virtual reality garment software, the study hopes to find its use can optimize the pattern drafting process, create a strategy for virtual try-on sessions, decrease the number of prototypes, and better communicate with the intended user on the apparel design and their wanted features.

**Social Model of Disability**

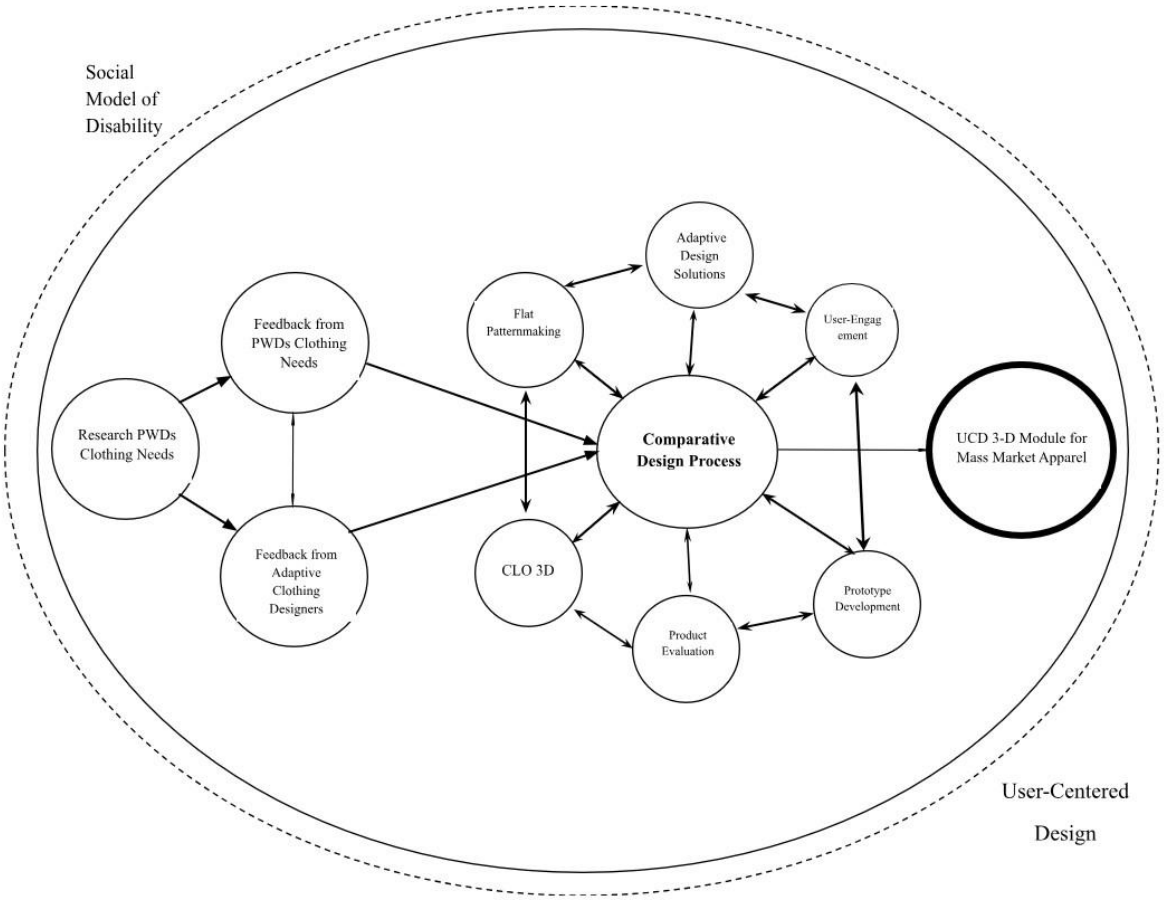
The medical model of disability views disabilities as a defect within an individual person. Overall, the view is individualist; a person with a disability is receiving karmic retribution for sins or is a biological anomaly (Shakespeare, 2013). To improve the life of PWDs their disability should be “cured,” minimized, or eliminated. Here, only health

care professionals have the power to correct these conditions and they have the obligation to do so (UCSF, 2013). This model suggests that the built environment actually improves the ability for PWDS to live independently (Clark & George, 2005). Thus, the problem is purely individual.

The social model of disability states that disability is a restriction in being able to fully participate in home and community activities (Shakespeare, 2013). The model separates impairment from disability. Someone's impairment is an individual matter that doctors seek to improve. On the other hand, disability is seen as a historical and social restriction that can be changed (UCSF, 2013; Shakespeare, 2013). Barriers exist because society does not accommodate the social, emotional, or physical needs of PWDs (Oliver, 1983; Shakespeare & Watson, 1997).

PWDs experience their impairment in the social context of being excluded or unable to participate (Berghs et. al, 2019). The goal of the social model of disability is to push for full participation in society and to challenge social discrimination against PWDs (Berghs et. al., 2019). The social model of disability connects to apparel because both are social constructs; when disability is viewed as a social restriction, issues in apparel fall on the onus of the fashion industry (Lamb, 2001). In addition, apparel designers continue to use the medical model; this has led to an inaccurate view of the needs of PWDs. Thus, this study aims to include PWDs in the development process in order to minimize barriers the fashion industry has placed on clothing for PWDs. Therefore, incorporating a social model of disability approach to the clothing design process, will help ensure PWDs are participating fully in the design process, thus enhancing the user-centered design experience.

## Conceptual Model




This conceptual model describes the connection between the theoretical frameworks and the research aims. In regards to research question 1, this is addressed through both research on clothing needs for PWDs and the feedback from PWDs and adaptive clothing designers. For research question 2, it is addressed through the previously mentioned interviews as well as the flat pattern making part of the comparative design process, including the prototype development and product evaluation. Research question 3 is answered by the CLO 3D section of the model, including the user engagement, prototype development, and product evaluation. Research question 4 is addressed by the results of the comparative design process, which inform the

development of the user centered design module for mass market apparel. First, the researcher creates a knowledge base through the literature review process in order to develop research questions. The researcher will then interview both intended users (people with disabilities) and industry professionals (adaptive clothing designers) in order to inform both design features and the design process. This helps develop a well rounded data set of both the desired features of the end product and the utility of the design process. The researcher will then use these findings to inform the design process to create the garment. The intended user and designer will work together to evaluate the end product and create design iterations. Each step refers back to the assessment from the intended user group to keep the process user centered. The entire process is informed by the social model of disability and user-centered design theory; this places the focus on independence for the individual users and having the end product assist with full participation in social activities.

**Objective & Research Questions**

The purpose of this study is engaging PWDs in the apparel design process to develop a user-centered design approach using virtual reality garment design software that can be utilized in the mass-market apparel industry. In summary, to accomplish the intended research goal set forth by the study, the following research questions were purported and examined:

**RQ 1 -** What are the clothing needs specific to people who use wheelchairs?

**RQ 2 -** How does or does not traditional flat pattern making assist in the garment design for people who use wheelchairs?

**RQ 3 -** How does or does not virtual reality garment design software assist in the garment design for people who use mobility aids?

**RQ 4 -** How can designers integrate virtual reality garment design software into user centered design processes to create a more engaging and inclusive experience for the users?

## Chapter III: Method

Chapter III contains the following sections: (a) qualitative research, (b) sample selection, (c) Institutional Review Board (IRB), recruitment, and consent, (d) data collection, (e) trustworthiness, and (f) positionality.

### Qualitative Research

A qualitative research method was used for this research study as a guide to determine how virtual reality garment software can assist in the garment design process for people who use mobility aids. This study was conducted in two phases. During Phase I, semi-structured interviews were conducted with female wheelchair users and apparel designers and product developers who work within the adaptive apparel space. Phase II emphasized the comparative design study contrasting the benefits and drawbacks of using traditional flat patternmaking and virtual reality garment software to design for women who use wheelchairs.

Research is a systematic process to collect information to improve or grow a specific base of knowledge (Merriam & Tisdell, 2016). Research design is the procedure for collecting data and accomplishing research (Creswell, 2014). There are three broad categories for research design. Quantitative research is a way of testing objective ideas or theories by looking at the relationship between two or more variables (Crewell, 2014).

What qualifies quantitative research is variables that can be measured on instruments with a resulting numbered data set that can be statistically analyzed (Creswell, 2014).

Qualitative research is a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem (Creswell, 2014; Merriam & Tisdell, 2016). The process of qualitative research involves emerging questions and procedures, data collected from the participant's setting, data analysis that is built inductively from specifics to general themes, and the researcher making interpretations of the meaning of the collected data (Creswell, 2014; Merriam & Tisdell, 2016). This form of inquiry emphasizes viewing research in an inductive fashion, which focuses on individual meaning and rendering the complexity of the situation (Crewell, 2014). There are many different methods to collect primary data when using qualitative methods; these include interviews, field observations, focus groups, narrative analyzation, and review of archives, notes, or reports (Ghaljiaie et. al., 2017).

The purpose of this study is engaging PWDs in the apparel design process to develop a user-centered design approach using virtual reality garment design software that can be utilized in the mass-market apparel industry. To support the overall goals of this study, a qualitative research approach was used. This study uses both semi-structured individual interviews and a comparative apparel design process to gain an in-depth and contextual understanding of the experiences women who use wheelchairs' have with fashion as well as the experiences apparel designers and product developers have when designing adaptive apparel for people with disabilities, as well the comparison of traditional and virtual reality garment design methods.

**Sample Selection**

Sampling is the process of selecting a section of the population to represent the larger population of the study. There are two types of sampling are probability sampling and non-probability sampling (Creswell, 2014; Ghaljaie et. al., 2017). Non-probability sampling is more commonly used in qualitative research due to qualitative studies focusing on small sample sizes that examine real life phenomena (Creswell, 2014). To justify non-probability sampling, a clear reasoning statement is required for the inclusion of certain individuals in the study over other individuals (Taherdoost, 2016).

For this study, purposive sampling was used. Purposive sampling is a type of non-probability sampling that is utilized for the "identification and selection of information rich cases related to the phenomenon of interest" (Palinkas et al., 2013, p. 533). Purposive sampling is used to identify typical, normal, and average cases within a population (Merriam & Tisdell, 2016). In an individual interview process, purposive sampling is used to select interview participants who understand the most about the intended study topic (Creswell, 2014; Merriam & Tisdell, 2016). Purposive sampling is more often used in research studying marginalized groups; it can help provide access to individuals who are otherwise inaccessible in typical recruitment methods (Woodley & Lockard, 2016). In order to find individuals who were women wheelchair users, the researcher used purposive sampling.

In addition, snowball sampling was used to continue recruiting additional participants to the study. Snowball sampling is a method that is ideal for studying a relatively small population for a qualitative or exploratory study (Woodley & Lockard, 2016). Once one person is recruited for the study, that individual could suggest other

individuals who may be interested in participating as well. From that connection, the newly recruited participants may know additional individuals who would like to participate in the study (Creswell, 2014). This helps the researcher work with a network of individuals who have knowledge about the intended study topic and gain access to an otherwise inaccessible community (Woodley & Lockard, 2016).

Participant criteria for the study included participants who were (a) between the ages of 25 and 35 years old at the time of the study, (b) identified as a part time or full time wheelchair user, and (c) identified as a woman. In addition, participants were recruited for the study that (a) identify as working as an apparel designer or product developer within the adaptive apparel space. The first set of criteria was used to gather data directly from PWDs to create a baseline of knowledge of desired design features and apparel struggles. The second set of criteria was used to develop an understanding of current apparel design practices for PWDs.

**Recruitment**

The researcher recruited from the specific sample selection identified in the previous section. To find the sample selection needed for this two-phased study, two procedures were used in the recruitment process.

First, interview participants were recruited from two social media platforms (Facebook and Instagram) as well as community disability services. Second, for the prototype development phase, the researcher contacted potential participants from the population of participants who completed the interviews and indicated potential interest.

All interviews, fittings, and video communication were conducted over Zoom teleconferencing software. The Institutional Review Board (IRB) required only verbal

consent to participate in the study. Verbal consent was given before any interviews began. The research study's IRB project number is 2094547, titled Using 3D Garment Design Software to Create Custom Avatars for Wheelchair Users: A User-Centered Design Approach Exploring the Use of 3D Software to Design for People with Disabilities. The consent script used for the participants is provided in Appendix A.

### *Phase I: Semi-Structured Interviews*

For recruitment for Phase I of the study, the researcher developed a recruitment flier and social media posts that were distributed by the researcher to local community and on-campus groups as well as social media. The flier was distributed to a disability center at a large midwestern university. The social media posts were distributed to Facebook and Instagram groups after being preapproved by the administrator or moderator of the group.

Social media platforms can help identify and obtain background information potential participants before establishing contact (Dosek, 2021). Platforms on social media can offer speed, efficiency, and the ability to target and attract specific candidates in the recruitment process (Broughton et al., 2013, p. 1). The population of users ages 25 to 35 are very likely to use social media; 70-77% of 25 to 35 year olds use Facebook, while over 80% utilize Instagram as a daily social media platform (Auxier & Anderson, 2021).

In addition, purposive sampling was also used in recruiting two individuals who are apparel designers or product developers within the adaptive apparel space. Personal network contacts were utilized to recruit the first participant in order to verify they

currently work within the adaptive space. Once the first participant was contacted, snowball sampling was utilized to find an additional participant.

### *Phase II: Prototype Development*

During Phase II, the researcher recruited one participant who completed the interview process and also indicated interest in participating as a fit model for this study. The intended participant was contacted to verify their consent to participate in the additional section of the study. The IRB approved recruitment scripts and recruitment materials can be found in Appendix B.

## Data Collection

For this study, two methods were used to collect data: semi-structured interviews and prototype development through a comparative design study. The research study obtained IRB approval before participant recruitment or data collection and analysis.

### *Semi-Structured Interviews*

There is a spectrum of research interview types, from unstructured to highly structured (Merriam & Tisdell, 2016). Structured interviews follow a strict interview structure with predetermined and developed questions that are asked in sequential order to gather mainly demographic data (Yin, 2014). Unstructured interviews allow all open-ended questions that mimic a typical conversation. If the researcher does not know enough about the phenomenon or topic to ask relevant questions, they use unstructured interviews to help develop knowledge (Creswell, 2014).

Semi-structured interview supports the development of a guide for asking questions, but also allows flexibility in the order or type of questions asked (Merriam &

Tisdell, 2016). Semi-structured interviews allow the researcher to "respond to the situation at hand, to the emerging worldview of the respondent, and to new ideas on the topic" (Merriam & Tisdell, 2016 p. 111). The goal of this study was to interview 6-7 participants (at least 5 women who use wheelchairs and 1-2 adaptive apparel designers). According to the research, the sample size is justified once:

> The study aim is narrow, if the combination of participants is highly specific for the study aim, if it is supported by established theory, if the interview dialogue is strong, and if the analysis included longitudinal in-depth exploration of narratives or discourse detail. (Malterud et al., 2016, p. 1756)

Thus, this study supports the use of a small sample size, as the study aim is highly specific in these areas: (a) the use of virtual reality garment software to design for PWDs, (b) the garment needs of women who use wheelchairs, (c) the virtual reality garment software practices of adaptive apparel designers, (d) the use of established theory (the social model of disability and the user-centered design framework), and (e) the utilization of in-depth interview dialogue and comparative design process.

### *Comparative Design*

Within Phase II of the study comparative design was utilized to gather data for prototype development, using both the traditional flat pattern design method and the virtual reality garment simulation method. Qualitative comparative analysis was created as a case based method for "comparing wholes as configurations of parts" (Ragin, 1987, p. 84). In addition, qualitative comparative analysis "compares cases to identify necessary and sufficient conditions for an outcome" (Mello, 2021, p. 2).

For this study, comparative design was used to compare and contrast design methods to determine the root cause of issues in creating clothing for PWDs. Undoubtedly, different aspects of an apparel product (i.e., fit, function, textile selection, intended target market, etc) are decided at various stages of the product development process (Joseph-Armstrong, 2010). Thus, separating and analyzing the two methods can help determine which method creates a better product for both apparel designers and disabled users.

The research design should establish research questions that answer who, what, where, how, and why (Yin, 2014). Using research questions that align with the purpose of the study and the theoretical framework underpinning the study, helps the researcher identify the relevant information needed to conduct the analysis (Yin, 2014). The research questions in this study derive from the conceptual model. Table 3.1 presents the research questions and their subsequently developed interview questions.

Interview questions posed to women who are wheelchair users are preceded by the label "WW" and those posed to apparel designers are preceded by "AD". In addition, the researcher used a method of probing during the interviews. Probing allows for the researcher to ask follow-up interview questions to help guide the interview and develop a deeper understanding about the phenomenon (Merriam & Tisdell, 2016).

**Table 3.1**

*Research Questions Related to Conceptual Model and Interview Questions*

| Research Question | Interview Questions |
|---|---|

| | |
|---|---|
| **RQ 1** - What are the clothing needs specific to people who use wheelchairs? | 1. WW - Could you please describe your disability or disabilities?<br>2. WW - How much do you use a wheelchair?<br>3. WW - What attributes do you prefer in clothing?<br>4. WW - What do you look for when shopping for pants? |
| | 5. AD - What changes did you make to wheelchair pants that are not in other pants you design? |
| **RQ 2** - How does or does not traditional flat pattern making assist in the garment design for people who use wheelchairs? | 1. WW - What attributes do you find most frustrating about clothing?<br>2. WW - What has been your experience with adaptive clothing?<br>*[Probe for more insight if they provide short answers. Ask specifics about whether they have heard of adaptive apparel, if so do they purchase, if not why?]*<br>3. WW - If you could give apparel designers any advice on designing clothes for you, what would that advice be? |
| | 1. AD - What strategy do you currently use to design adaptive apparel products?<br>*[Probe for more answers. Ask about rounds of fitting, getting products to testers, collecting feedback.]*<br>2. AD - What struggles do you face designing adaptive clothing? |
| **RQ 3** - How does or does not virtual reality garment design software assist in the garment design for people who use mobility aids? | 1. WW- Do you use visual virtual tools (online reviews with pictures, online shopping) to help make purchase decisions?<br>2. WW - What is your first impression of the CLO3D environment?<br>3. WW - How could you use a 3D mockup to visualize if clothing could work for you?<br>4. WW - What are your opinions on using a custom avatar to help visualize apparel designs? |
| | 1. AD - What has been your experience with 3D garment software?<br>2. AD - What is your impression of the CLO3D environment?<br>3. AD - How does this compare to traditional paper methods of making patterns? |

| | |
|---|---|
| **RQ 4** - How can designers integrate virtual reality garment design software into user centered design processes to create a more engaging and inclusive experience for the users? | 1. WW - How could designers use 3D software to include people with disabilities in the design process? |
| | 1. AD - How would virtual reality garment software change virtual fitting sessions for you?<br>2. AD - How would your communication with fit models or product testers change if you were able to utilize 3D software?<br>3. AD - How would the prototyping phase change with the features provided in 3D software? |

**Data Analysis**

Qualitative data analysis is the process of collecting open-ended data and developing an analysis of that data from the information supplied during the data collection process (Creswell, 2014). From the analysis of the data, the researcher can interpret themes from the units of analysis (Creswell & Creswell, 2018). This allows for final conclusions to be drawn from the data. The researcher used two types of data analysis: coding and theme development for Phase I and comparative design analysis for Phase II.

***Phase I: Coding & Theme Development***

While a review of the literature is conducted before the start of data collection and analysis, the researchers do not know what will be discovered at the conclusion of data collection. The conclusions of the study are shaped by the data analysis (Merriam & Tisdell, 2016). According to Creswell (2014), the data analysis process begins once saturation is reached and is a continuous process. In data, saturation is established once "gathering fresh data no longer sparks new insights" (Creswell & Creswell, 2018). Once saturation is reached, the coding and theme development process begin.

Coding is assigning a type of shorthand marker to different aspects of the data so that the researcher can easily retrieve specific data points later when creating themes

(Merriam & Tisdell, 2016). After all data has been coded, themes are constructed. Themes "can be a pattern, a finding, or an answer to a research question" (Merriam & Tisdell, 2016, p. 204). According to Merriam and Tisdell (2016), the conceptual themes occur across numerous individual examples.

After receiving IRB approval, the researcher completed preliminary semi-structured interviews with women who use wheelchairs to establish their overall opinions on RTW clothing options available to them, their feelings about their clothing options and use of adaptive clothing, desired apparel design features, and their thoughts on using 3D technology to communicate apparel design. In addition, interviews were conducted with adaptive apparel designers and product developers to establish the current industry practices when creating adaptive apparel, challenges in the product development process, and overall feelings of how virtual reality garment design could or could not assist in the process. A total of seven individuals participated in the interview process, five women who identify as wheelchair users and two adaptive apparel designers. The preliminary interviews helped support the development and evaluation of the comparative design process (Fernandez et al., 2021). A pseudonym was assigned to each participant using a random name generator and any information that could potentially identify participants was removed.

Interview records were transcribed using transcription service Otter.AI. Each transcription was then reviewed with the original recording to ensure proper translation of the audio. User verbatim transcription was used for this study. Both inductive and deductive coding processes were used for this study, which adds rigor to the data analysis process and expands overall research findings (Creswell, 2014). The deductive data

analysis tested current theories in established research and reinforced findings already documented about PWDs in regards to clothing. Inductive data analysis allows other findings to emerge from the data that are not documented in other research. This allows for a richer understanding of the target group of study and for other findings to emerge that would not have if deductive were the only method utilized (Creswell, 2014).

After interview recordings were transcribed, the researcher reviewed the transcripts five times each. The first reading was to familiarize the researcher with the content from the interviews so they could begin coding (Saldana, 2016). After initial readings, the second review of the transcripts, the data was coded according to the user-centered design framework, the social model of disability, and previous literature. This was a part of the deductive method of data analysis, which helps expand overall research findings based on other research (Creswell, 2014; Saldana, 2016). During each round of the coding process, the researcher started off with broader key words and narrowed the focus each subsequent round (Saldana, 2016). For example, if "fit" was a key word, subsequent reviews may look for words like "tight in the waist", "length in the leg", or "added additional ease".

Following that, recurring words or phrases were highlighted. This type of coding is called "coding for patterns" (Saldana, 2016). Saldana (2016, p. 5), says "When you search for patterns in coded data to categorize them, understand that sometimes you may group things together not just because they are exactly alike or very much alike, but because they might also have something in common." The researcher tried to uncover patterns in types of preferred clothing, common struggles with clothing and dressing, and adaptations in order to develop a picture of clothing aspects that are a struggle for PWDs.

The researcher utilized manual coding for this project because of the small size of the sample (Saldana, 2016). Codes were determined based on the research questions and previously reviewed literature. To start, the researcher had 24 total codes. As the coding process continued, unused codes were eliminated, like textile issues, lack of availability of adaptive clothing, and othering.

**Table 3.2**

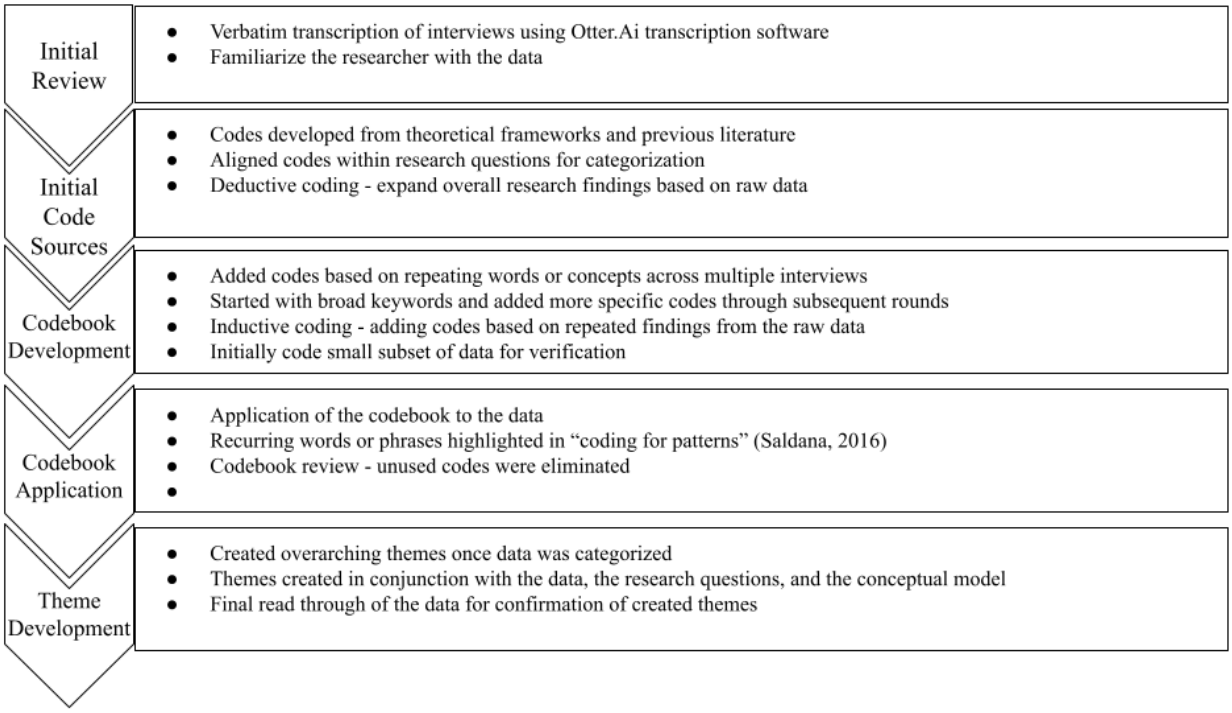
*Coding Chart with Research Questions*

| Research Questions | Codes |
|---|---|
| RQ 1 - What are the clothing needs specific to people who use wheelchairs? | 1. Adaptive Features<br>2. Fabric Type Preference<br>3. Feature that assists in dressing<br>4. Feature that assists with comfort<br>a. Elastic |
| RQ 2 - How does or does not traditional flat pattern making assist in the garment design for people who use wheelchairs? | 1. Challenges Donning<br>2. Challenges Doffing<br>3. Challenges Using Closures<br>a. Buttons<br>b. Zippers<br>4. Improper Fit<br>5. Lack of inclusivity<br>6. Risk of pressure points |
| RQ 3 - How does or does not virtual reality garment design software assist in the garment design for people who use mobility aids? | 1. Uses virtual fitting aids<br>a. Photos<br>b. Videos<br>c. Reviews<br>2. Self Fitting<br>3. Fitting Remotely<br>4. Custom Sizes |
| RQ 4 - How can designers integrate virtual reality garment design software into user centered design processes to create a more engaging and inclusive experience for the users? | 1. Visualization<br>2. Fitting assistance<br>3. Iterative Process<br>4. Body Scanning |

Next, the researcher went through the data again to construct potential themes developed from the previously coded data and research questions. The researcher was able to find overarching themes from the findings once the data was categorized; these themes were guided based on the conceptual model and the previous literature review. The five themes were: a) fit issues, b) donning and doffing assistance, c) lack of inclusive features, d) virtual avatars as a fitting tool, and e) the value of disabled voices. The themes were guided by the research questions and conceptual model which would help inform the comparative design analysis.

**Figure 3.1**

*Coding Flow Chart*




***Phase II: Comparative Design Analysis***

The comparative design process approaches apparel design in two phases. The goal of comparative design is to test apparel design methods to determine which is a

better fit for the product and ultimately the user (Ogulmus, Ureyen, & Arslan; 2015). To evaluate the appropriateness of each design method these factors were investigated, a) quality of fit, b) ease of donning & doffing, c) attractiveness.

Phase I created a baseline of knowledge for Phase II. Using the data collected from the interviews with PWDs, a list of intended features for the end apparel product was created. This included (a) a partially elasticized waist, (b) a high waisted style to allow for ease across the abdomen, (c) fabric that contained some percentage of stretch, (d) increased back rise, (e) faux closures, (f) accessible pockets, and (g) no back pockets. The information collected from the adaptive apparel designers and the wheelchair participants helped inform fitting practices and evaluation criteria. The themes were translated into evaluation criteria for the prototype development. The comparative design process compared flat pattern drafting and CLO 3D virtual simulation. Using comparative design, a pair of pants were prototyped for a woman who uses a wheelchair.

During the comparative design process, the researcher worked with a fit model to develop the prototypes. This person was recruited from the interview participants which informed the comparative design process. The researcher collaborated with the user following a user centered design process. Based on the themes of the interview, design criteria were established and sent to the user for approval before the design process began (Table 4.1). Thigh pockets were the only eliminated design features, as the user felt this was not something they would be able to access with limited hand dexterity and would prefer to use a separate bag.

**Table 3.3**

*Design features based off Interview Themes*

| | |
|---|---|
| **Theme I: Fit Issues** | a) High waisted style to accommodate abdomen fluctuations<br>b) Elastic Waistband<br>c) Increased back rise to add crotch ease<br>d) Fabric with a degree of stretch |
| **Theme II: Donning and Doffing Issues** | a) Pull on donning method<br>b) Faux closures<br>c) Independent donning & doffing<br>d) Longer/wider belt loops for donning assistance |
| **Theme III: Lack of Inclusive Features** | a) Eliminate back pockets<br>b) Add thigh pockets |
| **Theme IV: Virtual Avatars as a Fitting Tool** | a) Flat patternmaking - circumference measurements (Joseph-Armstrong, 2013)<br>b) Virtual reality garment software - Avatar measurements guide (CLO3D) |
| **Theme V: The Value of Disabled Voices** | a) User-centered design framework |

In addition, a measurements chart based on the Joseph-Armstrong (2013) flat pattern design method and a chart based on the virtual avatar algorithm in CLO3D were sent to the user (Appendix C). The researcher provided the user with a guide for measuring their body. The researcher then verified these measurements and front, side, and back profile photos via Zoom video call.

All communication and fitting sessions with the user occurred over virtual methods, including Zoom video conferencing software, email, and text messages. While in-person methods of fitting would be preferred, this is consistent with the method that adaptive apparel designers use to test products based on the interviews. Once the features were approved, a preliminary design was created via traditional flat pattern and CLO3D

virtual reality garment software. The preliminary design was approved by the user before physical prototypes were developed. Once the pattern was developed and approved, two prototypes were made using a bottomweight fabric with 15% stretch percentage. These prototypes were mailed to the user to try on. A Zoom fitting session was scheduled once the items were received.

Based on the previous themes, three main evaluation criteria were developed: quality of fit, ease of donning and doffing, and attractiveness (Ogulmus, Ureyen, & Arslan; 2015). In the first prototype fitting session, the researcher allowed the user to share all initial thoughts and opinions about the flat-pattern prototype first, followed by the CLO3D prototype. Then, the user tried on the flat-pattern prototype and gave feedback on the quality of fit, ease of donning and doffing, and attractiveness. Following this, the CLO3D prototype was donned and the same evaluation was used. All feedback was given verbally and recorded. The researcher also took notes during the process. See Table 3.4 for notes from the virtual fit session.

**Table 3.4**

*Notes from Virtual Fit Session*

| | |
|---|---|
| ***Quality of Fit*** | a) How does the fit feel?<br>b) Are there any areas that are tight or uncomfortable<br>c) Are there any areas that feel especially comfortable?<br>d) How do you feel about the fabric? |
| ***Ease of Donning and Doffing*** | a) How did it feel to put the pants on?<br>b) Did you need assistance to try on the pants? |

| | |
|---|---|
| | c) How easily would you be able to use this in a bathroom stall? |
| ***Attractiveness*** | a) Do these pants seem like something you would wear?<br>b) What kind of occasions would you wear these pants? |

After the initial fitting Zoom call, all data was collected and translated into design edits for the final prototype. Once these edits were translated into the patterns, new prototypes using the same bottomweight fabric were created. These prototypes were mailed to the user and another Zoom fitting session was scheduled. The same evaluative criteria was used with the addition of: "How do you feel the edits were translated into this version of the design?"

A total of four prototypes (two flat pattern and two CLO3D prototypes) were created. The researcher continually evaluated the design process using the user-centered design framework. The evaluation process was focused on the ability to communicate with the user about the design features and process.

**Table 3.5**

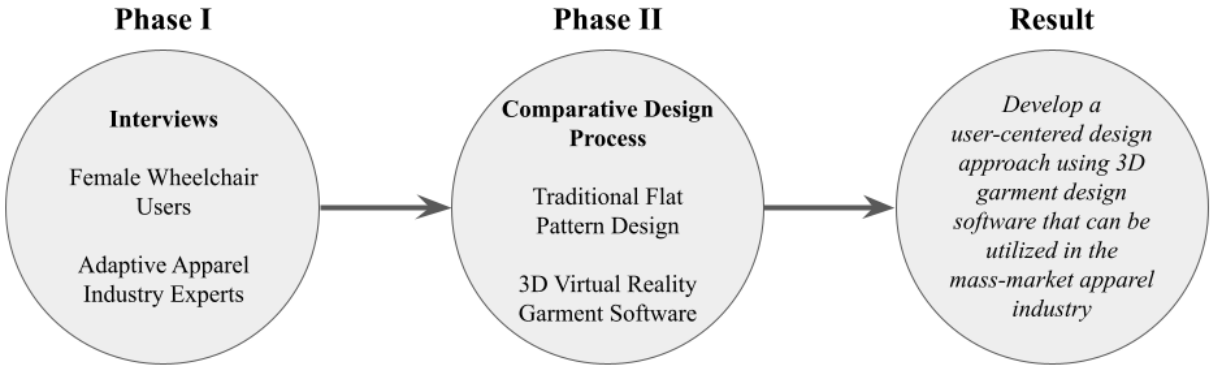
*Evaluating the Design Process*

| | |
|---|---|
| Specify the context of use (Karat, 1997) | a) Do the design methods help meet the needs of the purpose of the product?<br>b) Can the user perceive the intended design based on the information provided? |
| Determine the goals of the user (Karat, | a) Does the product fit correctly? |

| | |
|---|---|
| 1997) | b) Can the user donn and doff independently?<br>c) Does the attractiveness of the product fit the intended use? |
| Create solutions (Karat, 1997) & asses whether the product satisfies the user's needs (Karat, 1997) | a) Were the suggested design features successful for the needs of the user? |

**Figure 3.2**

*Phases of the Research Project*




## Trustworthiness

Rigor of a study can be validated by the use of four tests to ensure quality of the research design (Yin, 2014). The four tests are (a) external validity, (b) construct validity, (c) reliability, and (d) internal validity. External validity is tested in the research design phase. For this study, theoretical frameworks were used to guide the design, which helps strengthen the ability of the researcher to collect and analyze data (Yin, 2014).

During the data collection phase, construct validity and reliability can be tested. Construct validity allows for the identification of the correct operational measures for the concepts being studied (Yin, 2014, p. 46), while reliability ensures that data collection procedures used can be replicated (Yin, 2014). In order to meet the standard of construct validity, the researcher must (a) define their concepts and relate them to the research goals, and (b) identify the operational measures that match these concepts, including citing published studies that make similar connections (Yin, 2014). In terms of this research, all the concepts have been identified, defined, and established, according to prior research. This is outlined in the literature review.

In addition, the use of multiple sources of evidence in a study can help increase the construct validity of the research. During the process of this study, the researcher used semi-structured interviews from two populations (women who use wheelchairs and adaptive apparel designers) and a comparative design study to provide validity to the phenomenon in the study. The semi-structured interviews were used to provide a baseline of knowledge to incorporate into the comparative design process and to give PWDs the voice in the type of clothing that was designed. The comparative design process also utilized a fit model who continually provided feedback, as is consistent with the user-centered design framework.

Reliability supports the replication of a research study by other researchers. This is to help minimize biases and errors in the study (Yin, 2014). In order for the research to be replicated, all procedures that were followed during the data collection and analysis must be documented (Yin, 2014). For this study, the researcher used video conference recordings to create transcriptions, which were used to develop themes for coding and

analysis of the data. All questions asked in interviews were documented so another researcher could replicate the interview protocol (See Table 3.1). In addition, fit sessions were recorded for reference when editing the comparative design prototype. Multiple versions of the prototype files were created which can be referenced to see the iterative design process.

Internal validity is related to the data analysis phase of the study. When the researcher wishes to explain how and why one event leads to another event, internal validity is necessary to establish a correct relationship (Yin, 2014). Data triangulation was used to establish internal validity for this study. This is the process of using multiple sources of data to "cross examine" information (Johnson, 1997, p. 3). In this study, the data was triangulated by the review of previous literature, use of interviews, and use of the comparative design study to help understand the phenomenon.

**Positionality Statement**

It is important to address the potential biases of the researcher of this study. I have conducted research within the disability community for the last five years. During my career as a researcher, I have engaged with dozens of people with various types of disabilities as well as my personal relationships. Thus, I have an understanding of the barriers that the disability community experiences on a daily basis. While it is important to be involved within the community to develop the understanding needed to proceed with this research, it could be considered as bias in these research findings.

In addition, I am a part of the disability community as someone with hypothyroidism and myalgic encephalomyelitis (better known as chronic fatigue syndrome). This research could be seen as self-serving. However, the subjects of my

research are typically individuals with physical disabilities, those who use mobility aids and assistive devices. While I can sympathize by being a part of the disability community, I currently do not have the experience of using a wheelchair. I argue that having a disabled researcher interviewing a disabled participant affords a level of trust that a nondisabled person may not receive. There is a level of distrust within the disability community of researchers, assuming they are here to take advantage of people's labor to generate their own income. However, many of these feelings are subsided when the researcher can relate in some small way to their struggles.

While I currently work for an adaptive apparel company, I was not employed by this company when I began my research. This does cause a potential conflict within my research; I could possibly use what I learned during the course of the research to benefit my own career goals. However, I believe the results of my research will be publicly shared, allowing anyone to have access to the process of designing using virtual reality garment software when involving PWDs.

Because of this potential conflict between positive and negative related to my career, my previous knowledge, and my disability status, it was imperative that I remain aware of that issue and actively address my potential biases during the data collection and analysis of this project. During each interview, I did not make my own suggestions of potential features or problems because I wanted each individual to tell their own story without prompting. In addition, I allowed the fit model to guide each fit session with their opinions first before returning to a list of questions. I find these initial thoughts extremely insightful, as they are often unfiltered and contain important information.

Throughout the study, my personal beliefs did influence my data collection and analysis. I was frustrated to hear about participants being unable to wear the clothing they wanted to wear and their struggles dressing and undressing. However, I had to ensure that my own emotions did not dictate any of the participants' answers or allow my emotions to selectively analyze any of the data. This study allowed me the opportunity to see through the implications of a study firsthand; I was able to create a working prototype for a woman using a wheelchair who also has limited hand dexterity. In addition, I was able to suggest possible methods to make the creation process of adaptive apparel easier to actual members of the apparel industry. This has allowed me to have hope for the future of clothing for people with disabilities; there can be a world where clothing is accessible for everyone.

## Chapter IV: Findings

Chapter IV contains the findings for the following sections: (a) Phase I: Semi-structured interviews and (b) Phase II: Comparative design process.

### Phase I: Demographics

The semi-structured interviews were completed by seven individuals–five who identified themselves as someone who uses a wheelchair and two who work as apparel designers in the adaptive apparel space. All the individuals who completed the semi-structured survey identified as female. Table 4.1 below lists the demographic characteristics for the semi-structured interviews.

**Table 4.1**

*Semi-structured Interviews Demographic Variables*

| Variables | Frequency | Percent |
|---|---|---|

| | | |
|---|---|---|
| **Age** | | |
| 25 - 29 | 3 | 42.86% |
| 30 - 35 | 4 | 57.14% |
| **Gender** | | |
| Female | 7 | 100% |

After coding and analyzing the semi-structured interviews, the researcher found interesting information regarding the desired clothing attributes of women who use wheelchairs, the current issues in apparel product development with PWDs, and the potential benefits of utilizing virtual reality garment software for adaptive clothing design. Overall, fit issues ranked as the number one issue that women who use wheelchairs had with pants, followed by donning and doffing issues, then lack of disability-friendly features. Additionally, the adaptive apparel designers indicated that these issues were the same aspects they had faced when trying to design wheelchair-friendly pants. Through the researcher's analysis of the data collected, the study data presented five main themes relating to the development of products for wheelchair users: a) fit issues, b) donning and doffing assistance, c) lack of inclusive features, d) virtual avatars as a fitting tool, and e) the value of disabled voices.

### *Theme I: Fit Issues*

Waistband and stomach. The wheelchair users described the overall fit of pants as poor. One of the main issues was fit around the waistband and stomach. Because of the shape of women's abdomens when sitting in a wheelchair, participants were often unable to button pants when sitting. One participant named Danielle discussed:

> So I'm sitting all the time, my stomach. I'm like slouched so my stomach is out more and I can't like button jeans that are the right size. So I basically have to buy… jeans that are too big if I want to button them.

Additionally, Danielle indicated that added ease is important when seated, "Yeah, I think an elastic waistband is really helpful…I can't wear like just standard jeans…Because it's just too difficult and uncomfortable honestly, to sit in jeans all day like that."

Another participant, Jaime, spoke about the struggles she has finding pants that fit her proportions. If a person's body is outside of the range of proportions of a "standard" block pattern, finding clothing that fits often means sacrificing one aspect of a good fit (Joseph-Armstrong, 2010). She states, "My waist to hip ratio is about 14 inches at times. So the back is usually just gaping or riding down. Especially when sitting, it's like the most uncomfortable thing."

Lola, talked about her process of sewing her own pants and what she edits to make them work for her. She states, "Pants are hard. So what I do mainly is I add crotch ease, like two inches or more." Lola also mentioned that she preferred "lightly stretch fabric" to accommodate the fitting process as a wheelchair user. Amy echoed the preference for stretch fabrics when creating her own clothes. She said, "I actually love working with jersey. It's stretchy when my shape changes…sometimes my tummy just really bloats so jersey is really forgiving."

All participants also mentioned their preference for elastic to help accommodate fluctuations in weight or shape. Amy said, "I love elastic, very loose elastic, not tight…I just put a length of elastic in the waistband, but never tight." On the topic of closures, Lola added, "Zippers are not very flexible. I like elastic." While, Makayla talked about a

recent session trying on clothes. Because of a lack of elastic, she was unable to find pants that were comfortable for her. She states, “There’s no elastic in the waist. So instantly I know that’s not going to work, I didn’t even try them on.”

Danielle talked about a pair of pants with elastic that allowed her to finally try out different styles. She states:

> “But I did find some form [brand] that have like elastic in the back. And I bought those and they’re pretty stretchy too. And they’re super nice! I can wear them and have a high waisted look comfortably. It’s the first time I’ve ever had a pair of jeans like that.”

**Length.**

Length is also a challenging part of the fitting process for women who use wheelchairs. In regards to her own experiences buying pants, Danielle said, “I’m a very short girl. So I need to have inclusive sizing, something like that. [Brand] usually has short jeans and extra short jeans that you can buy, which is helpful.” Amy talked about editing her pants sewing patterns to make them for her. Sewing patterns often do not accommodate changes to sitting or standing bodies, similar to RTW clothing. Amy stated:

If you could see my patterns now…everything is different. My legs are quite long as well. Because the lengths that you need when you’re sat down is different [than] the lengths you need when you’re stood up…They need to be much longer to cover your legs. Otherwise, they are halfway up your legs if you made them normal length.

Data gathered from the apparel designers echoed many of the problems the previous women suggested in their interviews. Designer Kate spoke about the research

her company did during the product development process to create wheelchair pants. She stated, “So many of the issues were the same. ‘It rides down in the back, I can’t button it, [jeans] are uncomfortable to wear all day.’ So many people just…can’t wear pants at all. It’s like, literally not even an option for them.”

Designer Kelsey spoke about the importance of fit when creating adaptive clothing products. She said, “It’s the biggest struggle but also the most important. If it doesn’t fit they aren’t going to buy it. But there is only so much data we have on body size. A lot of people don’t know how to measure. But it is really frustrating. If I have a hard time (buying clothes) and I’m standing, I don’t want to factor more into that.”

### *Theme II: Donning and Doffing Issues*

#### Closures.

Due to inaccessibility of closures, all of the participants have struggles donning and doffing (putting on and taking off) clothing independently. Makayla was recounting a recent shopping trip to buy appropriate work clothing for her job. In addition to using a wheelchair, she also has limited hand dexterity to manipulate closures. In trying on a pair of pants, she said, “The pants did decently well…but the fascinating thing on those pants is that it hurt my hand putting them on just to try them on.” About another pair of pants, she said, “The buttons on these were the size of my pinky nail. There’s no way I’m doing that easily.”

In addition, Makayla takes medication that requires staying hydrated and frequently using the restroom. This factors into her pant choices. She said, “Another side is having to find a pair of pants that’s not going to make me want to lay on the floor in the bathroom for a half hour trying to get them on four times a day.” Being unable to

manipulate a closure independently can prevent someone from taking care of basic needs, like using the restroom. Further on in the interview, Makayla said:

> You're having to fight for your life to get your jeans on. I stopped working one day and went to the bathroom. And I was wearing a very unfortunate pair of pants that day. The button…is just a really short shank, and a really big button. I have to wrestle with it on a good day. So I just didn't go to the bathroom. I was like, 'If I go, I'm stuck in here and I can't get these back up. So I just stopped drinking water. I had already had to pee and I had like two and half hours left in my shift.

Amy echoed similar sentiments about independence in regards to closures. In talking about what type of clothing she prefers, she shared:

> It's about comfort when you're sat down in the chair, but also about the logistics of how you're going to get in and out of that garment when you're on your own. Because I like to be independent. I don't want to be a need. You don't want to be out somewhere and need to toilet and then have to ask someone to come into the toilet with you. That's not good.

All five participants preferred no closures on their garments and to pull garments on instead of manipulating fastenings. Amy has multiple sclerosis which makes working with closures more difficult. She shared, "On a bad day, when my hands aren't working very well, it's just easier. And it's one less thing. When you've got balance issues, it's one less thing to worry about."

Jaime primarily uses a wheelchair and shared that closures can cause uncomfortable friction on her skin. She said, "When you're sitting for a long time, [closures] can dig in as well. Any excess stuff just digs in after a while." Participants also

expressed the need to have an anchor on the clothing to grab onto. Oftentimes, the belt loops work best. Unfortunately, this can cause tension on the garment and cause the fabric to rip or break. Makayla shared, “I use the belt loops to help me get things up. I don’t have to bend my fingers as much. But I wish they were bigger, like getting three fingers in there would help more than just one or two.”

Adaptive apparel designers expressed the desire for their designs to be able to be manipulated independently if possible. Designer Kate shared, “A lot of adaptive clothing is there to help the carers or just assume those who use wheelchairs can’t do anything. They totally can. If we can change the position of a button or pocket to make it easier, they can do it on their own. That’s so important to us. You can do things on your own.”

### *Theme III: Lack of inclusive features*

#### Pockets.

All participants commented on the lack of inclusive features on RTW clothing. One of the main remarks was about pockets. Makayla shared that standard scoop pockets on jeans were typically inaccessible because of their limited hand dexterity. She said, “Yeah, putting my hands in my pockets is definitely not happening. Pockets are not designed for your hands. But I would like somewhere to put my hands to take stress off my shoulders.”

Lola also said that in a seated position, she can’t use pockets. She shared, “I remove the pockets always because they are no use for me. I can’t get my hands in them.” Additionally, Amy shared that the shape of her wheelchair keeps her from using pockets. She said, “I have a shoulder bag and I put things in there. It’s easier than trying to get some pockets that are virtually impossible to get into. The bar on the wheelchair

won't let me use side pockets" Danielle has a limited range of motion because of her disability. She shared:

> You know [not being able to use pockets] is something I'm actually so mad about. Because I wish that I could have some pockets. I feel like this would look weird, but the best place for pockets for me would be on the kneecap. That would be somewhere that would make sense for them to be able to reach…For utilization, that would be so helpful.

The adaptive clothing designers echoed this same sentiment. They moved the pockets on jeans to the thigh so that wheelchair users could use and reach them. Kelsey spoke about the decision to change the pockets, "Yeah, people literally couldn't use them. But you have to have somewhere to put your stuff. And you can't use back pockets. Honestly, I think these look cool."

**Price and Style.** In addition, three out of five participants shared about the inaccessible price and styles of adaptive clothing. Amy owns some adaptive outwear items to help shelter her from the cold in her area. But for other items, she found it cheaper and easier to make her own than pay for adaptive clothing. She shared, "I was going to get some adapted jeans, but they were incredibly expensive. And I just thought 'I can make these.'" Further in the interview, she shared, "(Clothing companies) are trying to keep their image by offering adapted clothing. But then it's ridiculously expensive. So it's not accessible." Lola shared that she owns adaptive clothing, but "they don't have enough color." In addition, she shared, "it would be nice to have more affordable options. Because most options are expensive brands."

Danielle shared that she owned some adaptive clothing, but the benefits did not outweigh the cost. She shared:

> I know that it's not a common thing that's made, which makes it more expensive. So then…I would just rather buy the cheaper thing most of the time. Because for me personally, adaptive clothing doesn't make it super easy for me. It might make it a little bit easier, but it's not really worth spending double the price at this point in time.

***Theme IV: Virtual Avatars as a Fitting Tool***

Before demonstrating the abilities of the virtual avatars, participant Amy talked about a fitting process called tissue fitting, which involves using tissue paper to "drape" and fit directly onto an individual before cutting out and creating a toile. Amy said,

> (The tissue fitting) was a revelation for me because it meant that I could tweak until I got it right before actually even starting on a muslin because it's a lot of effort to make and then take it a part…it's a very, very similar in a way to what they do in the Paris fashion houses. When they have a client, they will actually build a pattern for that client and then store that.

Additionally, Lola talked about the process of draping pants on herself to position the waistband. She said, "I do it on me, like try it on with the waistband on top. And I just mark where I want it and just stand up and see if I like it."

Participants also spoke about their current use of virtual tools when evaluating clothing decisions. Jaime talked about her online shopping experience:

> I love when there are a lot of pictures. Sometimes they even have a picture of someone sitting down. I think I saw [brand] do that. Even that helps me see better.

> I want to see how the fabric moves or if it has elastic or tiny buttons. Trying things on is hard for me, so I want to minimize what I'm trying on and returning.

Makayla echoed a similar sentiment about a recent in person shopping experience buying pants for her job. She said, "It was just such a waste. But they don't have good photos online. So I have to go in person …I need to know what kind of fabric it is or if it has belt loops."

All the participants with a disability echoed that virtual avatars would help improve the fitting process for adaptive clothing. Danielle could see implications for buying clothes online. She said, "Oh my god, I could try things on online. I could see if it's gonna fit before I even buy it. That's so cool!" Amy echoed the similarity to tissue fitting. She stated, "So I could just drape and fit anything on there? I'd love to buy this myself. Wow, that would be like…game changing for me." Lola had similar excitement and wondered if any current adaptive apparel companies were using it. She said, "Is anyone using this? I think this is awesome. Imagine if they could just scan someone and there they are. They can make any sizes. That would be so great. How can I try it?"

Similarly, the adaptive apparel designers echoed a desire to use the software. Apparel designer Kate said, "I want a collection of virtual models. Maybe then we could get some real data. It could make the whole process easier. It would make it easy to try things before sampling."

However, there were some concerns with the standardized algorithm that an avatar is created, which could pose an issue for PWDs who have measurements that fall out of a "standard" range. Designer Kelsey said,

> Yeah, I've played around with the custom sizes. I think it's really awesome. But, you can only do so much. Sometimes things get funky when you put a number in that it doesn't like. Or when it's sitting, it doesn't always lay right. But, it's definitely a tool to look into. Maybe they'll start having options for people with limb differences, or people with different shapes. Maybe we could even scan someone directly, it could help.

***Theme V: The Value of Disabled Voices***

An unintended finding of the study was the potential of using home sewists with a disability to assist in the product development and fitting process of adaptive clothing. Home sewists with a disability often have tried-and-true fitting techniques that allow them to create clothing that works for them. In this study, three of the five interview participants with disabilities were also home sewists. They were able to provide deep insight into the types of fabrics that worked best for them, common fit adjustments they make to patterns, and understand how clothing was constructed to articulate a fit issue. The possible implications of this are echoed in struggles apparel designer Kate has trying to conduct virtual fittings:

> It's really hard (to conduct virtual fittings). I'm not there with them so I can't see. I just have to go off what they say. And a lot of times, if it's just better than what they had before, they say 'it's fine'. I can't really do anything with fine. I can try stuff on myself or local people. But it's just who's here. I can only get what I see on camera. Which…isn't that much.

In addition, the participants indicated they have had previous struggles with adaptive clothing not meeting their needs. Overall, the participants felt like someone with

a disability was not included in the design process for adaptive clothing. While she owned some adaptive clothing, Lola shared that she did not seem like the target market for the items. She shared, “They’re targeting older people or something. For me, it doesn’t tick the boxes to be good for wheelchairs…they don’t change the cut, they don’t change the shape.” With further questions, Lola shared about the loss of independence that adaptive clothing could make someone feel:

> They just add adaptive closures like Velcro or stuff like that. By the way, I’m not against Velcro. But lots of disabled people have a loss of hand strength. So if you cannot pull the velcro then you cannot get it on or off to use…which makes you lose autonomy.

When asked about adaptive clothing, Amy shared:

> A lot of it isn’t actually particularly that practical anyway. It’s designed by somebody that is able bodied that’s thinking what a disabled person would need, rather than actually speaking to disabled people and finding out what they really need.

When probed further about what she meant, Amy elaborated with this:

> For me, it’s that they don’t quite understand what it feels like to be sat in the chair. So they design as to what they think you need. For the cut of the trousers? Definitely not right. They’re thinking that I need Velcro all the way down my legs. I don’t. And I worry that would split open at some point, or that it just wouldn’t be but they just assume that that’s what you would need. I mean, maybe some people do. But certainly for me, that’s not it. And some of the designs as well, they assume that you just want to be in jersey leggings. No, we do want

> some fashion as well. You know, just because we're in the chair doesn't mean that we don't care how we look.

Participant Danielle had experience working with an adaptive design group to help create a jacket that worked with her disability. In speaking about her experience, she stated:

> I did a little Zoom workshop with them. And I helped to create this thing. We called it a placket jacket or something. So you put it on the sleeves of jackets, so that it opens…like a t-shaped thing…the caregiver can put their arm into the jacket easier. And then it buttons instead of like zipping or something. It just made like the actual putting on jackets easier, so I could wear a proper size for me, instead of like an oversized jacket.

When asked about her feelings about adaptive clothing, Danielle shared:

> I think it's a step in the right direction. And honestly, if it's helping one person, then it's a good thing. I know that there's been like some pushback and stuff in the media…like it isn't necessary. Yes, we have made do with inaccessible enough. We could probably continue to make do with that. But we shouldn't have to in this day and age. So if there's a way that we can make clothing more accessible for people, why are we not doing it? You know?

Overall the findings indicate that there are continual issues with both RTW and adaptive garments for PWDs. For adaptive clothing designers, there are issues communicating with fit model participants about the fit of the clothing. Participants felt positively about how virtual reality garment simulation could assist in the design process for both the user and the designer.

### *Phase II: Comparative Design Analysis*

The comparative design analysis evaluated both flat pattern making methods and virtual reality garment simulation methods to compare which methods created a better fit for the product and the user (Ogulmus, Ureyen, & Arslan; 2015). As detailed in Chapter III, the main criteria for evaluating the effectiveness of the prototypes (as based on the semi-structured interviews) were a) quality of fit, b) ease of donning and doffing, and c) attractiveness. Following that, the two methods of design were evaluated for their adherence to the user-centered design method.

#### Quality of Fit.

Overall, the prototype developed in CLO3D had a markedly better fit than the prototype developed using flat-pattern making methods. Due to the flat-pattern making method assuming some standardized measurements (like for hip curve or crotch curve), it was difficult to achieve a proper fit within those parameters. In addition, there was no effective strategy for determining the success of the paper pattern before creating the prototype and sending it in the hands of the user.

In terms of the CLO3D prototype, the initial prototype took almost two times as long to create due to the ability to visualize the overall shape and details of the prototype before creating it in fabric. In addition, the researcher created a customized virtual avatar to help evaluate the fit on a more accurate basis. Thus, the researcher took more time creating the original prototype design because issues could be eliminated before sewing a physical item. In addition, the tools within CLO3D that allow the fabric to be translucent, the researcher could detect the intended ease on the avatar instead of going by standardized ease profiles.

At the conclusion of the first prototypes' fitting session, the user had multiple significant edits that needed to be made to the pattern before it could be retested. In the CLO3d version of the prototype, there were some edits. But overall, there were small tweaks to the overall ease of the garment, the intended hem length, and the placement of the elastic. Specifically, the fit of the back rise was much more successful in the CLO3D prototype than the flat pattern prototype, which is a problem area in pants for many women who use wheelchairs.

In creating the final prototypes, it was much more difficult for the designer to visualize how many inches to add to a certain section of the pattern, especially the crotch curve. With the second prototype, the flat pattern took much longer to edit to a place to try a new prototype than the CLO3D pattern did. Overall, the CLO3D pattern was much easier to iterate with as the researcher could visualize changes instead of assuming measurements.

In conclusion, the traditional flat pattern process did not assist in the garment design process in making apparel for women who use wheelchairs. The lack of visual cues made it difficult to perceive whether the flat pattern would fit before making the prototype. Virtual reality garment design software did assist in the garment design process for making apparel for women who use wheelchairs. Because of the ability to create an avatar with custom measurements, different iterations of the pattern could be constructed within the 3D software before being made into a prototype. The researcher could evaluate fit before creating the physical prototype for user testing. This resulted in a better fit after the first prototype, with only minimal tweaks needed to make the second prototype have an improved fit.  Designers can integrate virtual reality garment design

software into a user centered design process to create a more engaging and inclusive process for the users by allowing the user to visualize the fit of the garment before trying on the physical prototype.

**Ease of Donning & Doffing.**

There was not a significant difference between the function of dressing or undressing between the flat pattern prototype and the CLO3D prototype. What seemed to affect the ease of dressing the most was the overall fit of the garment as discussed in the previous section. The flat pattern prototype was overall tighter, which made donning and doffing independently a much more difficult task. This may be in part to the practice of traditional pant block patterns having very little ease within the pattern to be able to iterate many different types of designs.

However, it was much more difficult to visualize the application of elastic in the CLO3D. The elastic and lack of closures were features to help aid in the ease of donning and doffing, but it was challenging to use the features within CLO3D to know the amount of elastic one would need to achieve the desired effect. The elastic feature is based on an algorithm with a relationship of percentage of stretch, the behavior of the fabric, and the amount of intended force the avatar body is exerting on the elasticized bit.

In a flat pattern, a designer can just cut elastic based on the percentage of reduction they want their elastic to have. It can be difficult to translate real life elastic properties into CLO3D. However, as of July 2nd 2023, new elastic features have been added that were not tested during this design process (CLO3D, 2023). This could allow for improved elastic use in CLO3D designs. Having said this, the CLO3D prototype was still more successful overall, despite the challenges with the elastic.

Overall, the flat pattern design process did not assist in the garment design process for women who use wheelchairs. The standardized ease profile of the garment drafting directions, along with the inability to visualize the fit of the pattern before creation of a prototype, resulted in a tight fit on the garment. In turn, this made the garment more difficult to donn and doff independently. The virtual reality garment software did assist in the garment design process by allowing the researcher to visualize the added ease of the garment. This allowed for an iterative design process without having to create multiple prototypes. However, there are challenges within the use of the elastic feature when translating physical products into CLO3D animation. The virtual reality garment software can assist in creating a more engaging and inclusive experience for the user in the ability to perceive the garment design (including the closures) before testing a placement of a closure. There are some limitations; garments are placed on top of a 3D avatar, so there could be constraints within how much a user is able to understand the ease at which they could donn or doff a garment from the stationary avatar.

**Attractiveness.**

Overall, the attractiveness of the CLO3D created prototype was rated much higher by the user than the flat-pattern created prototype. This is mainly due to the fit of the flat-pattern created prototype being extremely outside of the intended fit, thus was perceived as unattractive. The overall design elements were the same within both designs, which correlates with fit being a large indicator of intended attractiveness.

It was overall much easier to evaluate the intended design using CLO3D as the ability to visualize the design was inherent in the software. In addition, the researcher was

able to share renderings of the design in both seated and standing positions with the intended user in order to gain feedback throughout the design process.

Conversely, the only concrete time to visualize the aesthetics of a design in flat pattern was once a prototype was finished and created. It makes it virtually impossible to make changes quickly, which could lead to a designer settling on a “subpar” product because the cost to edit the design is simply too high.

However, it can be challenging to visualize the exact fabric type a designer would be using with their intended fabric design. CLO3D has preloaded textiles that work within their algorithm. Additional fabrics are available for purchase in their marketplace or provided by companies like Cotton INC. This does help grow the collection of textiles needed to visualize apparel designs. Still, this is a feature to consider building, perhaps a line of 3D specific fabrics that have properties entered into virtual reality garment software, and can be purchased from a manufacturer the exact same way. This could help designers have a greater handfeel for the garment overall if they are creating the garment remotely without the fabric to reference.

The traditional flat pattern making design method did not assist in the garment design process for women who use wheelchairs. As addressed in a previous section, the fit issues caused the garment to be perceived as unattractive. Using virtual reality garment software did assist in the garment design process for women who use wheelchairs. In addition to an improved fit, the user was able to have a full 360 degree view of the garment before the first prototype was made. However, there are limitations on the translation of fabric properties into CLO3D software. Designers can integrate this virtual reality software into their user centered design process to help the user feel more a part of

the design process. By seeing the garment before a prototype is made, the users can add suggestions or things to consider to be incorporated into a toile.

**User Centered Design Methods & Engaging with the User.**

In terms of engaging in the measurement process, the user had some apprehension about visualizing an avatar of themselves on a screen to evaluate design features. Viewing oneself in an objective way could potentially create some body image issues, especially for someone with a disability. In addition, there are only so many edits that could be made to an avatar. For example, this user is 4'11", which the algorithm was not programmed for. It created distortions in the limbs that needed to be corrected by manipulation of the internal armature. Additionally, the algorithm can only distribute fat and flesh in a small number of ways, which can cause variances from the intended user to the avatar. However, CLO3D has updated after the conclusion of this study to include more soft tissue editing capabilities, which could mitigate some of the aforementioned issues (Ryan Lee-Tang, 2023, June 15).

In terms of specifying the context of use (Karat, 1997), it was much easier for the user to perceive the intended design based on the information provided by CLO3D than in the flat-pattern prototype. For the flat-pattern prototype, all the researcher could provide were photos of the pattern pieces and a flat sketch of the intended design. With the CLO3D rendering, the user was able to interact with the intended design in full 360, view it seated and standing, and even interact with the fabric. Thus, both the designer and the user felt the virtual reality garment software created better specification of the context of the design.

Following the goals of the user (Karat, 1997), the product had a better fit, was able to be donned and doffed easier, and had a better aesthetic in line with the original design with the virtual reality garment simulation method than with the flat pattern design method. In addition, the user felt the visual elements of the CLO3D software assisted them in better communicating possible design ideas and features. For someone without design knowledge, they have a visual reference point to show potential issues and wanted features. In addition, the researcher was able to visualize the overall garment composition better than with flat pattern design.

For creating solutions (Karat, 1997) and assessing whether the product satisfies the user's needs (Karat, 1997), the virtual reality garment software was overall better at fulfilling these elements of the user centered design process. Overall, less prototypes were needed to achieve a satisfactory product with the virtual reality garment software than the flat pattern design. The researcher would need to create at least one more full prototype to refine the fit of the flat pattern design method. Thus, the virtual reality garment software was more efficient for this purpose.

In addition, there was greater engagement with the user through the evaluation of the virtual reality garment software prototype. On top of being able to visualize the design before receiving the prototype, they were able to use the virtual avatar as a means of reference when discussing different elements of the prototype. Having both 2D and 3D elements available to edit and refine, as well as instantly visualizing changes, made the process more engaging between the researcher and the user.

Thus, the traditional flat pattern making garment design method did not assist in the garment design process as much as the virtual reality garment software method did.

Designers can integrate virtual reality garment design software into a user centered design process to assist in better understanding of garment design details, more efficiency in the iteration process, and greater communication with the user about their needs and wants in the garment design process.

# Chapter V: Conclusions

Chapter 5 contains the following sections: (a) research goals, objectives, and gaps; (b) summary of findings; (c) contributions and implications; and (d) limitations and future research.

## Research Goals, Objectives, & Gaps

With an increasing number of PWDs (CDC, 2019), it is imperative for the apparel industry to create more inclusive apparel products. For the over one billion PWDs living worldwide, clothing that meets their physiological and psychological needs is simply not available or accessible (Chang et al., 2009; Suri, 2016; Kosinski et al., 2018). Further, the ready-to-wear (RTW) options for people with disabilities (PWDs) are limited in the mass-market apparel marketplace (Carroll, 2015). Adaptive clothing largely does not meet the needs of PWDs, lacking in features considered useful by consumers (Na, 2007; Rutledge, 2017; Sarcone, 2017; Ryan, 2018; Morris, 2019).

The apparel industry has largely lacked training when it comes to designing for PWDs (Koskini et. al., 2018). Currently, there is no standardized apparel design process for designing products with PWDs as the intended target market (Carroll, 2015). Many of the traditional methods of flat pattern design are based on a standardized form, which does not work for the unique body composition of PWDs (Carroll, 2015). Virtual reality garment simulation uses 3D software to draw, drape, and pattern clothing designs on 3D

avatar bodies. Almost all aspects of the software can be customized; fabrics, avatars, and designs can be manipulated based on purpose and end use (Gill, 2015). While criticism and limitations have existed for virtual reality garment development (i.e., Issues in realism of the textiles, need for customization in avatars, and user interface issues) the virtual reality software developers have made great improvements to address these issues (Liu et. al., 2020).

User-centered design is a design framework focusing on gaining a deep understanding of the person that will be using the product. Originally used in studying technology and user satisfaction (Abras, Maloney-Krichmar, & Preece, 2004). This iterative process focuses on five main stages of design which creates a feedback loop that continues until the design problems are solved. With a focus on research on the intended user, focus groups, and wear testing, user-centered design framework is an ideal strategy in designing for users with specific needs, like PWDs. However, there are still gaps in the literature about using a user-centered design approach to create designs for PWDs that can be replicated on a mass-market level.

Thus, the purpose of this study was to discover a more efficient and effective way of designing for PWDs through the use of 3D virtual reality garment design software. To achieve this objective, the user-centered design model and the social model of disability were used to inform a semi-structured interview process. The study deployed qualitative methods including semi-structured interviews with PWDs and with adaptive apparel designers. The researcher analyzed the traditional flat-pattern garment design methods and the virtual reality garment software using a comparative design process.

**Summary of Findings**

Overall, the semi-structured interview process found that there are continuing issues with the fit of garments for women who use wheelchairs. Issues with the waistband and stomach area are common among this population, and the current selection of RTW garments is not accommodating this need. The participants preferred for garments to have some degree of stretch for flexibility in fit. This includes stretch fabrics or garments with added elastic. Length is also a challenging part of the fitting process for women who use wheelchairs.

In addition, women who use wheelchairs have continuing issues donning and doffing independently, often having to ask for help or avoid situations in which they would have to undress. This includes avoiding going to public places or using the restroom for fear they will not be able to redress. The participants prefer a pull on method of donning and doffing instead of using traditional buttons and zippers. Adaptive fashion designers also prioritize the user being able to manipulate their clothing independently.

There is a continuing lack of inclusive features in clothing for women who use wheelchairs. Oftentimes, they are unable to use included pockets on pants because of positioning and hand dexterity. While there are some adaptive clothing options available for women who use wheelchairs, the participants said that they are often out of their intended price range and do not seem to be designed with a disabled person in mind. Overall, the attitudes towards adaptive clothing were negative.

Participants (both women who use wheelchairs and adaptive clothing designers) found potential in using CLO3D for garment design. Several of the participants were already participating in a kind of "self-draping", including techniques like tissue fitting

and personal placement of waistbands. Thus, the idea of using a customized virtual avatar to create clothing for women who use wheelchairs already had some traction. Other participants heavily depended on photos and online reviews to make a purchase decision. The adaptive clothing designers hoped to have a collection of virtual models in order to assist with their fitting processes.

One unintended finding from this study was the finding of women with disabilities who make their own clothing. This is an avenue that clothing designers may want to consider, as there is a sense of shared language between people who create clothing. This may help overcome barriers with virtual or remote fittings. The participants overall felt that adaptive clothing was not meeting their needs and that features included (like Velcro) may actually be a hindrance. Designers must consider a user centered design strategy in order to meet the needs of people with disabilities when designing clothing for them. Overall, these findings answered RQ 1 - What are the clothing needs specific to people who use wheelchairs?

During the comparative design process, the researcher found that traditional flat pattern design did not assist in the garment design process for people who use wheelchairs. Overall, the inability to visualize the design beforehand and the emphasis on standardized measurements to make the pattern drafting process correct led to issues with poor fit. These issues contributed to the lack of ease in donning and doffing and attractiveness. These findings address RQ 2 - How does or does not traditional flat pattern making assist in the garment design for people who use wheelchairs?

Addressing RQ 3 - How does or does not virtual reality garment design software assist in the garment design for people who use mobility aids? The researcher found that

virtual reality garment software contributed to the garment design process for people who use wheelchairs. The ability to visualize the garment and communicate with the user assisted in the user-centered design process. While some improvements could be made with elastic features and custom avatar creation, the overall process of garment design was improved with the virtual reality software. The fit of the pants was better for the user, which led to easier donning and doffing and improved attractiveness. Overall, the user and the researcher thought the prototype designed with CLO3D software was more successful.

In conclusion, apparel designers can integrate virtual reality garment software to assist in the user centered design process because the barriers of visualization of the garment and lack of design knowledge on the part of the user are reduced. In addition, iterative prototyping is much easier and efficient. The ability to create custom avatars via body scanning and soft tissue modification can assist in creating a more realistic physique of someone with a disability, thus improving the fit of garments designed for them. These findings address RQ 4 - How can designers integrate virtual reality garment design software into user centered design processes to create a more engaging and inclusive experience for the users?

**Contributions & Implications**

Using a user-centered design approach, the research found that 3D garment software can be used to show live, movable, in-action 3D simulations of garments. By using a virtual reality environment, the potential user can feel a connection to the garments and suggest potential fit and design challenges early on in the design process. Further, the use of custom avatars can be used to simulate the measurements and body

shape of PWDs. PWDs have anatomical differences (Wang et. al., 2014) that cause fit issues in RTW clothing. Therefore, working with CLO3D to create custom avatars can help mitigate some of these design differences. It can also add to the decreased stigma related to the lack of access and availability of clothing for PWDs.

Additionally, the researcher found that the study's findings can benefit academia. In academia, researching how to create better user experiences and apparel design for PWDs is important when addressing the apparel needs of users. Further, as the long-term effects of COVID-19 impact the design process through the increased use of virtual prototyping (Choi, 2022), apparel design students must be prepared to learn how to design, interpret fit, and communicate through a 3D virtual environment.

Finally, the apparel industry is increasing its focus on the disabled consumer (Ryan, 2018) as an increasing number of apparel brands have begun to incorporate adaptive design into their clothing lines. However, a gap remains for PWDs as they remain either unaware of adaptive apparel or find adaptive apparel lacking support of their disability needs (Sarcone, 2017). Using this more engaging user centered design process can address these concerns with the intended user groups. Therefore, this study established a more efficient and cost effective method that designers can use to create clothing to accommodate the apparel challenges facing PWDs.

**Limitations & Future Research**

There is still a significant opportunity for improvement in this research study. First, the study mainly focused on the needs of wheelchair users who identify as women. This research is lacking input from users of other mobility aids. In addition, the sample

size of the study was small, especially with adaptive apparel designers. It could benefit the study to include more of their perspectives on challengings designing for PWDs and the use of virtual reality garment software. In addition, there are future research opportunities exploring the needs of older users, as the oldest user in this study was 35. As people age, they have a greater propensity to become disabled, so their input on the types of clothing they need and are interested in is an important area of study.

Secondly, it was challenging to recruit adaptive apparel designers to participate in this study. There is no documented network of adaptive apparel brands, and it can be difficult to find their contact information and have them answer a research inquiry. However, it is of the utmost importance to hear their insight, as they are the link between the industry, PWDs, and clothing access. Future research recruiting adaptive apparel designers should put a stronger focus in recruiting participants from a variety of adaptive apparel firms.

Third, all interviews and interactions with the fit model occurred virtually due to access. This means that only internet-affluent individuals were able to participate in the study. While this is typical based on the information provided by the adaptive apparel designers, it did make feedback sharing more difficult. As a result of the findings, future researchers could consider a partnership with a local organization centering around disability in order to have in person access to the intended user group.

Finally, the researcher only used one fit model to accomplish this study due to time and resources constraints. While some findings strongly supported the use of virtual reality garment design software to improve the garment design process for PWDs, these findings should be tested by a larger sample to see if the results will scale to the mass

market. In addition, a variety of body shapes would need to be incorporated in order to test for full inclusivity.

However, even with the described limitations, the research study can represent an improved strategy for how apparel designers can better design clothing products for people with disabilities. Further research could find ways to incorporate this process into an actual adaptive apparel design organization. Also, a study could be conducted about the reduced cost of using virtual reality garment software. Further prospective research should be conducted to test the effectiveness of user-centered design to design other products or products for other disabilities.

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## Appendix A

### Consent to Participate in a Research Study

Project Title: Using 3D Garment Design Software to Create Custom Avatars for Wheelchair Users: A User-Centered Design Approach Exploring the Use of 3D Software to Design for People with Disabilities

Principal Investigator/Researcher: Mackenzie Miller; Dr. Kerri McBee-Black

IRB Reference Number: 2094547

You are being invited to take part in a research project. You must be 25-35 years of age or older, female, and a wheelchair user or an apparel designer who works in the adaptive apparel space. Your participation is voluntary, and you may stop being in this study at any time. This project is investigating the use of CLO3D virtual apparel design software facilitating a better apparel design process for users with a disability. The goal of this research is to develop a module demonstrating the use of custom avatars to engage wheelchair users in the apparel design process using 3D garment design software and user-centered design approach. You are being asked questions about your clothing needs, experience with virtual reality, and apparel design process. Your participation should last up to 30 minutes. The information you provide will be kept confidential and only the research team will have access

If you have questions about this study, you can contact the University of Missouri researcher at 919-930-1901 or mlmywd@umsystem.edu. If you have questions about your rights as a research participant, please contact the University of Missouri

Institutional Review Board (IRB) at 573-882-3181 or muresearchirb@missouri.edu. The IRB is a group of people who review research studies to make sure the rights and welfare of participants are protected. If you want to talk privately about any concerns or issues related to your participation, you may contact the Research Participant Advocacy at 888-280-5002 (a free call) or email muresearchrpa@missouri.edu.

You can ask the researcher to provide you with a copy of this consent for your records, or you can save a copy of this consent if it has already been provided to you. We appreciate your consideration to participate in this study.

## Appendix B

**Recruitment Script**

Hello,

My name is Mackenzie Miller and I am a graduate student in the University of Missouri Department of Textile and Apparel Management. I am conducting research about the experiences of those who identify as disabled who are interested in clothing and the apparel industry. Specifically, I am looking to ask about your experience in regards to clothing needs, experience with virtual reality, and apparel design process. Participants will need to be female wheelchair users between the ages of 25-35 years and/or apparel designers who design for people with disabilities.

I would very much value your insight for this study. Your identity will be kept confidential, and you can choose to not participate at any time.

The study involves a recorded interview via Zoom, and could take 30 minutes to one hour. I will be asking you about clothing needs, experience with virtual reality, and apparel design process. I will also ask if you have other interview questions you think we should add.

If you're willing to participate, please let us know your availability in the next 2-3 weeks. A contact email is mlmywd@umsystem.edu and the number is 919-930-1901. If you have questions, comments or concerns, please don't hesitate to contact me by phone or email.

Thank you for your interest and consideration.

Sincerely,

Mackenzie Miller

**Recruitment Materials**

# Appendix C

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. Bust | 2. Waist | 3. Abdomen | 4. Hip | | | | |
| 5. CF Length | 5. CB Length | 6. Full Length F | Full Length B | 7. Shoulder Slope F | Shoulder Slope B | 8. Strap | |
| 9. Bust Depth | Bust Radius | 10. Bust Span | 11. Side Length | 12. Back Neck | 13. Shoulder Length | 14. Across Shoulder F | Across Shoulder B |
| 15. Across Chest | 16. Across Back | 17. Bust Arc | 18. Back Arc | 19. Waist Arc F | Waist Arc B | 20. Dart Placement Front | 20. Dart Placement Back |
| 22. Abdomen Front | Abdomen Back | 23. Hip Arc F | 23. Hip Arc B | | | | |
| 24. Crotch Depth | 25. Hip Depth CF | 25. Hip Depth CB | 26. Side Hip Depth | 27. Waist to Knee | Waist to Ankle | Waist to Floor | |

| Measurement Type | Description | Measure |
|---|---|---|
| Height | in inches | |
| Underbust Circumference | where a bra/binder band fit | |
| Neck Base | Where a choker fits | |
| Bust | | |
| Bicep | 3.5 inches down from shoulder tip | |
| Elbow | | |
| Wrist | | |
| High hip | around the fullest part of the adbomen before the hip | |
| Low hip | around the fullest part of the hip | |
| Thigh Circumference | | |
| Knee Circumference | | |
| calf Circumference | | |
| Inseam | | |
| Bust Apex to Apex | | |
| High Point Shoulder to Apex | Where the neck meets the shoulder to apex | |
| Center Back Neck to Waist | | |
| Center Front Neck to Waist | | |
| Total Rise | From CF waist to CB waist between the legs | |
| Waist to High Hip | | |
| Waist to Low Hip | | |