Experiencing the difference between a virtual and in-person fit session

Keywords: Body-scanning, Fitting-simulation, Avatars, Structure, Muslin-Fitting

Abstract

This research explored the concept of using avatars as fit models. Participants who had 2D/3D computer-aided design skills developed two basic garments and virtually draped the garments on two avatars, one was the program's default avatar and the second was a personal avatar captured through a 3D body scan. The garments were also assembled in muslin and fit during a live session. Photographs of the three scenarios documented the static fit of the garments. Overall, the participants were satisfied with the evaluation of the virtual garment on their personal avatar, though disappointed that the avatar itself was not a cleaner image. There was some difference in the fit results between the personal avatar and the live session which was due to fabric appearance and difference in draping. Further research, and advancement in virtual textile rendering, needs to take place as this affects the visual fit on the avatar. Virtual fit has the potential to be a time- and cost-saving practice for industry.

Experiencing the difference between a virtual and in-person fit session

Keywords: Body-scanning, Fit, Avatars, Visual Analysis

Introduction

This research compared the fitting differences between a personal avatar simulation, a generic computer avatar and a live fitting to explore fitting accuracy and examine outcomes which can be useful for researchers, industry and to guide future directions of computer fitting simulations. Through adoption of technology, both small and large retailers could increase sizing accuracy and gain consumers' trust thereby increasing profits.

Currently, garments are either patterned or draped based on a sample size as determined by each company. The garments are stitched by sample makers on an individual basis and fit to a static dress form for an initial review of fit and style. Once approved and any needed alterations are completed, the garment is placed on a fit model. Industry fit models are individuals whose measurements accurately represent the company's target population. They are rarely "perfect" on every measurement but main measurements and proportions match. The fit model is used for a couple of main reasons, they are able to give verbal feedback if the garment feels tight, is loose, hard to work a closure, etc. and when there is a lack of visual cues to determine the issue. Also, there are times in which the garment should be fit on an active individual - sitting, reaching or other activity can be accomplished through the use of a fit model.

Retail sales of women's clothing in the United States was approximately $41 billion in 2018. However, there is a high level of garment returns with the most common reason being poor fit (Bougourd, 2007). Apparel fit is the most important attribute for consumers in determining overall satisfaction with apparel purchases (Otieno, Pisut, & Connell, 2007). Therefore, if the apparel industry can find valid methods to help improve the fit of garments for their target market, it could increase profits significantly.

Literature Review

Fitting Apparel

As stated by Ashdown, Loker, Schoenfelder and Lyman-Clarke,

> "a well-fitted garment is a garment that hangs smoothly and evenly on the body, with no pulls or distortion of the fabric, straight seams, pleasing proportions, no gaping, no constriction of the body, and adequate ease for movement. Hems are parallel to the floor unless otherwise intended, and the garment armscyes and crotch do not restrict the body" (2004, pg. 3).

Industry fit experts analyze the fit of clothing on a fit model in a standard size based on their chosen target market. However, every human body does not come in standardized sizes and finding a best fit for any item of apparel can be difficult. Indeed, this is one aspect of the industry which researchers have tried to improve since the O'Brien and Shelton anthropometric study in 1941.

Many research studies have suggested that standardized garment sizes do not satisfy consumers and cannot provide good fit regardless race or age groups (Shin & Damhorst, 2018; Ibáñez et al., 2012; Alemany, et al., 2010; Manuel et al., 2010; Otieno, et al., 2007; Beyah & Lin, 2001). Experts agree that fitting issues are the top reason that customers return items purchased on-line (Bain, 2016; Mapel, 2015). Consumer surveys and return rates confirm that poor fit is the main reason for returns of apparel, indeed between 35% and 50% of female customers in the United State have found the fit of apparel not to meet their expectations (Desmarteau, 2000; Goldsberry et. al., 1996; LaBat, 1989). Fit is the most important factor (78%) for many women in their decision to purchase an item of apparel (Cotton Incorporated, 2020). Indeed, returns are one of the main reasons that retailers hesitate to expand their online offerings.

Sizing Standards

Sizing standards, such as the ones published by American Society for Testing & Materials (ASTM), are largely based on outdated body measurement studies, historical data and customer feedback. These systems are based on grouping measurements in order to create an approximate body, the aim of which is to “fit the maximum number of people with the minimum number of sizes” (Apeagyei, 2010; p. 59). Current sizing systems do not fit the entire population as typically only 50% of the population is covered by a standardized system of sizes (Human Solutions, 2020).

In traditional garment making a muslin sample is used to examine fitting on a standard dress form by an experienced dressmaker/patternmaker. Companies use an individual fit model who corresponds to a size that they feel mimics the shape of their target market. Typically, this is a misses’ size 8 or 10. A team consisting of patternmakers, designers, and product development experts analyze the fit on the model, make alterations based on their experience and then sign off or approve the production of the garment once satisfactory fit has been achieved. Due to the costs associated with developing, fitting and altering a garment, companies only create one sample size leaving them with a small size range which fits adequately.

This method, even with the use of experts, does not guarantee good fit for everyone. Standardized charts are developed for specific body proportions. Desmarteau (2000), referring to a Kurt Salmon Associates study, stated that “50% of women ...cannot find a good fit in apparel and other studies have shown that 50% of catalog returns are because of fit problems” (p. 28). The industry has struggled with sizing standards and grading rules. Schofield and Labat (2005), in their research on grading of women’s bodices found 6 false assumptions in the grading rules used by industry. They also found that the assumptions made for the main circumference measurements of the body, mainly the bust, waist and hips are not constant for all sizes, as is assumed in the industry sizing tables.

Using the size number indicated on the item of apparel does not help the consumer determine fit either. “One of the problems with apparel sizing is... that numerical size labeling has no real meaning for many female consumers” (Brown and Rice, 2-14, p. 202). Vanity sizing, the practice of manufacturers who use smaller size labels on clothing than what the measurements would indicate, is also at fault here and creates additional confusion to the question: *what size am I?*

Body scanning

Many countries have conducted anthropometric studies using 3D body scanners in order to create a database of body measurements for a variety of purposes, including the fit of clothing. The United Kingdom was one of the first to conduct a survey when they created the organization SizeUK in 2001 (Young, 2014). Since then, we have seen many other countries follow suit which include SizeUSA in 2003, SizeThailand (2008), Sizing Up Australia (2009), SizeNorthAmerica (2019) and others. Regularly updating body scan data is important to identify changing body sizes and shapes in order to develop properly fitting garments for consumer purchase satisfaction.

3D body scanning technologies offer anthropometric data and body surface area and body volume measured for evaluating the differences or changes in body shape in the fields of health and sports sciences (Funato et al., 2012). For the comfort during body movement, 3D body scanning can also be used to evaluate the air gap and garment sliding situation during the body movement (Hu et al., 2019).

Fit issues

The clothing retailer Amazon announced the use of body scanning to reduce major returns due to fitting issues after acquiring the start-up company Body Labs in 2017 (Yusuf, 2018). Their objectives in body scanning and avatar creation were to improve garment fit, increase consumer satisfaction, and increase the use of virtual fitting simulation before clothing is manufactured or shipped out. Body scans can generate a personal size model for an individual's avatar in order for customers to self-assess for fit and style. Conversely, online consumers demand on-line fitting opportunities including fitting methods and equipment.

Product visualization techniques, such as a personalized avatar, also increase the entertainment value of shopping online (Kim & Forsythe, 2008). This study found that while consumers liked the entertainment aspect of virtually trying on a garment, they lacked confidence that this technology provides reliable information in terms of fit. One participant in the Kim and Forsythe study (p. 51) commented on the personalized avatar stating "For fun, I will do it, but it doesn't provide me with a whole lot of information...the clothing doesn't look realistic to me". Although many websites provide on-line virtual fit, these tools are not yet useful for accurate fitting but mainly for two dimensional virtual observation (Januszkiewicz et al., 2017).

Currently there are a number of applications (apps) such as Sizer, MySize, FitFinder and Selfie Styler, all of which promise to give consumers their correct size in specific brands. These apps use a variety of methods in order to complete their size prediction. FitFinder uses consumer driven information in the form of height, weight, belly shape and fit preference. Selfie Styler spent a few years developing a size prediction algorithm from front and side views of a consumer to predict measurements. MySize requires the consumer to move their iPhone to specific sections on their body to allow the app to measure the body by placing your phone directly on these areas. All apps promise reduced returns but none have reached full immersion in the marketplace. Researchers propose the 3D personal mannequin to replace generic dress forms to reflect personal measurements for testing fit (Hu et al., 2019). Data-driven 3D reconstruction of human bodies has been adopted to simulate dress form by some researchers (Ballester et al, 2016). By using standardization of size and shape, researchers can create virtual human bodies for apparel products (Kim et al., 2019).

3D Body scanning

Body scanning technology has been available commercially since the late 1990s (Ashdown, 2019). Early scanners were large, cumbersome and, for the most part, stationary. While some were considered portable by the manufacturer, it took 3 - 4 people to assemble/disassemble and a large cargo van or truck was needed to transport. These early scanners were mostly used for anthropometric studies such as Size USA (2003) but also for custom manufacturing, suggesting apparel sizes and the development of personal avatars (Ashdown, 2019).

Body scanning has come a long way from the late 1990s. Commercial body scanners are smaller but current technology also allows for body scanning to take place with an iphone application, though with less accuracy. Body scanning allows for quick and accurate measurements to be taken of a three-dimensional object in a very short period of time, typically in seconds. It can also capture the garment’s relationship to the body, or the ease of a garment, accurately in a 3D image (Ashdown et al., 2004). Body scan data is generated in the form of a point cloud from which a computer extracts information to build surface details and can identify body landmarks to generate measurement data.

There are many formats of capturing a body scanning (i.e., photogrammetry, laser, white light, microwave) that can develop and provide 3D simulation models (Treleaven & Wells, 2007). One example is the Human Solutions scanner which is based on laser technology and uses 4 dual camera sensor heads to acquire over 100 body measurements in 12 seconds through laser triangulation (Maurer, 2012). However, the footprint of most commercial body scanners is at least 4-foot square.

Traditionally body scanning is conducted once the participant steps into a scanning area or the area in which the scanning devices (i.e., laser, white lights, etc) can read the body. The participant must stand still in a set position while the equipment moves vertically, reading the body through fixed horizontal sensors. The scan begins when either the participant pushes a button within the scanner or when another person initiates the scan on a computer monitor. While this type of body scanner is easy to operate, the fixed sensor captures only in a fixed direction (horizontal) to obtain body data and requires the use of a software architect (typically automatic) to complete the model using mathematical modeling.

A handheld sensor, such as the Structure Sensor, takes longer to capture the body, but it is able to be adjusted to capture body angles and uneven body shapes in order to complete a more accurate simulation model (See Figures 1 and 2). Structure Sensor can capture data in 360 degrees, and can be moved in a variety of angles along with curved body shape to capture different parts of the body. Structure is easy to adjust in order to capture at different distances.

Figure 1

Structure can be used to capture data in 360 degrees and can be moved in a variety of angles along with curved body shape.

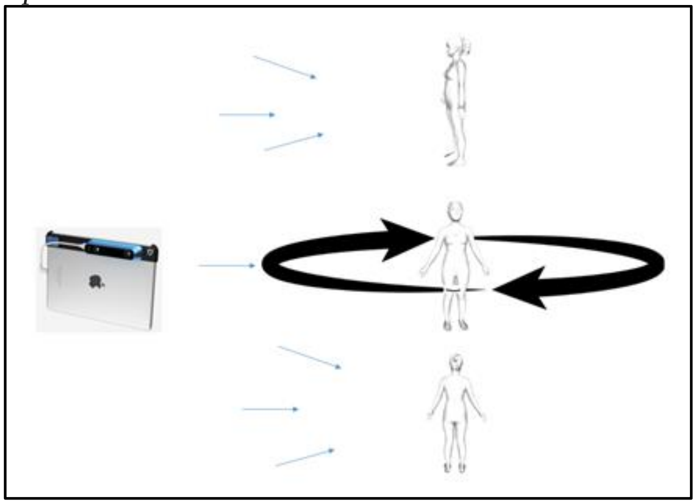
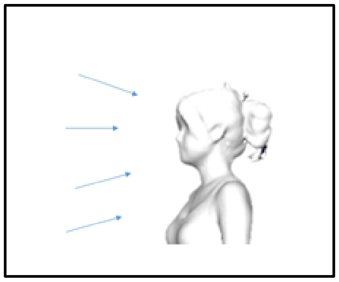


Figure 2

Moving a handheld scanner around angles to capture different parts of the body.



Apparel fit

When body scanners were introduced about 20 years ago, they were often referred to as the solution to fit in the apparel industry (Ashdown, 2019). Dress forms are manufactured using body scan data that can accurately depict the identical shape of a fit model. Designing clothing in order to fit a target population requires an understanding of the body shapes and sizes for the population. However, finding a good fit for everyone in the population is difficult as the human body varies greatly in all dimensions and combinations of length and circumference.

Even if the designer has accurate anthropometric information, it may still be difficult to achieve good fit because body measurements do not translate easily into garment dimensions. Indeed, human variability is such that there are no correlated dimensions (length/circumference) and most sizing charts only fit a certain percentage of people (Gupta, 2014).

Many researchers suggested that 3D virtual simulation technology can effectively visualize the fit and silhouette of apparel as well as products of mass-customization (Huang et al., 2002; Song & Ashdown, 2015). Many styles such as pants, and other close-fitting garments adopted 3D body scanning technology for fitting methods (Troynikov & Elnaz , 2011; Song & Ashdown, 2015).

The avatar is a whole-body scanned visualization that replicates the user's body size and observed body shape. The measurements are more accurate than the traditional hand measuring with a physical tape measure. Adopting 3D body scanning to create 3D simulation models can replace taking body measurements in person with greater accuracy (Huang et al., 2002; Simmons & Istook, 2003; Gill, 2015). The resulting avatar and measurement information is retrievable for future use. These avatars, based on actual human bodies, can be used for accurate fitting purposes including as fit models, made-to-measure, or/and mass customization for the apparel industry (Yan & Kuzmichev, 2018). This research adopted 3D body scanning technology to create 3D simulation models as a personal avatar that can be used to drape/simulation clothing for fitting evaluation.

Structure Scanner

Body scanning using iPad with a Structure lens was adopted not only for its scanning accuracy but also due to its affordable price, ease of purchase and operation. The Structure Sensor captures body scans with infrared LEDs and a camera to measure and map 3D coordinates. The Structure Sensor is a mobile scanner, therefore body scanning can be done in a location of choosing by the participant thereby increasing their comfort.

The apparel industry should have a minimum accuracy of ±0.5mm in choosing a scanner at which point raw eye observation can not detect the difference. Structure Sensor provides a point maxima accuracy 0.5mm for less than US$1,000 compared to more than US$2,500 or more to reach maxima accuracy of 0.1mm (Rosicky et al., 2016). This scanner integrates with other existing applications (CAD) in various file formats (STL, PLY and OBJ) and therefore it is easy to work between software programs. According to a research report, the average of body scan measurement is within 1-6 mm of manual measurement for stature, head circumference and arm circumference (Conkle et al., 2018).

Method

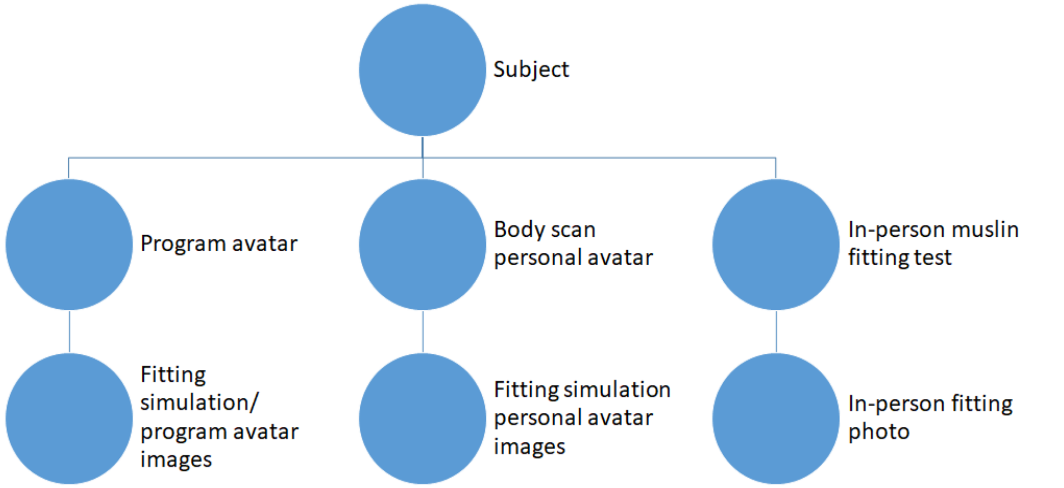
This research took place in a course within a fashion design program. The Product Lifestyle Management course requires students to have already passed a 2D/3D Computer-Aided Design course, and therefore students are familiar with clothing drape/simulation using a standard program avatar. This course's first project is on production line development (mass production) and the second project is a 3D simulation of a fit session so that students can experience fitting issues and develop their critical thinking skills. The final project builds an entire specification package for both a high-end item and a budget priced item.

The purpose of this project was four-fold. First, students in the 2D/3D CAD course were taught and executed 2D and 3D integrated pattern designs and 3D simulations. Students in the Product Lifecycle Management course learned to scan each other using an iPad with Structure lens. The chosen model could be registered as a student in the course or may be a volunteer recruited by a student, such as a fit model. This class is designated as an oral focus class, therefore, students are required to present three oral reports. One of three oral presentations was on their fitting evaluation. The students each created a personal avatar based on their 3D body scan. This process included cleaning the point cloud as avatars need to be edited particularly if there is a busy background or to clean the image. Also, students were required to check that their personal avatar is positioned in the center of the axis (i.e., the origin 0 with coordinate; x,y,z : 0,0,0) to coordinate with other software. With origin 0, the personal avatar could be used in the design program during drape/simulation process (Ashdown, 2019). Students then used a virtual fitting simulation activity to evaluate fitting issues on their or their volunteer's personal avatar.

As a practice, students viewed a pre-programmed avatar and conducted a fit session using two basic garments (skirt and dress). In preparation for their own evaluation, students participated in a group critique by using blind review. Examples of a volunteer wearing a muslin in real life was shown along with the same volunteer as an avatar wearing the same muslin. Separately, images of traditional muslin fitting tests were used to compare fitting differences with virtual fitting evaluation. Therefore, the student had some knowledgeable guidance and actual fit experience before completing their personal avatar critique. There were two sections of the fitting evaluation. Section I was a comparison program avatar and personal avatar with more than 100 students while Section II was an additional in-person fitting evaluation. Participation in this study was voluntary and there were 15 female, college-age participants in this study. Figure 3 depicts the participants body scanning project and fitting simulation.

Figure 3

Workflow comparison and evaluation of fittings based on three types of photographic images.



Body scanning

The Structure Sensor, which attaches to an iPad was the preferred method of capturing the personal body scans. Once the body scan was completed, uploaded into Optitex and the avatar was made, a total of 3 images (i.e., front, back and side views) were used to compare and evaluate the fitting situations of a one-piece dress and a flare skirt. The following were the artifacts examined:

A. Personal avatar created in Optitex using their drape/simulation function,

B. Patterns of one-piece dress and a flare skirt were digitized to conduct a clothing fitting simulation in Optitex program avatar,

C. Paper patterns of the same one-piece dress and a flare skirt were made with muslin to compare the fit.

There were three sets of 3 photographs. All photos of scenarios A, B, and C were used to compare and analyze fitting differences and fitting issues (i.e., a smooth look, with no pulls or wrinkles, no sagging or baggy areas, and the evenness of hem and/or hem with waves) between the three methods. Figure 4 shows a personal avatar from 3D body scanning and a program avatar from Optitex software. The first image is a personal avatar body scanned using the Structure Sensor with the subject wearing a non-compressing bra and tights.

Figure 4

Personal Avatar and Optitex Avatar

 Personal avatar viewing via Meshlab	 Program avatar viewing via Optitex

Body scanning using iPad with Structure lens was adopted due to its affordable price, ease of purchase and ease of operation. Participants were all body-scanned using the iPad with a Structure lens. Following the scanning process, subjects responded to a 20-item questionnaire about the process and resulting avatar. Overall, participants expressed satisfaction with their avatar and body shape.

Students were then asked to alter the basic skirt and dress pattern to fit their own measurements. This involved the students learning to create and edit 2D pattern designs and 3D images output, insert a textile pattern and perform clothing simulation on avatars using Optitex. Once the designs were completed, students took screenshots of front, side, and back views which were then placed into a PowerPoint presentation to record the results of the virtual fit session.

The students' description of fitting issues based on the simulation were expected to go along with these clipped graphics.

Personal avatar

To produce a personal avatar by using body scanning, the dress code was set as sleeveless and collarless tight clothing (non-compressible short pants), preferring to expose arms and legs. The instructor provided an option to students, with personal reasons, who could not participate in the body scanning process and were allowed to recruit a volunteer.

Skanect software develops the images collected by the Structure Sensor into a full color, 3D model or avatar. Students must first open the Structure Sensor app on the iPad, then the Skanect program on the computer. Settings for Skanect have to be adjusted every time they open the program. For this project, the participants found that the bounding box has been most effective at around 0.6 meters and the scene setting should be changed to object. Once the Structure Sensor is synced with the iPad, the light turns green to show that the connection has been made. One issue that came up is that the user must be sure that the Structure Sensor and the computer are on the same wifi signal in order to sync with each other. Once the sync is complete, the operator can start the scanning process.

In order to capture the body scan, the scanner operator (being held by a secondary participant) must move completely around the fit model/participant/volunteer being scanned (360 degrees), and the fit model needs to be as still as possible. There is a platform for the fit model to stand on, as well as two metal rods for the participant to brace themselves with in order to reduce the amount of movement. The scanner operator must direct the scanning lens up and down the body and make sure that it recognizes all parts of the body. The scanner operator should go somewhat slowly, as this will result in greater detail and accuracy.

Preparing simulation

The preparation of the avatars and the clothing drape/simulation is a long path and complex process. The program MeshLab was used to view, edit, and measure the personal avatar which was created using the iPad with a Structure lens. MeshLab is an open source and free 3-D visualization software used to process and edit 3D meshes or point clouds. It is free to download and available to everyone. There are numerous instructional YouTube videos available to share the knowledge of how to adopt and operate Meshlab programs. One in particular is the Mister P. MeshLab Tutorial channel which offers over 80 lessons on how to use MeshLab.

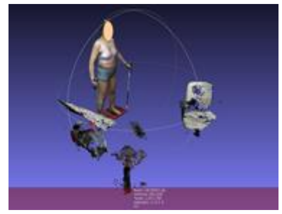
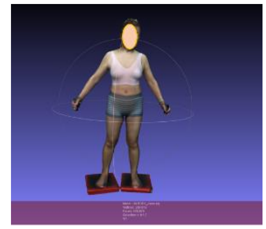
The body scan is converted to a personal avatar at which point it can be viewed and edited in the MeshLab. Editing an avatar can be challenging, therefore participants were given instructions to advance their technology skills and prepare the avatar for the fit simulation. The program MeshLab was used to view, edit, and measure each personal avatar. Three MeshLab-related videos on editing were also developed specifically for this project and made available to share with the public. The following videos were also suggested to the students as a good starting place for their own edits:

1. *MeshLab: How to move objects in the center,* 688 views since published;
2. *Change axis in the Meshlab*, 927 views since published; and
3. *How to remove objects other than main objects by using MeshLab*, 164 views since published.

The 3D body scanning process also captures objects in the near environment, therefore these unwanted objects need to be removed and cleaned before moving forward with the fitting simulation. The unwanted objects in the near environment create difficulties during the drape/simulation process (See Figure 5).

Figure 5

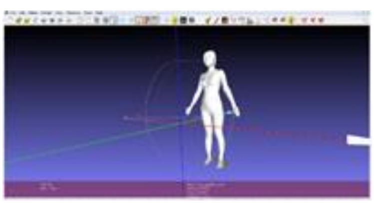
Method of cleaning and editing personal avatar

			
A. The first view of Avatar import into MeshLab	B. Move around the avatar, many environment objects were scanning into model	C. Move around the avatar, many environment objects were scanning into model	D. Unwanted objects have been removed

Once the unwanted objects around the personal avatar are removed, the personal avatar needs to be set in the center of the axis (*x*,*y*,*z*; 0,0,0) to prepare for fitting simulation. This procedure was the most challenging of the entire project. It required more time and patience on the part of the participants. Participants took a minimum of 50 minutes to complete this task. Figure 6 illustrates the procedure of adjusting the personal avatar into the origin of the axis.

Figure 6

Move personal avatar to the center of Axis

		
A. Scanned simulation models: Avatar most of time is not in the center of Axis	B. Using MeshLab to adjust Axis	C. Adjust x value
		
D. Adjust Y value	E. Adjust z value	F. Adjust avatar at the center of axis

Computer simulation

Participants prepared their own personal avatar for the final goal to conduct a fit test. Once the personal avatar is prepared and ready, using the Optitex program to conduct clothing drape/simulation is a straightforward process. The participant selected the proper fabric properties, digital garment pattern, and textile design within the Optitex program. Then they give assembly directions in order for the software to assemble the garment with the chosen attributes. Once the garment is complete, participants are ready for the fit analysis.

Live fit test

The live, in-person muslin fitting evaluation is a classic, traditional, and reliable fitting method which has been used for centuries and is considered a trusted fitting method. Using this method provides students with real world fitting experience, while providing an evaluated real body fitting test step by step. The patterns of one-piece dress and a flare skirt were printed out from the computer and made of muslin. The same two outfits, a basic dress and A-line skirt, as the computer simulation were used in the live fit session. Once the fit model put on the garment, they were posed in the same position as the computer avatar and photographs were taken from the front, side and back views. This allowed for a side-by side comparison with the images taken from the computer avatar and body scanned avatar. There were a total of 15 volunteers fit tested in-person for this study. All in-person fitting evaluations were evaluated on traditional visual cues such as smooth look, with no pulls or wrinkles, no sagging or baggy areas, nor unevenness at the hemline.

Evaluation Process

Each garment was given identical attributes. The grainlines, fabrication, and stitching lines of the computerized garment versions matched the fabric samples. The grainlines were kept vertical to the body running from head to feet. Both simulations were given fabric attributes to mimic the muslin of the garments. The live model wore basic brief undergarments, an unpadded bra and no shoes. As the patterns were identical in all cases, the stitching lines remains the same throughout.

The skirt was a basic flared skirt with a wide waist yoke. The sleeveless dress gathers at the front waist to accommodate the bust, has a midriff and the skirt falls straight with darts shaping from the waist to hips. The garments were constructed by the instructor to maintain quality.

Good fit is characterized by garments which follow the shape of the wearer's body with no points of stress, indicated by wrinkles. On a traditional woven garment, the shoulder seam should sit properly on the shoulder, and the curves at the neck, armscye, waistline and hips follow the contours of the body without tightness or sagging. The fit of a garment is one of the most important aspects of the purchasing decision. It is therefore important to develop a sample garment in the correct fabrication with the stated garment measurements and construction details. It is first evaluated on a mannequin or static model, which can give basic information on fit based on the presence or absence of such visual cues such as wrinkles (tightness), sagging (too loose) or bagginess (oversized). The fit assessment should start at the top of the garment and work its way down to the hem. For the flare skirt, it is very important to observe the evenness of the hem.

Participants were asked to conduct a comparison evaluation of the fit between the three modalities of computer avatar, personal avatar and live session using the same two garments. Figures 7 and 8 show photographic examples of each method. For the avatars, a screenshot of the front (A), back(B), and side (C) of the garment were taken for this comparison. and the same images were taken of the live model. The images were analyzed by students in all three views.

Figure 7

Skirt fitting evaluations: Flare skirt example A.

 1A Front view, program avatar virtual simulation	 2A Front view, virtual fitting simulation	 3A Front view, muslin fitting
 1B Front view, program avatar virtual simulation	 2B Front view, virtual fitting simulation	 3B Front view, muslin fitting
 1C Side view, program avatar virtual simulation	 2C Side view, virtual fitting simulation	 3C Side view, muslin fitting

Figure 8

One-piece dress fitting evaluations: Dress example B.

 1A Front view, program avatar virtual simulation	 2A Front view, virtual fitting simulation	 3A Front view, muslin fitting
 1B Front view, program avatar virtual simulation	 2B Front view, virtual fitting simulation	 3B Front view, muslin fitting
 1C Side view, program avatar virtual simulation	 2C Side view, virtual fitting simulation	 3C Side view, muslin fitting

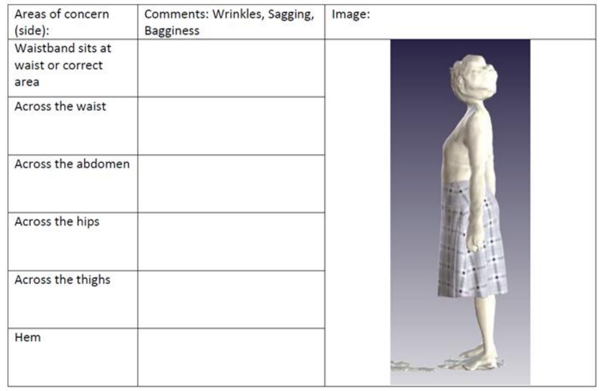
Participants were given a worksheet (see Figures 9 &10) to assess the fit of the two styles. They were told to look for ill-fitting areas of the garment by making notes of wrinkles, sagging fabrics and bagginess. The hem area was to look even and without excess dips or waves. This was done for front, side and back views. Participants were asked to make additional notes concerning posture. Note that each image shows a straight, vertical line which can help to evaluate fitting horizontal from shoulder, waist to hem. Figures 9 and 10 shows the worksheets the students used to complete that fitting evaluation in the proper sequence.

Figure 9

A-line skirt fitting evaluation sheet

<table>
<tr>
<td>Assignments, front view:
List all wrinkles, sagging, and/or bagginess from waist or correct area, abdomen, hips and thighs, and evenness of flare and hem.</td>
<td>
<table>
<tr><td>Areas of concern (front):</td><td>Comments: Wrinkles, Sagging, Bagginess</td><td>Image:</td></tr>
<tr><td>Waistband sits at waist or correct area</td><td></td><td rowspan="6"></td></tr>
<tr><td>Across the waist</td><td></td></tr>
<tr><td>Across the abdomen</td><td></td></tr>
<tr><td>Across the hips</td><td></td></tr>
<tr><td>Across the thighs</td><td></td></tr>
<tr><td>Hem</td><td></td></tr>
</table>
</td>
</tr>
<tr>
<td>Assignments, back view:
List all wrinkles, sagging, and/or bagginess from waist or correct area, abdomen, hips and thighs, and evenness of flare and hem.</td>
<td>
<table>
<tr><td>Areas of concern (back):</td><td>Comments: Wrinkles, Sagging, Bagginess</td><td>Image:</td></tr>
<tr><td>Waistband sits at waist or correct area</td><td></td><td rowspan="6"></td></tr>
<tr><td>Across the waist</td><td></td></tr>
<tr><td>Across the abdomen</td><td></td></tr>
<tr><td>Across the hips</td><td></td></tr>
<tr><td>Across the thighs</td><td></td></tr>
<tr><td>Hem</td><td></td></tr>
</table>
</td>
</tr>
</table>

Assignments, side view:
List all wrinkles, sagging, and/or bagginess from waist or correct area, abdomen, hips and thighs, evenness of flare and hem, puckering of side seams.

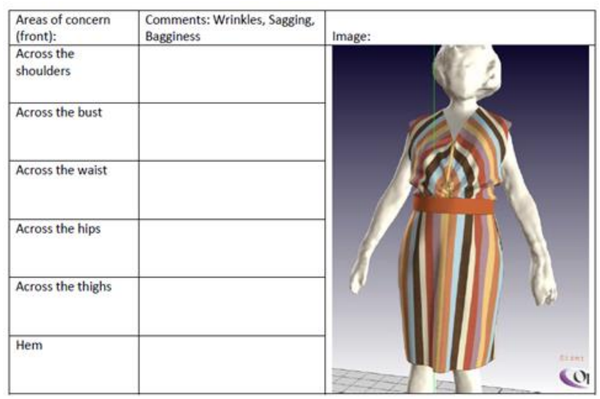


Areas of concern (side):	Comments: Wrinkles, Sagging, Bagginess	Image:
Waistband sits at waist or correct area		
Across the waist		
Across the abdomen		
Across the hips		
Across the thighs		
Hem		

Figure 10

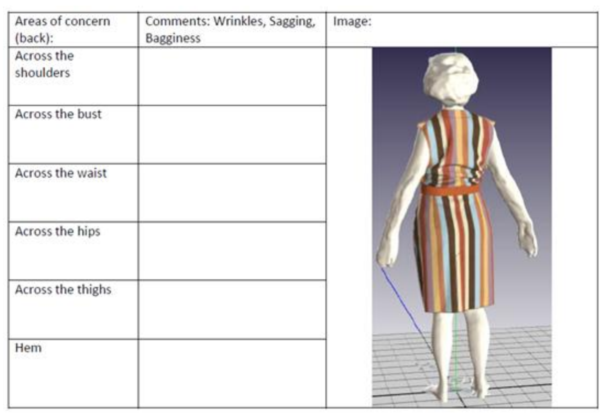
The dress fitting evaluation sheet

Assignments, front view:
List all wrinkles, sagging, and/or bagginess from shoulders, bodice, waist or correct area, abdomen, hips and thighs, and eveniness of hem.



Areas of concern (front):	Comments: Wrinkles, Sagging, Bagginess	Image:
Across the shoulders		
Across the bust		
Across the waist		
Across the hips		
Across the thighs		
Hem		

Assignments, back view:
List all wrinkles, sagging, and/or bagginess from shoulders, bodice, waist or correct area, abdomen, hips and thighs, and eveniness of hem.



Areas of concern (back):	Comments: Wrinkles, Sagging, Bagginess	Image:
Across the shoulders		
Across the bust		
Across the waist		
Across the hips		
Across the thighs		
Hem		

Assignments, side view: List all wrinkles, sagging, and/or bagginess from shoulders, bodice, waist or correct area, abdomen, hips and thighs, evenness of hem, and side seam.	

Areas of concern (side view):	Comments: Wrinkles, Sagging, Bagginess	Image:
Across the shoulders		
Across the bust		
Across the waist		
Across the hips		
Across the thighs		
Hem		

Participant Evaluation

Since this class is designated as an oral focus class within the university’s requirements, participants developed an oral presentation of their final self-fitting evaluation. Participants then blind reviewed two other participants' screenshots and developed a second written report.

Finally, the photographs of the live session were analysed by a fit expert. For the in-person fitting, a fit expert discussed fitting situations with participants to provide an educational opportunity. In-person fitting issues were kept private unless participants verbally agreed to allow their session to be used as an example. If participants agreed, they were offered an opportunity to present their in-person fitting results to earn additional bonus points.

Results

Using fit simulation technology and personal avatars, more than 100 participants conducted a virtual fit session with standard size patterns which were altered for a personal fit. This fit simulation helped students visualize how they will look when they wear the actual garment. Participants reported the virtual fit simulation resembled their bodies and was an accurate experience which they would appreciate being able to use in the future. Participants also reported that the procedure was clear to understand, accurate and results were displayed quickly.

Basic alteration skills were also taught in order to improve the fit simulation on the personal avatar. Instructors selected and prepared two garment styles in muslin for participants to try on and compare the fit to their personal avatar. Muslin fitting tests were limited by sizing as the two styles were only made up in a single size. For the participants whose measurements fit the chosen size, most were satisfied with the muslin fit tests. However, there remained differences in the fitting results between the personal avatar and actual fit session due to fabric appearance and draping.

Overall, participants were satisfied with the evaluation of virtual clothing on personal avatars during this fitting simulation. On the other hand, some participants indicated dissatisfaction with the body scan avatar as it was not a clean image, having a lot of lumps on the areas of thighs and arms. This occurred mostly because the arms and legs were too close to the body and therefore prevented the normal fall of the fabric on the body scan avatar. Participants also commented on the difference between the speed of fitting a standard size avatar with one click and conducting a fitting simulation on a personal avatar which can be time consuming due to body shape variations.

Discussion

This study has shown that the participants were able to conduct an accurate fit test in three modalities successfully. Actual scans are excellent in replicating body proportions, posture, body symmetry and other spatial relations. Scanners also have the capability to scan the body in different positions which could mimic active postures for fitting purposes. Industry could create an avatar based on a current fit model which would give them access to a fitting session immediately without the wait time or extra cost. The avatar image could also be captured while wearing a specific garment so that anyone could refer to it in the future.

Other positive attributes would include the reducing costs from multiple live fittings and sample garment creation, the ease of accessing the information when it is needed and the availability of the image on any computer within the company. Virtual fit also allows for quick pattern alterations for fit or style purposes. For example, a long sleeve dress was created and the buyer wants the same dress body but with short flutter sleeves. Instead of having a sample maker create an entirely new garment in a week, they could make the alterations within the software and generate a new garment within a few minutes.

However, there are still some issues which may need to be resolved before industry adapts this fitting method. First of all, while many software companies are working on draping fabric on avatars, this is not yet perfected and the differences could change the fit assessment of the garment. Small details are often not clear, even when the area is enlarged. This is also a new concept which would need to be adapted by industry professionals who are very skilled at fitting garments to live models. Accuracy may be off as they learn the new software and how to identify fit issues in this manner.

Research suggests that consumers express readiness to use avatars to try on clothing when the body size of the avatar appears to be close to their own size (Lin, et al., 2018; Lin & Mammel, 2011). The use of personal avatars appeal to consumers who envision a variety of applications such as monitoring health, taking exercise classes, clothing selection, and as an entertainment activity. E-commerce retail businesses can adopt virtual fitting rooms for virtual try-on as part of a business strategy to improve consumer satisfaction in terms of fit (Cho et al., 2010; Sul & Kang, 2010).

Conclusion

Product development teams should be trained to master the current software in order to use modern 3D body scanning and the future direction of the industry. Apparel manufacturers can reduce their risk of producing garments with fitting issues (Yang et al., 2015; Daanen & Hong, 2008; Istook & Hwang, 2011) as well as reduce returns due to poor fit. This body-scan project can apply to any age group and enable businesses to be on the cutting edge by responding to consumers demands in this new virtual world. Due to the positive responses from the participants, future plans are to integrate additional garment styles and increase participation. While 3D body scanning creates virtual body doubles that can bring many improvements for fitting to current methods, it does not introduce new concepts that depart from traditional fit practices yet it is potentially a powerful tool for industry and would have significant savings.

References

Apeagyei, P. R. (2010). Application of 3D body scanning technology to human measurement for clothing fit. *International Journal of Digital Content Technology and its Applications., 4*(7), 58-68.

Alemany, S., González, J. C., Nácher, B., Soriano, C., Arnáiz, C., & Heras, H. (2010). Anthropometric survey of the Spanish female population aimed at the apparel industry. In *Proceedings of the 2010 International Conference on 3D Body Scanning Technologies. Lugano, Switzerland*.

Ancutiene, K. (2014). Comparative analysis of real and virtual garment fit. *DE REDACTIE*, 158-165.

Ashdown, S. (2019). Full body 3-D scanners. In D. Gupta and N. Zakaria (Ed.). Anthropometry, Apparel Sizing and Design. Second edition. Oxford: Woodhead Publishing, (6)145-168.

Ashdown, S. P., Loker, S., Schoenfelder, K., & Lyman-Clarke, L. (2004). Using 3D scans for fit analysis. *Journal of Textile and Apparel, Technology and Management*, *4*(1), 1-12.

Ballester, A., Parrilla, E., Piérola, A., Uriel, J., Pérez, C., Piqueras, P., Beatriz, B., Julio, V., & Alemany, S. (2016). Data-driven three-dimensional reconstruction of human bodies using a mobile phone app. *International Journal of the Digital Human*, *1*(4), 361-388.

Bain, M. (July 3, 2016), Amazon is developing a 3D modeling system to solve online clothes shopping's biggest problem. Like A Glove. Retrieved from web

Bougourd, J. (2007). Sizing systems, fit models and target markets. In Ashdown, S.P., Sizing in clothing: Developing systems for ready-to-wear clothing. Woodhead Publishing, (4), 108-148

Brennan, M.A., Lalonde, C.E. & Bain, J.L. (2010). Body Image perceptions: Do gender differences exist? *Psi Chi Journal of Undergraduate Research*, *15*(3), p. 130-138

Cho, C., Park, J., Boeing, A., & Hingston, P. (2010). An implementation of a garment-fitting simulation system using laser scanned 3D body data. *Computers in Industry*. 61(6), 550.

Cotton Incorporated. (2020). Sizing Solutions: Technology assists in search for better fit. Retrieved from https://lifestylemonitor.cottoninc.com/sizing-solutions/

Conkle, J., Suchdev, P. S., Alexander, E., Flores-Ayala, R., Ramakrishnan, U., & Martorell, R. (2018). Accuracy and reliability of a low-cost, handheld 3D imaging system for child anthropometry. *PloS one*, *13*(10), e0205320.

Daanen, H., & Hong, S. (2008). Made-to-measure pattern development based on 3D whole body scans. *International Journal of Clothing Science and Technology, 20*(1), 15-25.

Desmarteau, K., & Speer, J. (2004). Entering the Third Dimension. *Apparel Magazine*, *45*(5): 28–33.

Gill, S. (2015). A review of replace take body measurement in person research and innovation in garment sizing, prototyping and fitting. *Textile Progress*, *47*(1), 1-85.

Gill, S., & Parker, C. J. (2017). Scan posture definition and hip girth measurement: the impact on clothing design and body scanning. *Ergonomics*, *60*(8), 1123-1136.

Goldsberry, E., Shim, S. and Reich, N. (1996). Women 55 years and older: Part II. Overall satisfaction and dissatisfaction with the fit of ready-to-wear. *Clothing and Textiles Research Journal*, *14*(2):121–32.

Gupta, D. (2014). Anthropometry and the design and production of apparel: An overview. In D. Gupta and N. Zakaria (Ed.). Anthropometry, Apparel Sizing and Design. Second edition. Oxford: Woodhead Publishing, (2) 34-66.

Hu, P., Ho, E. S., Aslam, N., Komura, T., & Shum, H. P. (2019). A new method to evaluate the dynamic air gap thickness and garment sliding of virtual clothes during walking. *Textile Research Journal*, *89*(19-20), 4148-4161.

Huang, Y., Yu, W., Chen, T., & Austin, T. (2002). Three-dimensional body scanning system for apparel mass-customization. *Optical Engineering*, *41*(7), 1475-1479.

Ibáñez, M. V., Vinué, G., Alemany, S., Simó, A., Epifanio, I., Domingo, J., & Ayala, G. (2012). Apparel sizing using trimmed PAM and OWA operators. *Expert Systems with Applications*, *39*(12), 10512-10520.

Istook, C.L., & Hwang, S. (2001). 3D body scanning systems with application to the apparel industry. *Journal of Fashion Marketing and Management. 5*(2); 120-132.

Januszkiewicz, M., Parker, C. J., Hayes, S. G., & Gill, S. (2017). Online virtual fit is not yet fit for purpose: An analysis of fashion e-commerce interfaces. *The 8th International Conference on 3D Body Scanning Technologies Proceedings*, Montreal, CA, 210-217.

Kim, H. S., Choi, H. E., Park, C. K., & Nam, Y. J. (2019). Standardization of the size and shape of the virtual human body for apparel products. *Fashion and Textiles*, *6*(1), 33.

Kim, J. & Forsythe, S. (2008). Adoption of virtual try-on technology for online apparel shopping. Journal of Interactive Marketing, *22*(2), 45-59.

Lin, S., Johnson, R. R., & Kang, J. (2018). Fitting simulation evaluation on personalized avatars. *Journal of Textile Engineering & Fashion Technology*, *4*(2), 123-128.

Lin, S., & Mammal, K. (2011). An analysis of digital 3D body imaging technology. *The 2nd International Conference on 3D Body Scanning Technologies Proceedings*, Lugano, Switzerland, 58-65.

Lee, H., & Xu, Y. (2020). Classification of virtual fitting room technologies in the fashion industry: from the perspective of consumer experience. *International Journal of Fashion Design, Technology and Education*, *13*(1), 1-10.

Liu, L., Wang, R., Su, Z., Luo, X., & Gao, C. (2014). Mesh-based anisotropic cloth deformation for virtual fitting. *Multimedia Tools and Applications, 71*(2), 411-433. doi:http://dx.doi.org.eres.library.manoa.hawaii.edu/10.1007/s11042-013-1437-5

Lu, Y., Song, G., & Li, J. (2014). A novel approach for fit analysis of thermal protective clothing using three-dimensional body scanning. *Applied ergonomics*, *45*(6), 1439-1446.

Manuel, M. B., Connell, L. J., & Presley, A. B. (2010). Body shape and fit preference in body cathexis and clothing benefits sought for professional African-American women. *International Journal of Fashion Design, Technology and Education*, *3*(1), 25-32.

Mapel, T. (2015). Ringing in the new year with a rush of online returns. Retrieved from: https://www.digitalcommerce360.com/2015/12/31/ringingnew-year-rush-online-returns/

Maurer, M. (2012). VITUS 3D Body Scanner. Asian Workshop on 3D Body Scanning Technologies, Tokyo, Japan. Retrieved on June 30, 2020 from https://www.3dbodyscanning.org/cap/papers/A2012/a12009_08maurer.pdf

O'Brien, R. & Shelton, W.C. (1941). *Women's measurements for garment and pattern construction.* Washington, D.C.: U.S. Department of Agriculture.

O'Connell, L. (2020). U.S. Apparel Market - Statistics and Facts. Statista report. retrieved from https://www.statista.com/topics/965/apparel-market-in-the-us/

Otieno, R., Pisut, G., & Connell, L. Jo. (2009). Fit preferences of female consumers in the USA. *Journal of Fashion Marketing and Management*, *11*(3), pp. 366–379.

Rosicky, J., Grygar, A., Chapcak, P., Bouma, T., & Rosicky, J. (2016, November). Application of 3D scanning in prosthetic & orthotic clinical practice. In Proceedings of the 7th international conference on 3D body scanning technologies (pp. 88-97).

Sayem, A. S. M. (2017). Objective analysis of the drape behaviour of virtual shirt, part 1: avatar morphing and virtual stitching. *International Journal of Fashion Design, Technology and Education*, *10*(2), 158-169.

Schofield, N.A. & LaBat, K.L. (2005). Defining and testing the assumptions used in current apparel grading practice. *Clothing and Textiles Research Journal*, *23*(3), 135-150.

Scott, E., & Sayem, A. S. M. (2018). Landmarking and measuring for critical body shape analysis targeting garment fit. *International Conference Exhibition of 3D Body Scanning Proceedings.* Lugano, Switzerland, 222-235.

Shin, E., & Damhorst, M. L. (2018). How do young consumers think about clothing fit?. *International Journal of Fashion Design, Technology and Education*, *11*(3), 352-361.

Simmons, K. P., & Istook, C. L. (2003). Body measurement techniques. *Journal of Fashion Marketing and Management: An International Journal*, *7*(3), 306-332.

Stjepanovič, Z., Pilar, T., Rudolf, A., & Jevšnik, S. (2012). 3D virtual prototyping of clothing products. *Innovations in clothing technology & measurement techniques*, 28-41.

Song, H. K., & Ashdown, S. P. (2010). Investigation of the validity of 3-D virtual fitting for pants. *Clothing and Textiles Research Journal*, *33*(4), 314-330.

Sul, I.H., & Kang, T.J. (2010). Regeneration of 3D body scan data using semi-implicit particle-based methods. *International Journal of Clothing Science and Technology*, *22*(4), 248-271.

Treleaven, P., & Wells, J. (2007). 3D body scanning and healthcare applications. *Computer*, *40*(7), 28-34.

Yan, J. Q., & Kuzmichev, V. E. (2018, December). Hierarchical fit criteria of made-to-measure men shirt with virtual technology. In *IOP Conference Series: Materials Science and Engineering* (Vol. 459, No. 1, p. 012086). IOP Publishing.

Yang, J. H., Kincade, D. H., & Chen-Yu, J. H. (2015). Types of apparel mass customization and levels of modularity and variety: Application of the theory of inventive problem solving. *Clothing and Textiles Research Journal*, *33*(3), 199-212.

Young, Y.A. (2014). Computer design and digital fit of clothing. In D. Gupta and N. Zakaria (Ed.). Anthropometry, Apparel Sizing and Design. Second edition. Oxford: Woodhead Publishing, (11), 305-319.

Yusuf, B. (May 8, 2018). Amazon is 3D scanning customers' bodies to improve online shopping. Retrieved from the web. https://all3dp.com/amazon-is-3d-scanning-customers-bodies-to-improve-online-shopping/#:~:text=Amazon%20is%203D%20Scanning%20Customers'%20Bodies%20to%20Improve%20Online%20Shopping,-by%20Bulent%20Yusuf&text=To%20help%20sell%20clothes%20more,microphone%20in%20your%20living%20room.