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A Study of the Relationship between 3D Model and 3D Garment Simulation

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Abstract

This research project investigates the differences of various body locations (between 3D body models) and drapes garments digitally onto 3D body models. Three different subject models will be given explication. It consisted of (1) data collection of three-dimensional scans (2) creation of 3D body representations (3) comparison of avatar shapes and measurements (4) visualization and assessment of 3D body models and their 3D virtual garments. The study tests a theory of impact by differences in avatars by pattern design. A visual inspection of avatars showed clear differences between the six avatar types (in the generating process); however, there was notably less difference between 3D garment simulations based upon the six avatars produced. This demonstrated that there was less influence on the 3D garments than was predicted after a visual inspection of the avatars.

Key words: Three-dimensional scan, 3D model, 3D virtual garments

I. Introduction

The technology base for garment development continues to grow at such a rate that is difficult to make use of everything it allows use to do. Technological innovation has had a positive impact not only on our ability to mass produce clothing, but also on our ability for precision design. At the same time, our use of technology has greatly reduced the size of our professional labor force. Technologies such as Computer Aided Design (CAD) and 3D scanning have the affordances to retrieve the industry's forgotten mission of personalized service, but little work has been done to make this a reality for society. Yet, with the increase of technology use has come an overall decrease in the knowhow and experience base of those who work in the industry (Locker et al., 2008). A complaint echoed by those who lived during our transition into the high tech world of mass production is, “They don't make 'em like they used to.” It is unlikely the case, however, that we cannot make them like we used to. If we are to make the quality of our clothing commensurate with the capabilities of our technology, research into the tools we use will be necessary to realize their potential. This study addresses this important discussion by providing a visual analysis of software used for body measurement and clothing design.

The ultimate goal of apparel production is to acquire the most affordable, best-fitted clothing for everyone. The designer's aim is to create the best-fitted clothing possible for each individual despite mass production and mass sizing. In order to achieve this goal, they must know body size and measurements because the human body is a complex form having many variations in shape, displaying a diversity of postures, and exercising a wide range of movement. The goal of measuring methodology is to provide a

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description of the body that will aid in the development of a garment that fits the intended body. This end, the current scanning technology affords improvements from past approaches to measurement. In addition to a realistic 3D representations of objects, it provides unlimited retrieval of linear, two, and three-dimensional measures of the object surfaces. It is inexpensive and there is no comparison in the level of precision for measurements to methods used in the past (Simmons & Istook, 2003). Using this data, software can create tools for the designer such as sizing systems, pattern-drafting methods, grading systems, 3D draping, and virtual clothing interaction (Petrova & Ashdown, 2008). While there have been improvements overall, appropriate translation of the data to applications of garment production remain a challenge for the industry.

Related works using 3D scanner can be categorized into three groups: 1) reproduction of mannequin (the making of a similar figure), 2) acquiring linear data of body measurements, making patterns, and simulations on the mannequin from the previous step, 3) inserting design lines or seam lines and applying them to 2D patterns.

One problem with all current measuring methods used to construct garment patterns is abstracting the garment shape to provide fit and comfort, but not replicate the body exactly (Song & Ashdown, 2010). While it does seem possible to create an accurate representation of the body, it is necessary to go beyond the body measurements and determine the ideal relationship between the body and the garment.

The shape of the body is closely related to aspect of dart including forms of dart, locations of dart, amount of dart, length of dart. In addition, it has great influence on the fitness of clothing. Data from linear length measurements such as height and circumference of body measurements does not give body shape information for pattern design. Even if new method might be quite complex compared to existing original forms, and it needs more measurement, it should not be much problem. Scanning technology development allows to measure faster with great accuracy, and it also makes the subject less bothered than linear or 2D measurement. Therefore, a substantial improvement would be the development of a method that drafts a well-fitted pattern for every person's body shape.

While current technology supports the use of personal measurements in the production of custom-fitted clothing, the data specifications needed to determine the interface of body data to garment is not an afforandance currently provided by technology. The critical issues of pattern development are how to measure the human body and how to interpret those measurements. Better interpretation requires two conditions. The first is the proper relating of data from the body to that of the product via identification of body landmarks allowing for correspondence from the data source to the actual end product patterns. Second, satisfactory fit must include accurate body measurements and appropriate amounts of ease. Developing software for the design and manufacture of apparel what meet these criteria would make it possible to produce custom-fitted apparel in a mass production environment.

As Horn described clothing as “second skin” in his paper (as cited in Locker et al., 2008), we can define clothing as duplication of parts that simplify the skin so that only part that important. Depends on the purpose of clothing, replication method can be different. For example, for athlete suit which emphasized on speed, protrude parts should be smoothly connected with flexible material to reduce the resistance. In case of daily wears, fit ease and style ease needed for activities are considered during the process of replication.

Designers impose an aesthetic and a utility in their imaging of clothing upon the body. Undesired curves in the contours of the garment are smoothened or eliminated. Accommodations for fit ease and style ease are incorporated. The same interpretations can be implemented when creating virtual dress forms and avatars. It is being done by virtual draping software to help designers make two-dimensional patterns over a three-dimensional body image.

Until the 3D scanner was developed, it was difficult to replicate body shape beyond measurements of height and circumferences of parts of body. Despite the technological advance, the data gleaned from 3D scanners merely measure the body. They do not guarantee improvements in clothing patterns. To utilize 3D measurements, pattern drafting must decide upon a minimum number of body points.

The density of 3D scan data is high. In case of $[TC]^2$, body scans create a bodily outline using 300,000 data points. “The $[TC]^2$ Software has automatic noise elimination, data filtering, data smoothing, hole filling, and data compression as part of a process which automatically creates a high fidelity segmented 3D model of the human subject.” (“5 Ways Body Scanners” 2010). <Fig. 1> is a comparison between the actual 3D scan data of a subject model and the $[TC]^2$ converted model created using that data. It is apparent in this figure that the shape of the body is changed in the creation of a 3D model, or avatar.

This research project was designed to investigate the differences at various body locations between 3D body models and to drape garments digitally onto 3D body models. Specific characteristics of three different subject models will be given explication. This description will make comparisons of both appearance and measurement values of the three subject models.

Even if avatar body shape and measurements are different, if the form of the draped garments is the same, the compressed data from $[TC]^2$ is sufficient for purposes of visual modeling. Furthermore, we assumed that differences between 3D models have correlations of the following characteristics of body descriptors: size, degree of obesity, shape of particular part of body. We attempted to uncover any dependencies as well anticipating their possible impact on improved measurement practices of 3D body models as well as customized apparel in terms of garment fit.

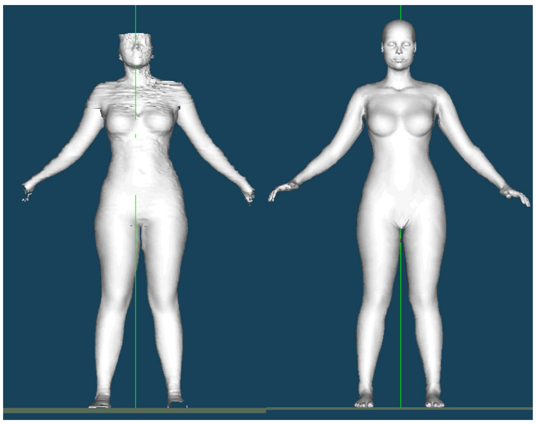


Fig. 1. Avatars: raw data versus 3D body models.

II. Methods

This study consisted of four major stages: (1) data collection of three-dimensional scans (2) creation of 3D body representations (3) comparison of avatar shapes and measurement (4) visualization and assessment of between 3D body models and their 3D virtual garments.

1. Data Collection of Three-dimensional Scans

We selected the scan of three participants who could represent varying degrees of obesity from June of 2010 to February of 2011. Participants were scanned in minimal clothing (underwear and tank top) using a $[TC]^2$ body scanner by Human Solutions. To provide a clear view of the side of the body and to obtain the data integrity and reproducibility (Mckinnon & Istook, 2002), participants were asked to stand with the foot spam held about 10.16 cm (4 inch) , the arms held about 25 cm (10 inch) away from the body.

2. Creation of 3D Body Representations

3D scan data is very dense as a dense cloud of over 300,000 points with either $[TC]^2$, a device that projects white incandescent light, or Human Solutions, a laser scanner. It can automatically create 3D body models from 3D body scan point cloud data.

The avatar designs considered for this study were DAZVictoria4_Texture_standard, Browzwear Debbie_Texture_standard, EvaDress_standard, LectraJulia_Texture_standard, OptiTexEva_Texture_standard, OptiTexEvaF3_ponytail, PoserFemale_Texture_stand-ard, and TukatechLisel_Texture_standard. These avatars were considered because $[TC]^2$ has the capability of simulating 3D garments on molds created by these designs. Among the eight, we considered only six, excluding EvaDress_standard and OptiTexEva-F3_ ponytail, as variation among the Eva designs were irrelevant for our purposes.

3. Comparison of Avatar Shapes and Measurement

3D body models which were generated into 6 avatars from [TC]^2, were loaded to Metasequoia Ver. 2.3. Then we compared the shape of avatars. Next, 3D body models were loaded on I-Designer. By using 'Body order tool', we measured height and circumstance of bust, waist and hip. Based on this value, we made comparison between the models. Again, using I-Designer, we loaded the models. By using 'get cross-section' function of 3D simulator system, we compared their cross section from various views.

4. Visualization and Assessment of between 3D Body Models and Their 3D Virtual Garments

As shown in <Fig. 2>, the garment styles used for the study were: T-shirt without dart, Shirt collar blouse with waist dart and hemmed 5 cm above the hip, Jeans with waist yoke, Shorts with pocket and wide waist band, Skirt with waist dart and waist yoke, Shirt dress with convertible collar and Knee length halter dress.

This style was chosen because of its ubiquity and potential for use as a base pattern for other styles. Patterns were made on PDS of Optitex and virtual draping was done on 3D models. While draping, adjustments were made for those needed for further fitting and analyzed. After making adjustments, the garments were draped on the 3D models.

Assessments were made regarding the consistency between 3D body models and their 3D virtual garments.

Fig. 2. 3D garment types simulated upon 3D models.

III. Results

1. Comparing Avatar Measurements

The juxtaposition of avatars produced by [TC]^2 reveal clear differences in the reconstructions of subject images based on the same data. <Fig. 3> shows the front view for avatars 1-6 for Subject 1. <Fig. 3> also shows the side view for avatars 1-6 for Subject 1. Upon visual inspection, variation in both shape and size are apparent. Readily perceivable variation is also apparent for avatars 1-6 for Subjects 2 and 3; only images for Subject 1 are shown here to illustrate the point of variation.

We measured the discrepancies of the three most critical body points for clothing construction (i.e. bus, waist, and hip) as well as height and under bust. <Table 1> compares these measurements across avatars and subjects. Between the three subjects, the greatest discrepancies in measurement were in height. 2.4 to 2.5 inches separated the heights of the tallest and the shortest avatars for each subject. Consis-

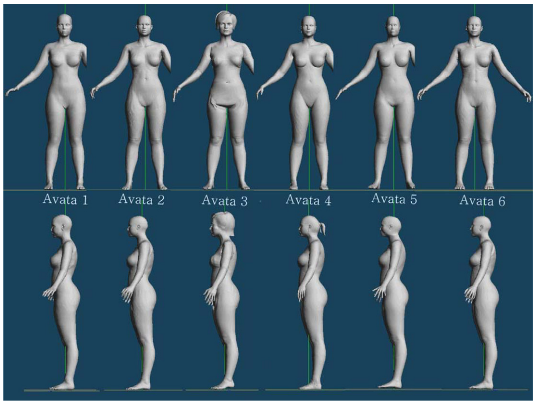


Fig. 3. Front and side views of 3D avatars for Subject 1.

Table 1. Comparison of torso measurements across subjects and 3D body models (Unit: inch)

Subject			ASTM Size USA_ Virtual Tryon	3D body models						Difference
				Avatar 1	Avatar 2	Avatar 3	Avatar 4	Avatar 5	Avatar 6	
Subject 1	Height		-	67.8	67.5	69.1	67.3	66.6	67.0	2.5
	girth	Under-bust	31.8	31.5	31.5	31.3	31.5	31.6	31.4	0.5
		Bust	38.8	38.7	38.8	38.3	38.7	38.7	38.7	0.5
		Waist	28.9	29.0	28.9	28.9	28.9	28.9	28.8	0.2
		Hip	40.4	40.7	40.7	40.7	40.6	40.5	40.7	0.3
Subject 2	Height		-	68.9	68.5	70.2	68.3	67.7	68.0	2.5
	girth	Under-bust	33.2	33.4	33.4	33.1	33.4	33.4	33.4	0.3
		Bust	39.2	39.1	39.1	38.7	39.1	39.1	39.1	0.5
		Waist	33.8	33.8	33.7	33.8	33.8	33.8	33.8	0.2
		Hip	45.7	45.8	45.8	45.9	45.9	45.7	45.8	0.2
Subject 3	Height		-	66.3	65.9	67.5	65.7	65.0	65.4	2.5
	girth	Under-bust	29.8	30.0	30.0	29.6	29.7	30.1	29.9	0.5
		Bust	34.1	33.8	33.9	33.6	33.8	33.7	33.7	0.5
		Waist	26.4	26.4	26.2	26.5	26.4	26.3	26.3	0.3
		Hip	37.2	36.9	36.8	37.0	37.1	36.8	36.9	0.4

Numbers in ▭ show the biggest value while numbers in ⬭ show the smallest value.
–: Fig. 1 shows that it is impossible to measure the height because of the difference of skin color and hair color

tently, avatar 3 was the tallest and avatar 5 was the shortest. The avatars stood in the following order: 3, 1, 2, 4, 6, 5. Systematic inconsistency among avatars reflects the differences in their generating process.

All of the other measurements taken revealed much less variance between avatars. The under bust is defined as the lowest point of the breast where it meets the torso. Differences for under bust among the three subjects ranged from 0.3 to 0.5 inches. Across subjects, the biggest was in avatar 5. The smallest difference was in avatar 3. Measurements most important for garment production are the circumferences of the bust, waist, and hip. For these crucial aspects, avatars revealed relative consistency with each aspect having a 0.5 inch or less variation between the largest and smallest measurements. The range of differences between largest to smallest bust sizes was 0.3 to 0.5 inches. For waist measurements, the range was 0.2 to 0.3 inches. Hip measurement differences were 0.2 to 0.3 inches. This level of inconsistency represents negligible differences for the purpose of garment production. The smallest bust size was on avatar 3 for all subjects, while the largest bust size varied. For all avatars, there was relatively strong consistency in this measurement (a variance of 0.1-0.2 inches).

2. Comparisons of Avatar Cross Sections

In order to visually inspect the relationships between avatar measurements, silhouette representations were superimposed upon each other. Image comparisons were performed from using cross sections of the avatars from xyz-axis perspectives with the axes being x) profile or side view, y) anterior or frontal view, and z) latitudinal view. Perfect alignment of all six avatar silhouettes from the same angle or body part from the same subject indicate consistency of avatar measurements. Multiple lines or blurry lines indicate variance in avatar measausements.

1) Comparison of Avatar Profile Views

The profile images compared were median plane cross sections extending from the middle of the nose to the crotch. Profile silhouettes for the six avatars based on Subject 1 were overlapped as shown in

<Fig. 4>.

Section A to B represents the top of the shoulders to the top of the head. Section B to C represents the torso. Section C to D represents the buttock to the crotch. Section B to C shows agreement among all six avatars. This section includes the points of the body that garment makers consider most and clearly displays the highest level of precision as a function of consistency. Section C to D represents the buttock (hip line) to the crotch.

On the other hand, sections A to B and C to D show obvious differences. The various head types used by avatar generating program help to explain the differences in height mentioned earlier. While the level of the top of the scalp is similar to the others, avatar 3 has the most amount of hair making it appear taller. For avatars 4 to 6, the highest point of the hair is similar. The ponytail on avatar 4 has no measurement implications for clothing development.

In section C to D, avatars 1, 2, and 3 display differences. Avatar 1 has a low crotch. Avatar 3 has a protruding crotch. For avatar 2, the buttock is steep and less rounded than the others. This dramatic depression is likely due to the particular program's attempt to represent the body at this cross-sectional midpoint. The avatars for all three subjects displayed similar tendencies in shape variation.

Taking the data from the previous table and figures together, height difference is not due to size or sizing of torso. Rather, variance can be accounted for by differences in selected head representations imposed by the programs that create the individual avatars. These differences do not appear to affect garment production because garment is produced based on torso measurements.

2) Comparison of Avatar Front Views

The anterior view presents a true silhouette rather than a cross section. Strict cross sections have a tendency to exclude important parts of the body. In addition, angles to maximize body representation would result in distortion of the body among subject images. Between subjects, the inconsistency of angles used to maximize body coverage for varying body shapes would be unhelpful. By using a two-dimensional approach, the resulting image includes all contours from a frontal view.

This silhouette comparison reveals clear inconsistencies between avatars in head, hands, and feet. When making clothing, these body parts are not considered. Therefore, these discrepancies are not import-

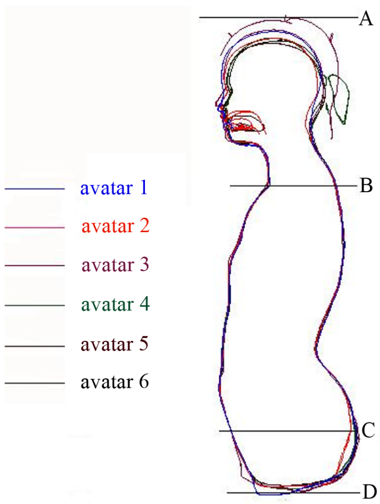


Fig. 4. Overlap of profile views.

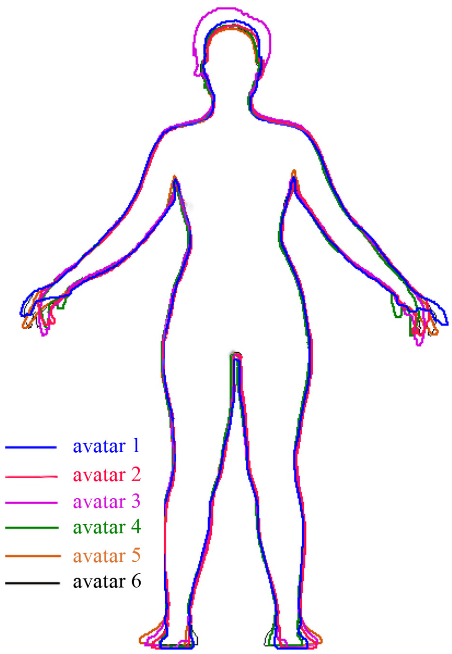


Fig. 5. Overlap of front views.

ant for the current study. As is the case in <Fig. 5>, the torso area shows consistency. Among the places on the body that are clothed, avatar inconsistency can be seen in the areas of the armpits and the crotch. This is because the creation of the individual avatars by computer programs vary in how they factor in space allowances for these areas.

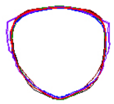
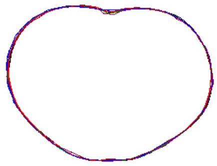
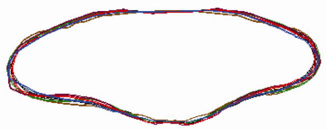
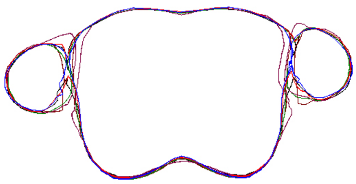
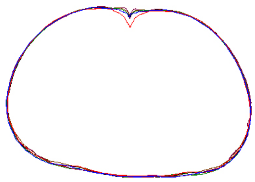
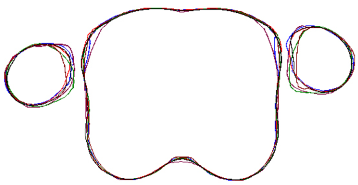
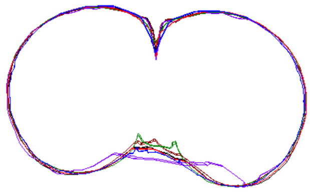
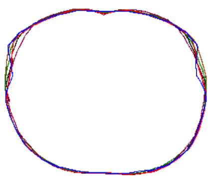
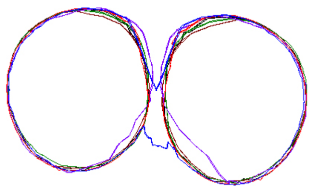
3. Comparison of Avatar Latitudinal Cross Sections

Among these cross sectional slices, the most important are those from the bust to the hip. However, measurements from the neck to the crotch are also pertinent and are included in <Table 2>. At the waist, there is agreement among the avatars. At the hip, there are differences in the depression of dimples. Avatar 2 shows some variance. This corresponds to the depression in the same avatar in <Fig. 3>.

For the bust and under-bust cross sections, the front halves show consistency as well as the center of the back, however, posterior laterals show variance. These locations are near the latitudes where the arms meet the torso, forming the arm pit. The variance in these sizes can be seen as a mediated effect of the variance in armpits as explained earlier. As in previous juxtapositions, there is little difference in torso images. For the current study, there is little need for foot and hand images.

The bust and under-bust pose an issue in measurement as a body in a stand-at-rest position will prevent coverage of the arm pits and below by 3D scans.

Table 2. Cross sectional slices of neck, shoulder, armpit, bust, under bust, waist, hip, and crotch of Subject 1

Neck		Waist	
Shoulder			
Armpit		Hip	
Bust		Crotch + 2cm	
Under bust		Crotch	

Current procedures in body scanning have subjects spread their limbs away from the each other and the trunk of the body. Generally, feet are positioned ten inches apart. The arms are abducted about 15 degrees from the trunk of the body. This helps to maximize scannable coverage for measurements of armpits and crotch, body parts that are normally hidden at rest, while minimizing distortion of other measurements when limbs are spread (e.g. bust size). When creating an avatar, programs demonstrate variance in the specifications with regard to armpit and crotch space allowance and the holes resulting from inaccessible places on the body. This helps to account for discrepancies in avatar comparisons.

This research was undertaken with the assumption that all aspects of the body from neck to crotch are relevant for how garments are worn. Analyses suggest that the consistency among measurements for bust, waist, and hips, the body parts for which the creation of garments is considered most critical, reveal a high level of accuracy. Conversely, those areas of the body that are difficult to measure directly or require "spacing" considerations during garment production show noticeable variance among avatar representations. This is due to both "holes" during the process of measurement and idiosyncrasies between the programs that develop the avatars. In addition, there is difficulty in locating landmarks on inner parts of the body.

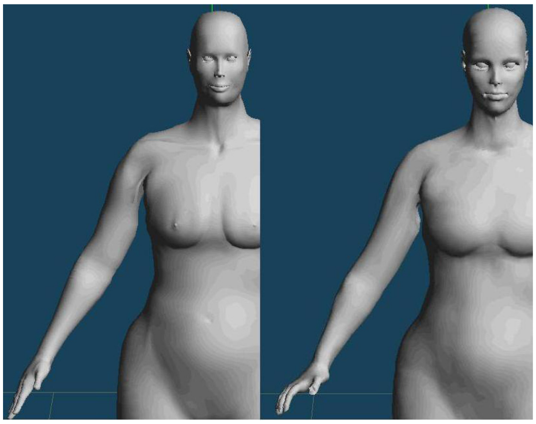


Fig. 6. Distortion of Subject 2 in avatars (Avatar 5 and Avatar 1 in Fig. 3).

Clothes are intentionally not made to match all of the contours of the body. They are made envisioning a straight plane that ignores muscular and skeletal curves. Avatar generating programs imposing this distortion as can be seen in <Fig. 6>. It is worth stating explicitly that the design of an avatar is driven most by the avatar generating algorithms, not by the data.

4. Comparison of 3D Garment Simulation upon Avatars

3D simulations of garments upon all avatars were created to see the impact of clothing created with the current TC2 which focuses on precision of the above four torso points upon the fit of the other mentioned body parts. <Table 3> shows 3D garment simulations draped on the six avatars for same subject without the avatars. The images for shirt, one pieces are similar to each other. The same is also apparent for skirts. As such, they are indistinguishable as clothing draped upon any particular avatar.

The same is not true for slacks. While 3D slacks "worn" by avatars 1, 2, 4, 5, and 6 are similar, the slacks for avatar 3 are clearly unlike the others. It would appear that either a different person is wearing the clothes or that the same person is wearing a different design.

Because of the obvious difference, the same experiment was done with jean pants and shorts. Although the variance was reduced with the new garments, the difference between representation 3 and the others remained apparent.

IV. Summary Sentences

This study sought to test a theory of impact by differences in avatars upon pattern design. While visual inspection of avatars showed clear differences between the six avatar types (in generating process), there was notably less difference between 3D garment simulations based upon the six avatars produced. This demonstrated that there was less influence on the 3D garments than was predicted after visual inspection of the avatars.

Table 3. 3D garment simulation of clothes without avatars

	Avatar 1	Avatar 2	Avatar 3	Avatar 4	Avatar 5	Avatar 6
T-shirts						
Halter dress						
Skirt						
Shorts						

V. Reason

Based upon this study, for garments draped around a body exact detailing of all parts of the body does not appear significant in clothing design as informed by 3D garment simulation. Supporting body parts are the body points that are significant as they define the contours of the garment.

In the case of one pieces and tops, details of the shoulders are important. The bust and the shoulder-blades are other significant points of protrusion. Garments flow along and fall off these regions crucial for defining shape of clothing. If the circumference of the bust and hips are the same, the size of the latter is insignificant except in cases of stretched clothing, like swimming suits

For slacks and skirts, the hips are the most significant measurement and the region from the waist to the hips most define the shape. In the case of skirts, the garment falls from that point making other any lower regions of the body irrelevant for shape. For slacks, on the other hand, the region of the body under the hip and the crotch are also influential.

In the generation of the avatar, measurements of the outer perimeter must accurately represent the body. In the case of difficult to measure body parts, like the armpit and the crotch, however, distortions have conditional significance. Avatars with representations of these areas that are more depressed than those for the actual subject do not affect 3D garment simulation. On the other hand, avatars that underestimate a depression or protrude do affect 3D garment simulation.

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