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Objective Analysis of the Drape Behaviour of Virtual Shirt, Part 1: Avatar Morphing and Virtual Stitching

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Abstract

This research addresses an objective approach to analysing the drape behaviour of virtual shirts with varying eases at the chest area and two different lengths. A set of bodyscan data was utilised to identify body measurements of M-sized British men for the purpose of pattern drafting as well as for avatar morphing within 3D CAD systems. Two different sets of pattern pieces (each set comprising 31 pairs of front and back panels with varying ease from 0.0 to 15 cm at the chest area at an interval of 0.5 cm) of sleeve-less men's shirt were drafted using a clothing CAD system. Size and shape of virtual avatars in two CAD systems were adjusted according to the anthropometry of M-sized British men before simulating pattern pieces on to them utilising the fabric parameters derived from the FAST system. This facilitated the objective analysis of the virtual drape of the simulated shirts with varying ease at the chest girth using three technical parameters namely tension, stretch and pressure. The results and findings will be presented later in part 2 of this paper.

Key Words

Virtual Shirt, Drape Behaviour, Virtual Fit, 3D CAD, Tension Map

1. Introduction

Notable works had been done during the period between 1990 and 2010 for the development of 3D clothing CAD systems (Sayem et al., 2010). Commercial 3D CAD systems that support simulation of 2D pattern pieces on virtual mannequin had started to appear on the market since 2001 (Goldstein, 2009). Today a number of such systems are available for use in the industry, such as Vstitcher (Browzwear), Modaris 3D (Lectra), TUKA3D (Tukatech), 3D Runway (OptiTex), AccuMark 3D (Gerber) and Vidya (Assyst-Bullmer). These software packages

come with a set of integrated virtual human models, which can be customised by means of a range of parameters, from age and gender, through body measurements and posture, to skin tone and hair style, and even through the stages of pregnancy. 2D pattern pieces can be wrapped on these virtual models to develop 3D virtual prototypes, which represent the realistic draping behaviour of fabric, based on mechanical properties. Usually a built-in library of fabrics and other related materials together with their mechanical characteristics is available within these systems. In addition to this, it is also possible to input new fabric properties taken from an objective fabric measurement system such as KES-f (Kawabata Evaluation System for fabrics) and FAST (Fabric Assurance by Simple Technique) in order to view differential drape. Very recently the software companies, for example Browzwear and OptiTex, have introduced their own fabric testing kits for the purpose of drape simulation and removed the KES-f and FAST data converters from the latest releases of their software packages. However, these newly commercialised fabric testing systems need standardisation (Power, 2013), approval, and accreditation from international standardisation bodies to be able to be used with confidence in the industry.

Several technical tools for virtual fit analysis such as tension, pressure, stretch and ease mapping tools are available within 3D CAD systems and they offer both subjective and objective evaluation of fit in combination of visual check of the simulated fit on the computer screen (Sayem et al. 2010, Lim and Istook, 2011). This provides an opportunity to review and forecast the clothing fit at the pre-manufacture stage and to take decision on the correctness of drafted pattern pieces. The suppliers are claiming several benefits of using these 3D systems such as better communication of design throughout the supply chain and reduction of product development time and costs (Ernst 2009). However, little information is available how and at what extent such technology is being used in the industry around the world and what practical benefits of using them are being experienced. A limited number of investigations on the accuracy and applicability of virtual prototyping and fit analysis tools has been reported so far.

It is apparent from the works of Kim (2009) and Kim and LaBat (2013) that only a visual check of virtual sample does not provide any conclusive clue for decision making on the state of virtual fit. They simulated a pair of woven trousers based on fabric properties and found that the appearance of virtual fit significantly differed from that of real fit of garments. Particularly wrinkles were not accurately reproduced on virtual prototypes, which were clearly visible on physical prototypes. They did not utilise any tension and pressure-mapping tool to facilitate virtual fit analysis. Lim (2009) compared virtual simulations of women's wear produced in two

different systems namely OptiTex and Vstitcher utilising identical material properties and found that visual appearances of simulated garments differed in two systems. He also did not utilise any tension, pressure and stretch mapping tools to validate virtual fits of their test garments. The findings of Kim (2009), Lim (2009) and Kim and LaBat (2013) are supported by Power et al. (2011) who highlighted the limitation of visual assessment of virtual fit. They found that fabrics with vastly different properties appeared to have a very similar appearance in virtual simulations. This demands the use of an objective approach to meaningful evaluation of fit of virtual clothing.

Wu et al. (2011) took an objective approach to fit analysis of virtual garment produced in a commercial CAD system. However, they did not make use of any tension or stretch mapping tools to evaluate the virtual fit, rather compared the linear measurements of waist, hip and hem widths taken from images of virtual and real fits. It does neither correspond to the fit analysis practice followed in the industry nor utilise the fit evaluation tools offered in CAD systems. However, they concluded that virtual simulation of skirt is generally accurate when compared with the real fit of physical prototypes. Lim and Istook (2011) and Sabina et al. (2012) took stretch and tension maps on virtual simulation of garments into account in addition to drape image to evaluate fit. Power (2013) indicated that virtual simulations with insignificant visual difference could show significant differences in pressure map. Sabina et al. (2014, 2015) applied virtual prototyping and fit analysis technique to correct trousers pattern sets prepared for female bodies with asymmetric characteristics. They utilised the tension-mapping tool of the OptiTex software to identify the highly strained area of the virtual garment based on the colour code offered by the system, such as red colour indicating highly strained area. However, they did not consider any numerical value of tension for decision-making. Porterfield (2015) applied the ease map available in the Lectra Modaris system to validate the fit of virtual costume but did not consider any tension, pressure or stretch values.
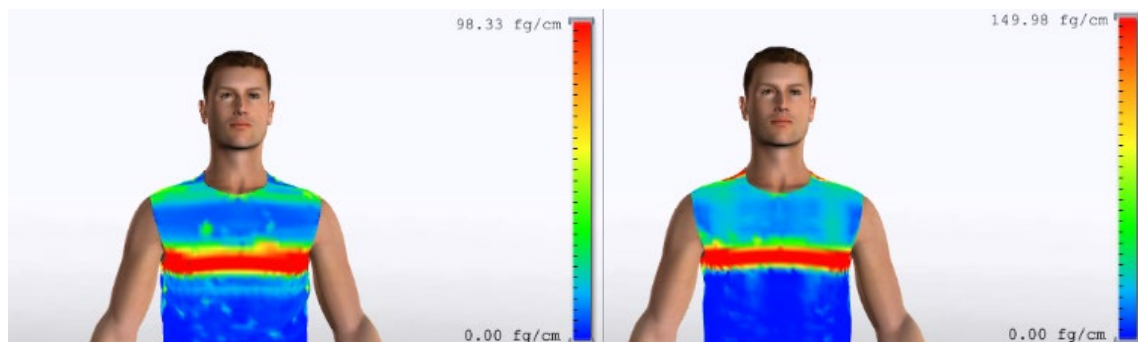

Fig. 1: Tension maps of two different fabrics in OptiTex

Taking decision based on visual colour codes or colour bands of tension, pressure and stretch maps is also someway a subjective approach, which can be quite misleading sometimes. As it can be seen in the Figure 1 that the colour bands of the tension maps from two different fabrics look almost similar but maximum tension values are far different from each other. A true objective approach would be to consider the numerical values of fabric tension, stretch and collision pressure of the virtual drape of a simulated of garment to evaluate virtual fit and thus taking decision on the accuracy of pattern pieces. This research undertook this approach to evaluate the drape behaviour of men's shirts simulated from pattern pieces with varying eases at the chest area. The aim of this paper (part 1) is to describe the processes of accurate avatar morphing and virtual stitching of digital pattern pieces with consideration of material properties, which lays the foundation for implementing the proposed objective approach to fit evaluation.

2. Methodology

Accurate body measurements are necessary for drafting pattern pieces and for adjusting avatar dimensions within the 3D CAD environment. It was intended to prepare a set of pattern pieces of men's sleeve-less shirt in size "M" with a variable ease at the chest area. The BS EN 13402-3:2004 (Size designation of clothes - Body measurements and intervals) provides a range of chest measurement from 96cm to 102 cm for size 'M' of men's shirts. As suggested in Aldrich (2011), a chest measurement of 100cm was selected as a control measurement for M-sized man. Appropriate body measurements for pattern drafting and avatar dimensions were derived from body-scan data as described in the next sub-section. Two 3D clothing CAD systems, OptiTex PDS 11 and VStitcher 6.8, hereafter mentioned as CAD system 1 and 2 respectively, were used for pattern drafting and implementing virtual simulation parts of this research. A shirt made of 100% cotton poplin fabric was bought from a known fashion retailer in Manchester in order to test the mechanical properties of its fabric by FAST system for use in virtual simulation.

3. Steps for Virtual Simulation of Shirt

3.1 Body measurements

In order to identify the representative body measurements of British male population with a chest of 100cm, a set of body-scans with the chest measurement ranging from 99cm to 101cm

(with an average of 100cm) was identified from a data bank of body-scans, which has been developed in our department by scanning interested male subjects using a KX-16 body-scanner (TC^2, USA). Appropriate ethical measures have been taken before and after the collection of body-scan data; each subject voluntarily singed a consent form prior to body scanning and provided unrestricted clearance to capture, store and use of their scanned data for research purpose. Absolute anonymity of the participants has been ensured to maintain the confidentiality policy.

After capturing, the body-scans are stored as reduced body data (RBD) in *.rbd* format within the KX-16 proprietary software system (version 2.2.1) and prior to the measurement extraction from them, each of the body models in RBD format was inspected to verify whether all landmark points are identified correctly by the software. A measurement extraction protocol (MEP) was developed for the extraction of body measurements from each of the body-scans within TC^2 system and the definitions of the major measurement parameters considered in the MEP are presented in the Table 1. Finally the body measurements from all body-scans were extracted into a Microsoft Excel sheet using the '*Batch Process*' tool of the KX-16 software. The average body measurements, as can be found in the Table 2, were used for drafting pattern pieces and for preparing avatar for garment simulation.

Table 1: Definition of Major measurement parameters in TC^2 KX-16 MEP

Measurement Parameters	Definitions in KX-16 MEP
Cervical Height	Back neck height
Neck Column girth	Measured at the middle of the neck where the collar of a dress shirt is usually positioned.
Neck base girth	Usual neck measurement at the neck base.
Chest girth	Circumference at 2cm below the armpit
Under chest girth	In TC^2 system, it follows the 'under bust' definition measured using a horizontal plane.
Waist	Smallest circumference around the torso within the limits of $\pm$1.27cm of 'small of back', which is roughly at the top of the pelvis. This is the default settings for waist in TC^2 system.
High hip girth	Measured at a 50% distance between hip and back waist
Hip girth	The largest circumference between crotch and waist
Thigh girth	The largest circumference at 5.08 cm (i.e. 2 inches) below the crotch. This the default setting in TC^2 system.
Low thigh girth	Measured at 40% distance from knee to crotch
Arm Length	Measured from shoulder point to wrist
Upper biceps girth	2.5 cm above biceps
Bicep girth	The Biceps are found at 5.08 cm (i.e. 2 inches) below the armpit. It is not the largest circumference in the upper arm.

	Outseam	Average of the distances above the floor of the left and right waist points.
	Inseam	It follows the inside of the leg like a tape measure would do.

Table 2: Average Measurements from body-scans and effective Avatar measurements

SL	Measurement Parameters	Average measurements (cm)	Effective Avatar measurements (cm) in CAD system 1	Effective Avatar measurements (cm) in CAD system 2
1	Height	179	179	179
2	Cervical Height	154	154	153.9
3	Neck Column girth	38	38	nn
4	Neck base girth	42	42	42
5	Shoulder slope	6	6	nn
6	Across shoulder	43.5	43.5	nn
7	Chest girth	100	100	100
8	Across back	36.5	nn	nn
9	Under chest girth	89	93.67	nn
10	Under chest Height	126	126	nn
11	Waist girth	84	84	84
12	Waist to Hip	20.5	19.5	nn
13	High hip girth	92.5	92.5	nn
14	High Hip Height	96	96	nn
15	Hip girth	99.5	99.5	99.5
16	Hip Height	85.5	87.67	nn
17	Thigh girth	56	56	56.5
18	Low thigh girth	45	45	nn
19	Knee girth	37.5	37.5	37.8
20	Knee height	50.3	50.3	nn
21	Calf	36.5	36.5	36.5
22	Ankle	26.5	26.5	26.5
23	Arm Length/overarm	58.5	58.5	58.5
24	Armscye girth (Armhole)	44.0	nn	44.0
25	Arnscye Height	135.75	nn	nn
26	Upper biceps girth	30.5	30.64	nn
27	Bicep girth	30.8	26.99	30.8
28	Elbow girth	25.5	25.5	nn
29	Forearm girth	25.5	nn	25.5
30	Wrist girth	16.5	16.5	16.5
31	Out seam	106	106	106.1
32	Inseam	82.5	82.5	82.5
33	Body Rise	68.75	nn	68.75
	nn = not necessary			

3.2 Pattern creation:

Two sets of pattern pieces, as mentioned below, were drafted in the 2D window of the CAD system1 :

a) Set A: 31 pairs of front and back panels with variable ease starting from 0.0 cm to 15 cm at chest area at an interval of 0.5cm and with a shirt length of 78cm;
b) Set B: 31 pairs of front and back panels with variable ease starting from 0.0 cm to 15 cm at chest area at an interval of 0.5cm and with a shirt length of 63cm (i.e 15 cm shorter);

The pattern pieces were drafted following the pattern cutting instructions for 'flat shirt block (woven fabrics)' presented in Aldrich (2011) and using the below measurements for front and back parts of a men's sleeve-less shirt.

Chest girth: 100 cm with variable ease from 0.0 to 15.00 cm at every 0.5 cm interval;

Scye depth: 24.4 cm;

Back neck to waist: 48 cm;

Neck Size: 42 cm;

Half Back: 18.5 cm;

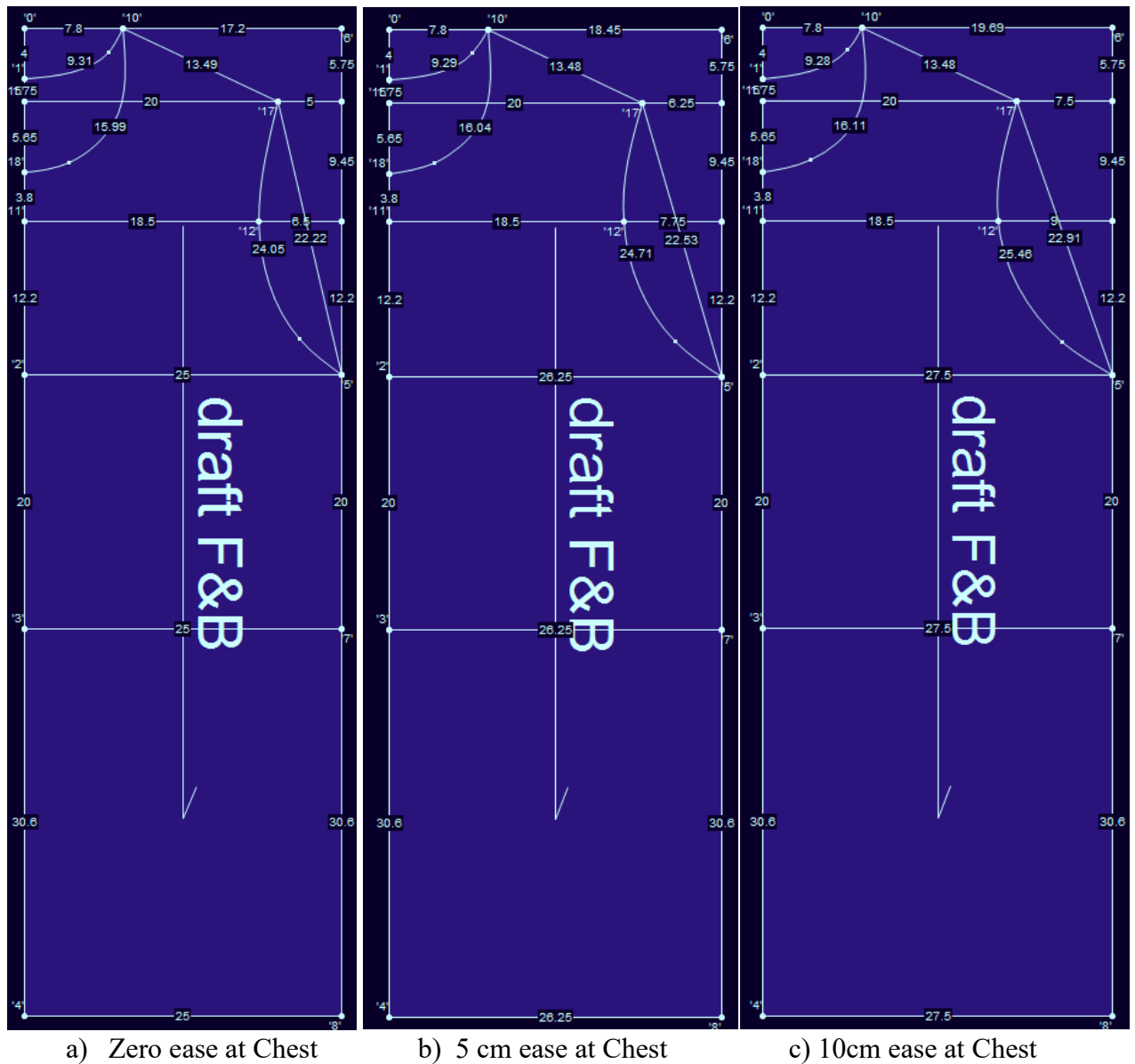Shirt Length: 78 cm for Set A or 58 cm for Set B.

a) Zero ease at Chest   b) 5 cm ease at Chest   c) 10cm ease at Chest

Fig. 2: Examples of Drafts of Front and Back Panels of Men's Shirt with varying Ease

The pattern pieces were primarily drafted within the CAD system 1 and later simulated into virtual garments as described in one of the next sections. The pattern pieces were also exported into the *.aam* format to facilitate importation into the CAD system 2 for simulating as virtual garments.

3.3 Body size and Avatar adjustment:
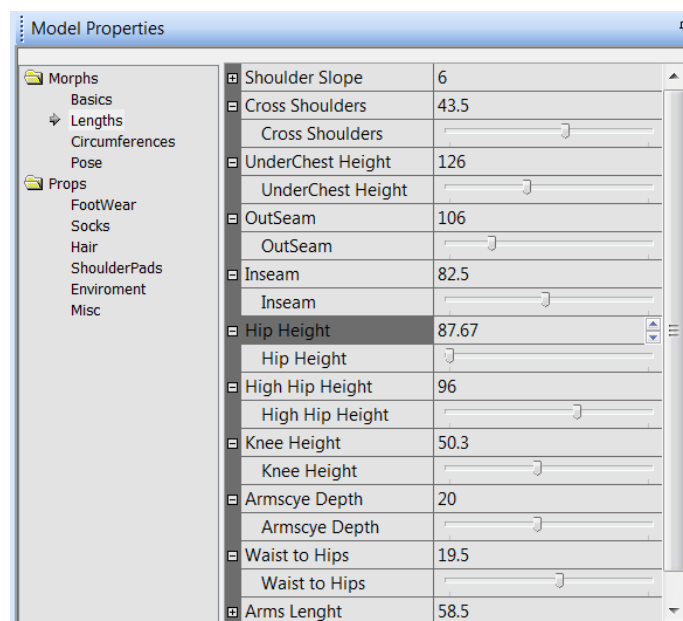
a) In CAD system 1

An appropriate male model namely "PMA_ADAM.mod" was selected from the mannequin library of the CAD system 1 to manipulate its size and shape in order to reproduce the anthropometry of an average M-sized British male using the extracted measurements mentioned in the Table 2. Under four morphing categories namely ***basics, lengths, circumferences*** and ***pose***, this CAD system uses in total 63 criteria to modify or adjust the anthropometric properties of a male figure, as can be seen in the Figures 3a,b & 4a,b. Out of these 63 criteria within the 'model properties window', 33 criteria accept numerical inputs of measurements. Remaining 30 criteria offer only sliding bars to adjust measurements instead of any option for inputting numerical values directly. Out of 33 criteria that accept numerical inputs, 29 could be adjusted using the measurements extracted from body-scan data as presented in Table 2. For three criteria namely body depth, body width and belly depth there are no measurements available from body-scan data as these are not commonly used parameters for apparel construction and there are also no definition for them is available in BS EN 13402-1:2001 (Size designation of clothes- Part 1; Terms, definitions and body measurements procedure). And for one criterion namely armscye depth, the definition followed within the CAD system 1 does not correspond to the commonly used definition for this measurement point; this will be further discussed in one of the next paragraphs.

It has been experienced while morphing the body size and shape of the male mannequin of CAD system 1 using the average body measurements of British M-sized male figures that the software system does not provide absolute freedom to modify all of the morphing criteria. The software system has been programmed with a certain logic due to which certain measurement criteria are interrelated and interdependent to each other. For example, the chest and under-chest measurements are interrelated. With an under-chest of 89cm, the maximum chest girth that could be imparted onto the male mannequin was 96.99cm. Therefore, to have a chest measurement of 100cm, the under-chest had been adjusted automatically to 93.67cm. Similarly, the outseam, hip height and high-hip height and waist to hip measurements were found to be interrelated too. For an outseam of 106 cm and a high-hip height of 96cm, the best achieved hip height and waist to hip measurements were 87.67 cm and 19.5 cm respectively. After adjusting all other measurements the biceps and upper biceps have been found to be

26.99cm and 30.64 cm, as these two measurement are also interrelated and dependent to other measurements within the CAD system 1.
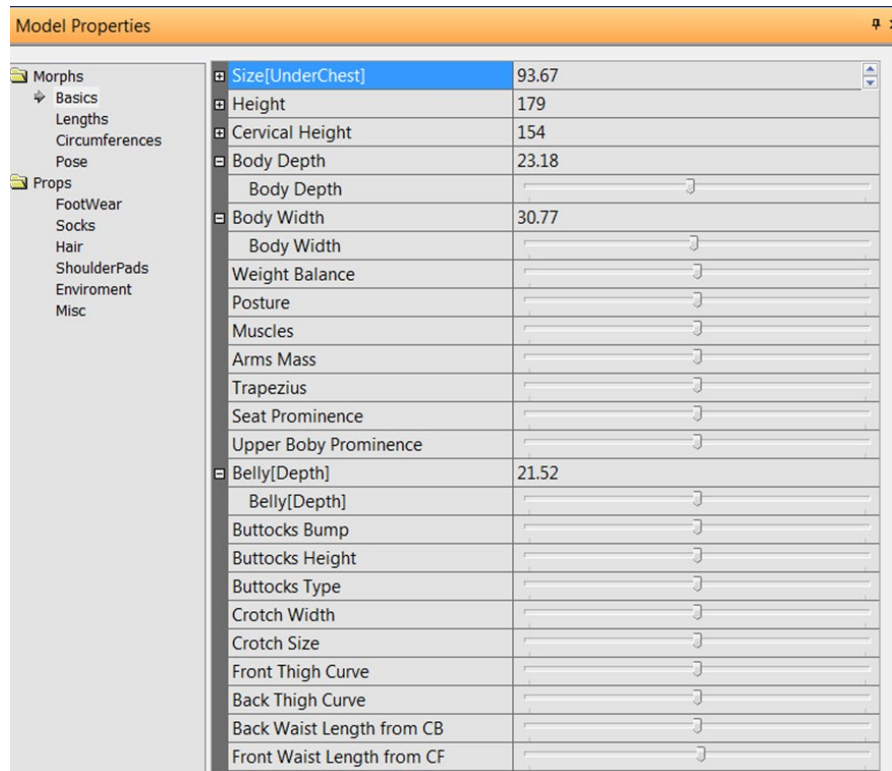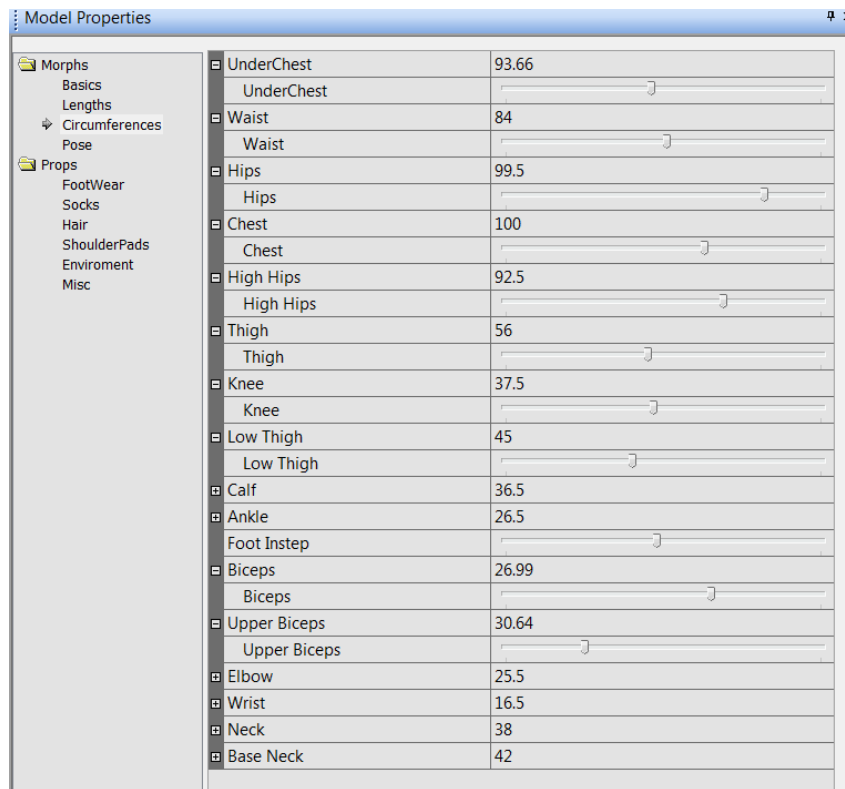

a) Basic measurement parameters

b) Length and Height measurement parameters

Fig. 3.   Morphing Categories in CAD System 1

a) Circumferential measurement parameters

b) Pose and Posture related parameters

Fig. 4.   Parameters for Avatar adjustment in CAD System 1

For armscye depth, this CAD system follows an unusual way to measure it as can be seen in the Figure 5. Traditionally armscye depth is measured as the vertical distance between the back neck point and across back position (Aldrich, 2011). The diagonal distance between back neck and armpit, hereafter mentioned as 'diagonal armscye', as measured by CAD system 1, cannot be directly derived from the body-scan data. However, this can be calculated using the half-

back measurement (a) and the difference between back neck height and armscye height (b), and applying the Pythagorean theorem as presented in the Figure 5. The calculated diagonal armscye (c) is 25.81cm, which produces an unusual geometry with very low armpit at the underarm area as illustrated in Figure 5. Therefore, an appropriate measurement of 20 cm was selected after visual check.
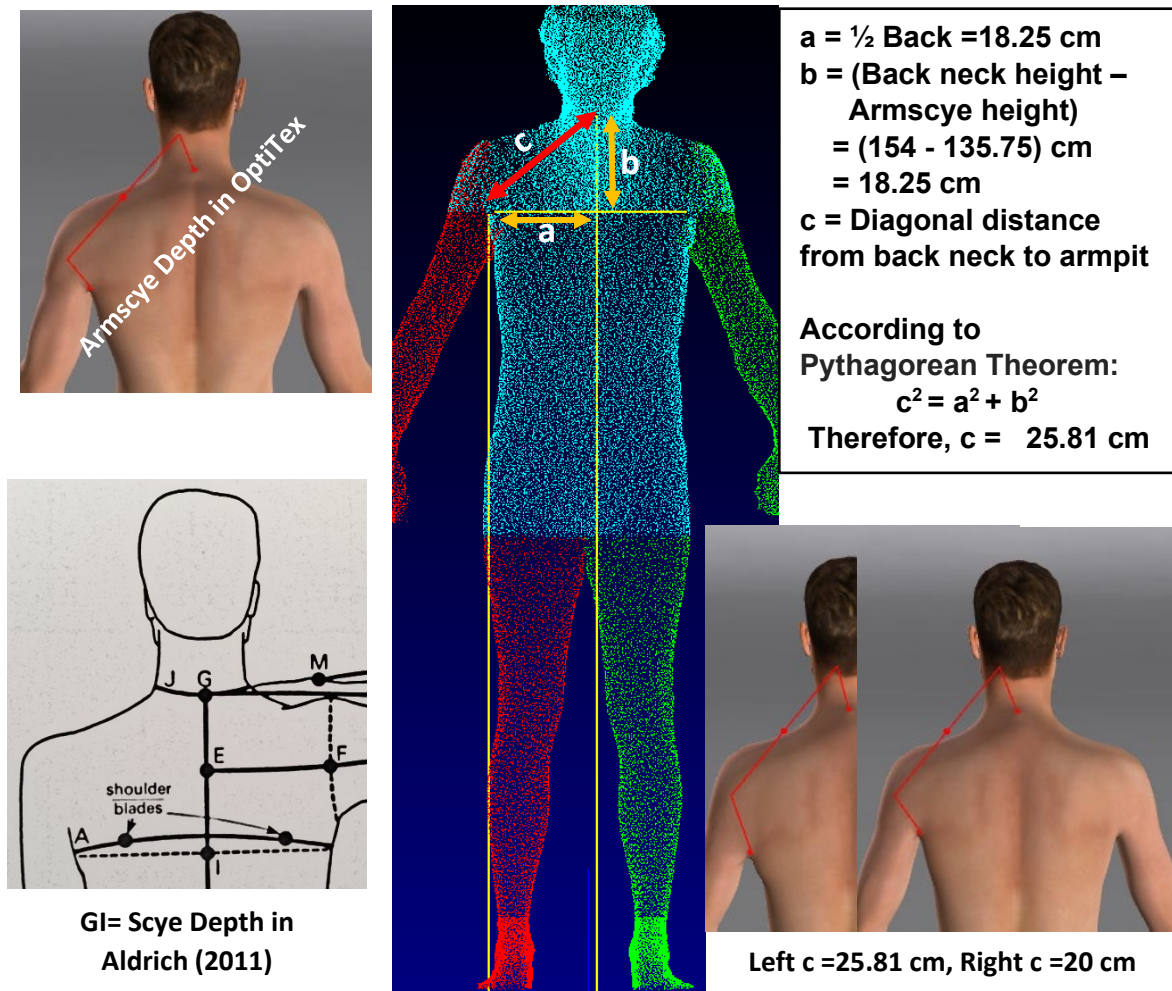

a = ½ Back =18.25 cm
b = (Back neck height –
    Armscye height)
  = (154 - 135.75) cm
  = 18.25 cm
c = Diagonal distance
from back neck to armpit

According to
Pythagorean Theorem:
$$c^2 = a^2 + b^2$$
Therefore, c = 25.81 cm

Armscye Depth in OptiTex

GI= Scye Depth in
Aldrich (2011)

Left c =25.81 cm, Right c =20 cm

Fig. 5: Arm Scye Depth Calculation for Avatar in CAD System 1

For body depth, body width, weight balance, posture, muscles, arm mass, trapezius, seat prominence, upper body prominence, belly depth, buttocks bump, buttock height, buttocks type, crotch width, crotch size, front thigh curve, back thigh curve, back waist length from CB and from waist length from CB, the sliding bars were positioned at average position in the middle as can be seen in the Fig 3a. The pose and posture related adjustment of the avatar is represented in the figure 4b.

b) In CAD system 2

From the mannequin library of CAD system 2, an appropriate male model namely "Adam_Aadam_m.adf" was selected to reproduce the anthropometry of an average M-sized British male using the extracted measurements mentioned in the Table 02.

Within the 'Avatar' tab-window of this CAD ssytem, the software offers five effective morphing categories namely *height, body silhouette, torso, legs, hands and body shaping,* under which there are in total 39 criteria to modify or adjust the anthropometric properties of a male figure, as can be seen in the Figures 6. Out of these 39 criteria, 23 accept numerical inputs and rest 16 offers sliding bars with a range of values from -0.5 to +0.5. Off the 23 criteria, those accept numerical inputs, the values of 21 criteria were taken from the average measurements of scanned male figures as presented in the Table 2. As waist and high waist, and knee and calf are interrelated in the Avatar system of CAD system 2, high waist and calf were adjusted with values of waist and knee respectively. For the remaining 16 criteria that offer sliding bars with a range of values from -0.5 to +0.5, a middle point (0.0) was selected for each of them a scan be seen in the Figure 6.

Fig. 6. Avatar adjustment Windows in CAD System 2

3.4 Fabric properties testing:

A set of physical and mechanical properties of fabric such as weight, thickness, resistance to bending, resistance to stretch, resistance to shear, co-efficient of friction etc. are required for realistic drape simulation (Luibe and Magnenat-Thalman, 2008). These have to be measured in a low force environment that corresponds to the loads a fabric is likely to undergo during garments manufacturing and wear. KES-f and FAST are two commonly used objective evaluation techniques that measure mechanical properties of fabrics under low force unlike the traditional test methods described in ISO (International Organization for Standardization) and ASTM standards. Although both of the techniques were initially developed for the prediction of performance of woollen fabrics in garment manufacture and control of the making-up process, the parameters necessary for virtual simulation of fabrics at garment states can also be derived from their measurements.

Breen et al. (1994) and Eberhardt et al. (1996) utilised KES-f parameters for simulating fabrics in virtual environment. Luibe and Magnenat-Thalman (2007, 2008) applied and compared both KES-f and FAST systems for deriving required parameters for both woven and knit fabric for the purpose of virtual simulation and identified certain limitations with both systems. Kim (2009), Lim (2009), Lim and Istook (2011), Wu et al. (2011) and Kim and LaBat (2012) utilised FAST system for testing fabric properties for use in simulation of garments on virtual mannequin.

In this research, a shirting fabric as mentioned in the Table 3 was tested by FAST technique for deriving the required parameters for use in virtual simulation within the CAD systems 1 and 2. The following equations were taken into consideration during FAST test carried out in a standard atmosphere using conditioned samples as per BS 139 - 2005:

Surface Thickness, ST = T100-T2 ………………….…………(1)
Where, T2 and T100 thicknesses measured at two different loads: 2 gf/cm^2 (19.6 mN/cm^2) and 100 gf/cm^2 (981 mN/cm^2) respectively.

Bending Rigidity, B (μN.m) = 9.81 x 10^{-6} x WC^3 ………………(2)
Where, C is the bending length measured in mm and W is the fabric weight in g/m^2.

Shear Rigidity, G (N/m) = 123/EB5 ………………….……… (3)
Where, EB5 is the bias extensibility in %.

Relaxation Shrinkage, RS = 100 x (L1 - L3) / L1 …………………(4)

Hygral Expansion, HE = 100 x (L2 - L3) / L3………..………..…(5)

Where, L1 is the dry length; L2 is the wet length and L3 is the relaxed re-dry length.

Table 3: Fabric Parameters for Virtual Simulation

Fabric Type: Shirting; Composition: 100% Cotton					
Construction: Ends: 55/cm; Picks: 30/cm; Warp Count: 15 Tex; Weft Count: 15 Tex					
FAST Data		Converted Data for CAD System 1		Converted Data for CAD System 2	
Parameters (Unit)	Value	Parameters (Unit)	Value	Parameters (Unit)	Value
Extensibility (%) at Warp [E100-1]	1.97	Stretch (g/cm) at warp	1955.67	Stretch (N/m) at warp	1917.86
Extensibility (%) at Weft [E100-2]	1.67	Stretch (g/cm) at weft	2307.69	Stretch (N/m) at weft	2263.08
Bending Rigidity (μN.m) at Warp	10.89	Bend (no unit) at warp	1089	Bend (dyn.cm) at warp	108.9
Bending Rigidity (μN.m) at Weft	5.96	Bend (no unit) at weft	596	Bend (dyn.cm) at weft	59.6
Formability (mm^2) at warp	0.20	-	-	-	-
Formability (mm^2) at weft	0.15	-	-	-	-
Shear Rigidity (N/m)	199.46	Shear (no unit)	1994.6	Shear (N/m)	199.46
Thickness (mm)	0.21	Thickness (cm)	0.021	Thickness (mm)	0.21
Relaxation Shrinkage (%) at Warp	0.27	-	-	Relaxation Shrinkage (%) at Warp	0.27
Relaxation Shrinkage (%) at Weft	-0.14	-	-	Relaxation Shrinkage (%) at Weft	-0.14
Hygral Expansion (%) at warp	0	-	-	-	-
Hygral Expansion (%) at weft	0.54	-	-	-	-
Weight (gsm)	135.33	Weight (gsm)	135.33	Weight (gsm)	135.33
-	-	Co-efficient of friction	0.20	Co-efficient of friction	0.2

3.5 Fabric Parameter conversion for simulation:

The CAD system 1 uses following parameters for fabric simulation: weight (gsm), stretch (gr/cm), bend (no unit), shear (no unit), and thickness (cm). Expect weight (g/m^2), other parameters from FAST test cannot be input directly to its 3D simulator. This CAD system considers *stretch* as the resistance of the cloth to stretching forces in the Warp (X) and Weft (Y) directions. These parameters affect the elasticity of the fabric. These can be derived from

the FAST parameters Extensibility (%) [E100-1 & E100-2]. *Bend* in CAD system 1 is the resistance of the cloth to Bending forces. This parameter affect the rigidity versus fluidity of the fabric and can be derived from the FAST parameter Bending Rigidity (μN.m) by using the fabric converter tool of the CAD system 1. *Shear* is the resistance of fabric to shearing forces, which are in action on the diagonal direction of fabric. This parameter affects the gliding quality versus stiffness of a fabric when cut in bias direction. This can be derived from FAST parameter Shear Rigidity (N/m) using the fabric converter tool available in the CAD system. However, the conversion of FAST parameters to the required fabric parameters of CAD system 1 cannot be done in its latest version (PDS 11) as this version of the software no longer contains the fabric conversion tool. Therefore, the fabric converter available in its earlier version (PDS 10) was used, similar to the work of Lim and Istook (2011), for converting all FAST parameters into the compatible parameters of CAD system 1, as presented in the Table 3. It should be noted that the conversion of *Bend* and *Shear* achieved from the fabric converter of CAD system 1 does not correspond to the known mathematical relationships of the relevant units, therefore those are mentioned as 'no unit' in the Table 3.

Fig. 7. Fabric Converter of CAD System 1

The CAD system 2 also uses similar parameters such as Weight (gsm), Thickness (mm), Bend (dyn.cm), Stretch (N/m) & and Shear (N/m) for fabric simulation. The FAST results for Weight, Thickness and Shear can directly be input into the fabric simulator of CAD system 2,

as the units are exactly the same. For bend, the FAST result of bending rigidity (µN.m) can be converted to the compatible unit (dyn.cm) of CAD system 2 using known mathematical factors of the units. For extensibility, the stretch unit (g/cm) of the parameter from CAD system 1 was converted into stretch unit (N/m) of the CAD system 2, similar to Lim (2009), using the following conversion formula:

$$1 \text{ gram-force/centimetre} = 0.98067 \text{ newton/meter}$$

FAST system does not measure co-efficient of friction of fabric. Ghani (2011) categorised shirting fabrics as light, light to medium, medium, medium to heavy and heavy based on their weights and tested them using KES-f system. She found the Co-efficient of friction of medium weight fabrics (101 -135 gsm) of 100% cotton fibres varied from 0.15 to 0.20. Based on this, a value of 0.20 is used as co-efficient of friction for the similar woven fabric used in this research.

3.6 Virtual Stitching

All front and back pattern pieces of set A & B (31 pairs for each with varying ease starting from 0.0 cm to 15 cm at chest area at an interval of 0.5cm as described in section 2.2) were simulated on the avatars (described in the section 3.3) within the 3D window of both CAD software systems. The simulation process includes the definitions of stitches and seamlines on the 2D pattern pieces and the use of relevant simulation properties presented in Figure 7.

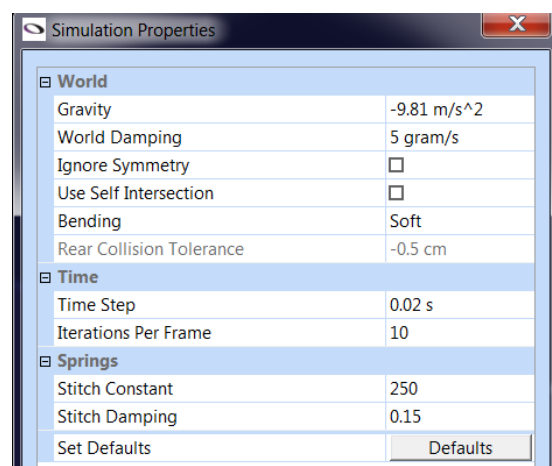| Simulation Properties	
World	
Gravity	-9.81 m/s^2
World Damping	5 gram/s
Ignore Symmetry	☐
Use Self Intersection	☐
Bending	Soft
Rear Collision Tolerance	-0.5 cm
Time	
Time Step	0.02 s
Iterations Per Frame	10
Springs	
Stitch Constant	250
Stitch Damping	0.15
Set Defaults	Defaults

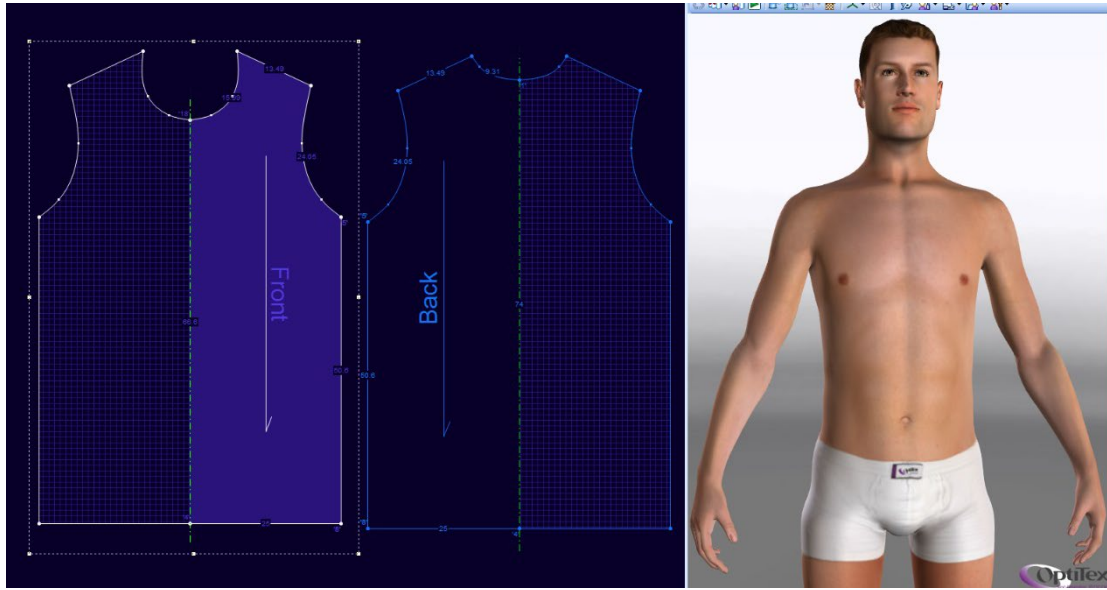**Fig. 8 Simulation Properties in CAD System 1**

Fig. 9 Pair of Front and Back Panels ready for Simulation in CAD system 1

Figure 9 shows a pair of pattern pieces ready for simulation on an avatar in the CAD system 1, and Figure 10 shows the steps of simulation and an example of tension map.
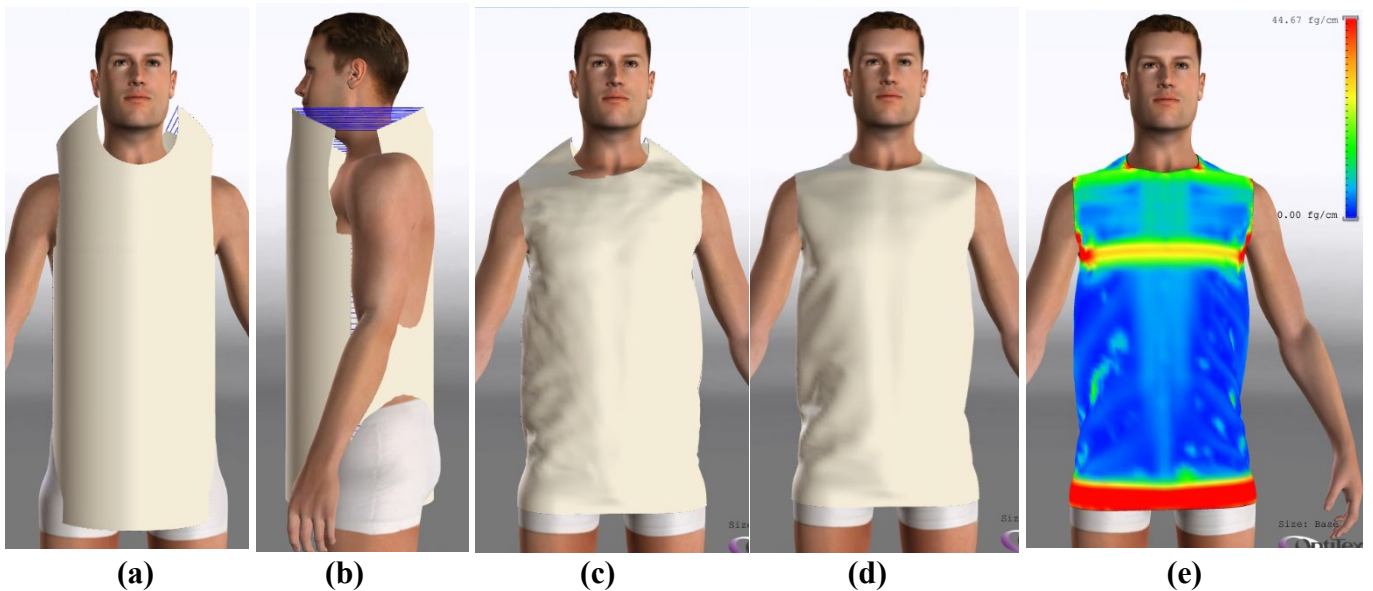

| (a) | (b) | (c) | (d) | (e) |

Fig. 10. The Steps of Virtual Simulation (a-d) and an Example of Tension Mapping (e)

Tension (gf/cm), Stretch (%) and Collision pressure (dyne/cm^2) on the virtual clothing were analysed for each and every pairs of patterns in the CAD system 1, which is further discussed

in the part 2 of this research. Similarly in CAD system 2, tension (gr/cm) in fabric and pressure (gm/cm^2) exerted from the stretched garment on virtual body were analysed.

4. Conclusion

The prevailing limitations with the visual assessment (Kim, 2009; Lim, 2009; Kim and LaBat, 2013; Power et al. 2013 and Power 2013) have set the rationale for undertaking an objective approach to virtual drape evaluation of garments. However, this can only be applied if the simulation process takes the physical properties of fabrics and appropriate avatar morphing features into account. It has been experienced that none of the CAD systems in use provided absolute freedom to adjust all avatar-morphing criteria to reproduce the target anthropometry completely. Moreover, the CAD system 1 followed an unusual way to measure the armscye depth. These issues need to be addressed by the CAD software companies to ensure a meaningful application of such systems within the fashion industry. This part of the research described the avatar morphing and fabric-specific drape simulation processes, which are the prerequisites for developing an objecting fit evaluation technique. Part 2 of this research further explores this novel approach.

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