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Enhancing accuracy of drape simulation. Part II: Optimized drape simulation using industry-specific software

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Abstract: Three-dimensional virtual representations of fabrics are done based on mass-spring modeling, which represents cloth as a mesh of particles connected by springs. The spring constant values input to the model correspond to the mechanical properties of the modeled fabric. For apparel, these representations have been incorporated into commercial software packages for use in design and development of garments. However, fabric mechanical property values as derived using industry test methods cannot be input directly into the commercial software to produce simulations that accurately represent a specific fabric. A systematic way of selecting input parameters to a particle model was developed by comparing the drape of circular fabric samples whose mechanical properties were measured by the Kawabata evaluation system to simulations produced by the particle model using methods developed in Part I of this paper. Also, a relationship was developed between measured fabric mechanical properties and simulation input parameters and then tested on simulations of apparel samples.

Key words: Simulation, fabric drape, particle model, 3D body scanner, garment drape.

INTRODUCTION

Accurate three-dimensional (3D) virtual representation of fabric drape is a very effective tool for the textile industry and would greatly facilitate many aspects of business processes. At present, drape simulation technologies lack accuracy in their representation of the diverse variety of apparel fabrics due to very little understanding of how variations in fabric mechanical properties affect drape simulations. Simulations based on particle models represent cloth as a mesh of particles connected by springs. The springs exert forces on the particles causing them to move, thus representing the deformation of fabric. The spring constant values input to the model represent properties such as bending, stretching, and shear stiffness of the simulated fabric. In the last decade, commercial software based on this approach has become available to garment producers. Such 3D drape modeling software is gaining attention in the textile industry as a tool for design, development, merchandising, and visualization of apparel.

The most well-known industry provider of software for two-dimensional and 3D CAD/CAM fashion design is OptiTex (Isaacs, 2005). OptiTex's commercially available cloth simulation software package, Modulate^{TM}, is based on an interacting particle modeling approach recently developed by Choi and Ko (2002). This formulation was inspired by, and is an extension of, the pioneering work of Breen *et al.* (1994). Modulate^{TM} allows users to input mechanical properties of a fabric and simulate its drape over a simulated human form. By varying the mechanical properties input to the software, the appearance of different fabrics can be simulated. Simulations done by the particle model approach used in Modulate^{TM} do not produce accurate representations of particular fabrics when mechanical property values derived using the Kawabata evaluation system (KES) (Kawabata, 1980) are input directly, leading to an ad hoc selection of input parameters to make the simulation look more like the drape of a particular fabric. There

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is a need to avoid this nonsystematic selection of input parameters. This paper presents a simple way of relating fabric mechanical properties measured by conventional testing systems like the KES to input parameters required for the particle model to produce realistic simulations. This relationship was developed by comparing the drape of circular fabric samples of various fabrics whose mechanical properties were measured by the KES to matching particle model simulations produced by Modulate™. Since drape is a complex function of many unpredictable variables, a simple way of varying only a few parameters in simulations without compromising their resemblance to reality has been developed. Figure 1 is a flowchart describing the process of developing the relationship. Steps 1, 2, and 3 in the flowchart were discussed in Part I of this two part paper. This paper elaborates on steps 4, 5, and 6.

GENERATION OF SIMULATIONS FOR CIRCULAR FABRIC SAMPLES

Many drape quantifying parameters for fabrics encompassing a wide spectrum of properties were obtained from drape testing of circular fabric samples. The drape coefficient (BS 5058: 1973; British Standard Institution, 1974b), the number of folds (nodes), and fold dimensions produced by each fabric during the variability tests described in Part I gave a clear idea of how each fabric draped in reality. The next step was to simulate the drape of a circular sample of each of those fabrics.

The Modulate™ software was used for generating simulations. The circular fabric sample simulations in Modulate™ were done using the same dimensions as those used for fabric variability testing, that is a 36-cm diameter fabric sample draped over an 18-cm diameter surface. The 18-cm virtual platform to support the simulated fabric samples for virtual draping was generated by the researchers and imported into the Modulate™ software.

Through experimentation, it was discovered that particle model drape simulations, like real fabrics, are most sensitive to changes in the bending stiffness parameter. Hence, the effect of varying the bending stiffness on drape shapes was studied by holding all except one of the other parameters constant. The weight input to the simulations was the actual value measured in the KES experiments. Matching simulations were performed for each fabric of the 14 fabrics investigated (refer to Part I) using input parameters shown in Table 1.

By varying only the bending stiffness while keeping most parameters constant, the task of selecting simulation input parameters for each fabric was simplified. Furthermore, there was no drop in the degree of resemblance of a simulation to the actual drape by using this approach. It should be emphasized that the bending stiffness value measured in the KES experiments does not produce correct drape shapes when input directly as the bend parameter in Modulate™. In fact, the key discovery in this research was the relationship between the bending stiffness of cloth measured by KES and an appropriate bending parameter for the particle model simulation to produce realistic simulations. Figure 2 shows snapshots of the simulation of the drape of a circular fabric sample using Modulate™.

Table 1 **Input parameters to modulate simulations**

Parameter	Value
Bending stiffness	Variable (dyne-cm)
Stretching stiffness	$X = 1{,}500$, $Y = 1{,}000$ g/cm
Shear stiffness	300 dyne-cm
Damping	0.01 cm/s
Shrinkage	$X = 0$, $Y = 0$
Weight	From KES (g/m^2)
Resolution	1.5 cm
Friction coefficient	0.25
Thickness	0.05 cm

CRITERIA FOR COMPARING DRAPE SIMULATIONS WITH 3D SCANS

Variability tests discussed in Part I showed that fabrics exhibit wide variation in drape shape during repeated trials. The significant outcome of the variability tests was the determination that there can be no single target drape shape for a simulation in order to conclude it matches the drape of a real fabric. Instead, if a simulation falls within a region of acceptance it can be accepted as a good match to an actual target drape. Hence, based on results of the variability tests, criteria were developed for determining whether a simulation was a good match to the actual drape of a fabric. The criteria were as follows:

- The drape coefficient of the simulation must be within ±10% of the mean value obtained from the variability tests.
- The number of nodes in the simulation must equal the number of nodes observed in at least one of the 12 trials done for each fabric.
- The dimensions of the nodes (d_1, d_2, d_3) of the simulation must be within ±20% of the mean value obtained from the variability tests.

To push the simulations toward the typical behavior for each fabric, criteria established for matching simulation and actual fabric were chosen to be more stringent than the variability exhibited by the draped fabrics. Unlike the values for real fabric drapes, simulation drape values do not vary when a simulation is generated repeatedly. Also, in generating simulations, the average values were targeted for each fabric. When a simulation of a particular fabric satisfied the above criteria, it was classified as a good representation.

TRANSLATING KES MEASUREMENTS TO MODULATE™ INPUT PARAMETERS

One simulation satisfying the criteria was generated for each of the fabrics whose mechanical properties were tested

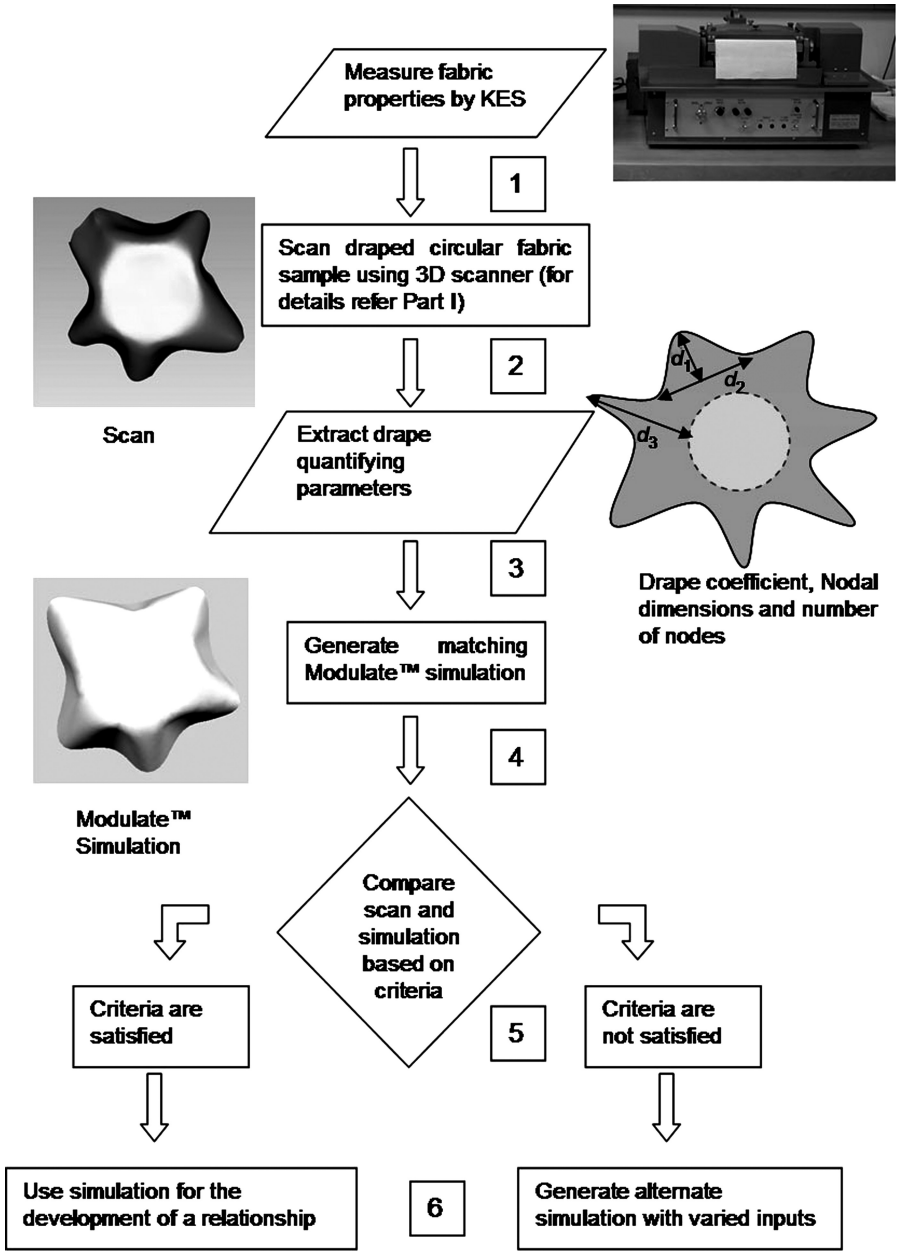

Figure 1 Development of relationship between fabric mechanical properties and particle model simulation input parameters.

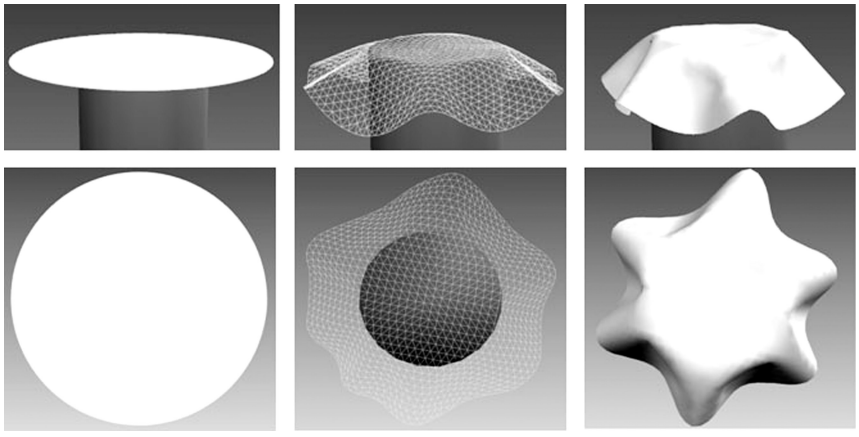

Figure 2 Successive stages of simulating drape of a standard circular specimen: Front and top views.

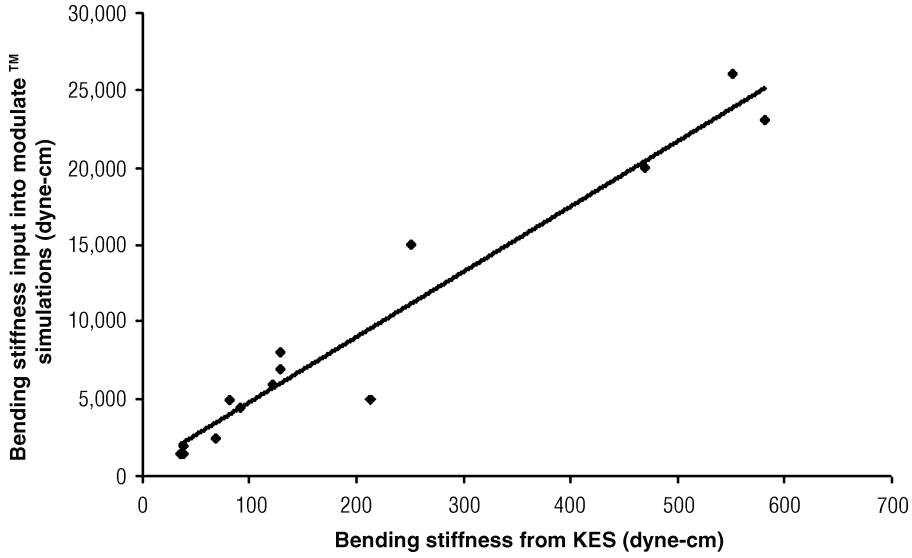

Figure 3 Plot of input to Modulate™ simulations versus KES bending stiffness.

using the KES. The simulations were input with parameters shown in Table 1. Figure 3 is a plot of the bending stiffness of the fabrics measured from the KES against the bending stiffness input to Modulate™ simulations. Each of the data points in the plot corresponds to the bending stiffness input to produce the optimal matching simulation for a particular fabric. The target simulation values were based on averages of several readings for the fabrics, so the goal was to best simulate the average behaviour. The points were fitted to a line. The significance of this plot is that in order to realistically simulate a fabric using the particle model approach, the bending parameter to be input into the simulation can be found easily from the graph once the KES bending value is obtained. Although other similar simulation codes may not use the identical translated values, the method would be applied for obtaining such values for another code. Other parameters to be input to the simulation are as summarized in Table 1.

APPLICATION TO GARMENT SIMULATION

To be of practical use, the stiffness relationship developed through drape testing of circular fabric samples should be applicable to simulating garments. This section presents details of application of the developed relationship to simulated garments. The testing was done using apparel that was expected to give the most variation in drape with variation in mechanical properties. The approach in our research was to study the drape of circular fabric parts and develop a relationship from it. So, it was logical to apply the relationship to garments that drape from the body. There are a wide variety of garments of all sizes that can be made to fit humans. Some garments cling to the body and exhibit very little variation in appearance when made of different fabrics. A garment designed such that it is a loose fit is an ideal case for drape testing because it will not cling to the body (a mannequin in our work) when donned. Loose fitting skirts and dresses were chosen as the garments to examine the applicability of the derived relationship.

The relationship was examined by scanning garments fitted to mannequins using the 3D scanner, running simulations of garments of the same dimensions fitted to the scan of the mannequin used in the testing, and comparing them based on the predetermined criteria. The process of generating scans of garments was the same as in the case of the circular samples and required multiple scans, registration and merging of the scans, and application of a surface. Scanning was accomplished using the 3D scanner and the processing was done using Geomagic™.

The garment simulation input parameters were derived from the previously obtained relationship between measured bending stiffness and the optimal bend parameter value used for simulation. Skirts and dresses of different fabrics and dimensions were constructed and draped on two mannequins of different dimensions. The garments were conditioned in standard atmospheric conditions (BS 1051: 1972; British Standard Institution, 1974a) before the experimentation. The flowchart in Figure 4 shows the process of comparing garment simulations and scans.

MEASURES AND METRICS FOR COMPARISON OF GARMENT SIMULATION AND SCANS

Two factors were used in the comparison of garment scans and simulations:

- The volume occupied by closing the top and bottom of the garment, a measure analogous to drape coefficient used with circular fabric samples. Figure 5 shows a typical draped skirt where this volume was computed via Geomagic™.
- The number of nodes obtained in the bottom section, a measure that is analogous to the number of nodes for the circular fabric samples.

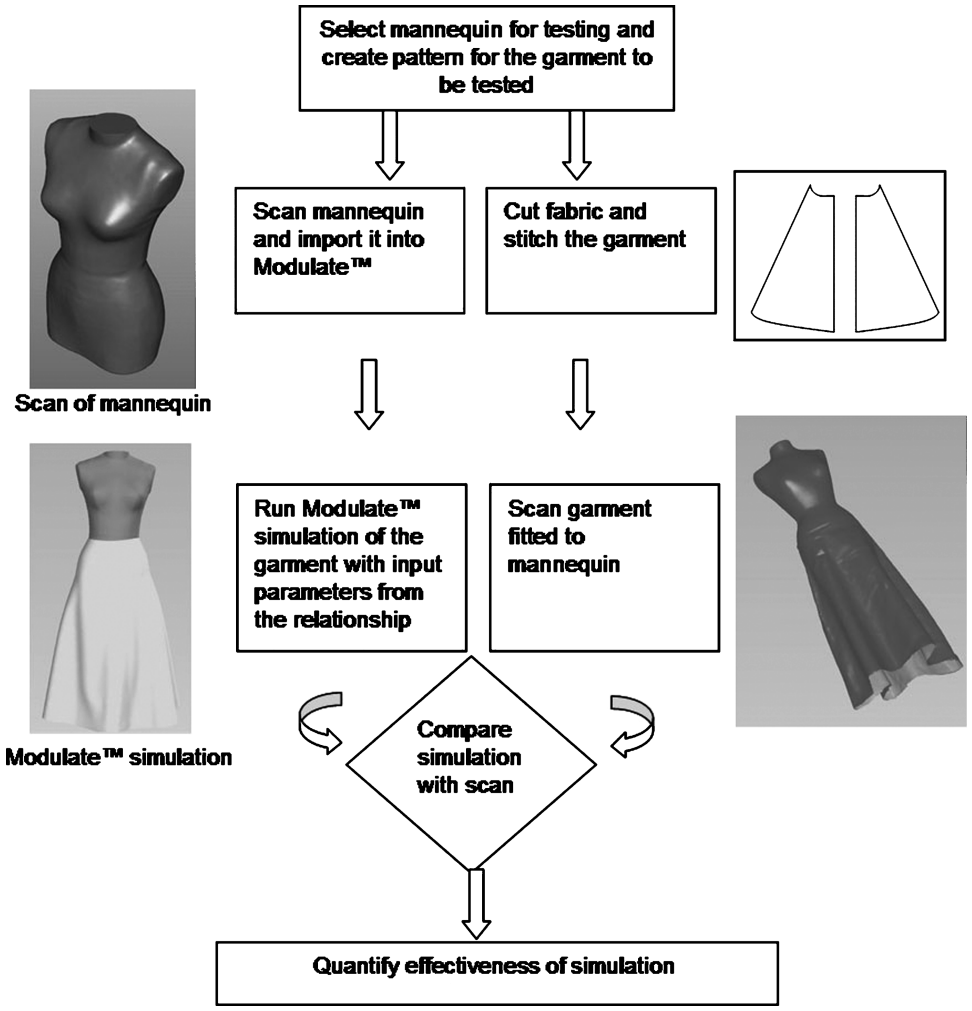

Figure 4 Flowchart of garment simulation evaluation process.

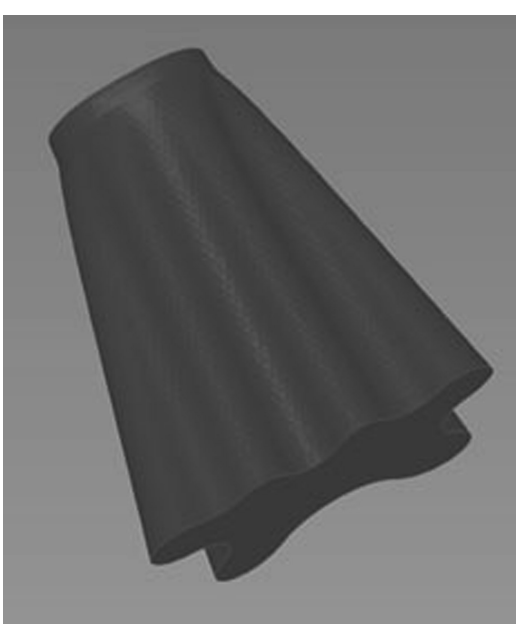

Figure 5 A scanned skirt closed at top and bottom for computation of volume.

Taking into account the range of variation that fabrics exhibit in their drape, criteria were established for classifying a simulation as an acceptable representation of a garment. The criteria were defined as follows:

- The volume occupied by the simulated garment should be within ±15% of the volume occupied by the scan of the garment.
- The number of nodes obtained in the simulated garment should be within ±2 of the number of nodes obtained in the scan of the garment.

RESULTS OF TESTING ON GARMENTS

Three different garments (two skirts, one dress) were created and evaluated on two uniquely shaped mannequins. The garments were constructed with a minimal number of seams to reduce their influence; other factors that could influence drape such as closures and hemming were avoided. The garments were always constructed with the warp yarn parallel to the vertical direction. Details for one of the skirts used in the experimentation are presented in Figure 6.

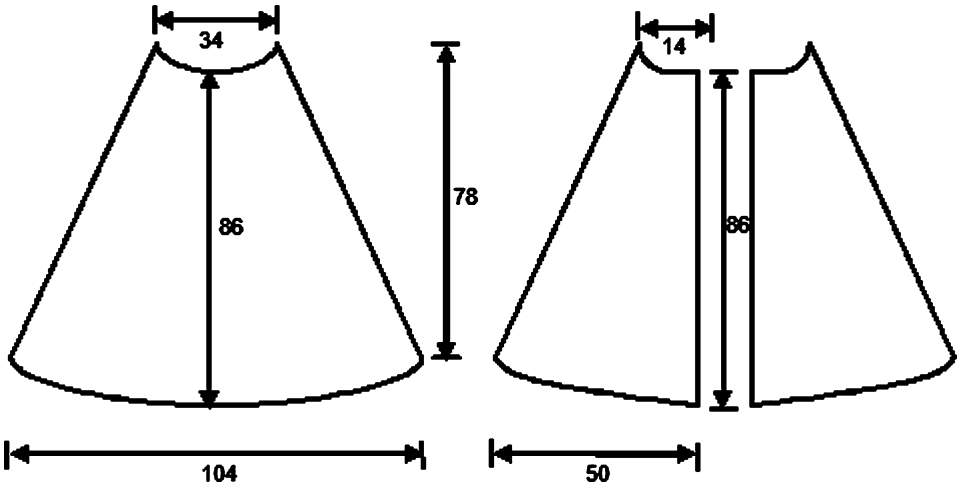

Figure 6 Pattern for a skirt used in garment testing (dimensions in cm).

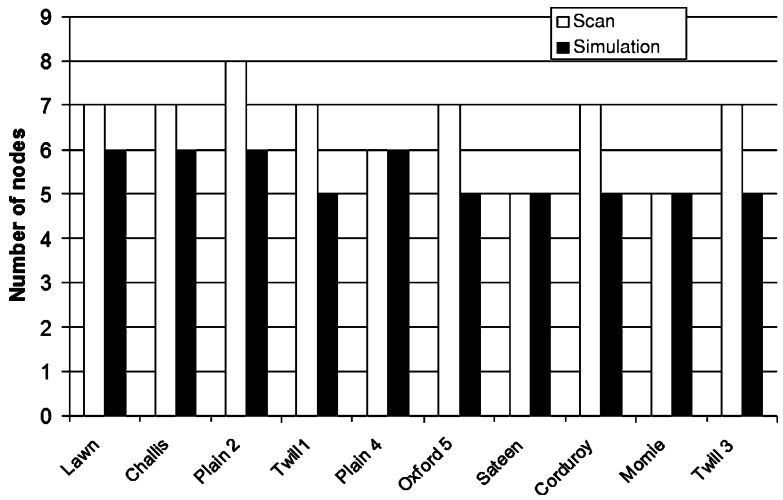

Figure 7 Number of nodes obtained in scan and simulation of the same skirt.

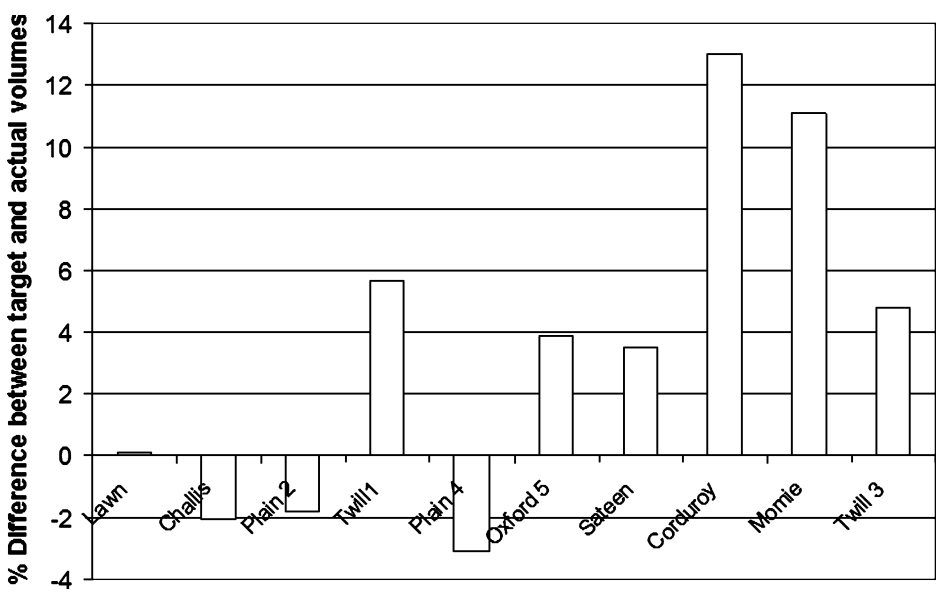

Figure 8 Percent difference in volumes obtained in scan and simulation of the same skirt.

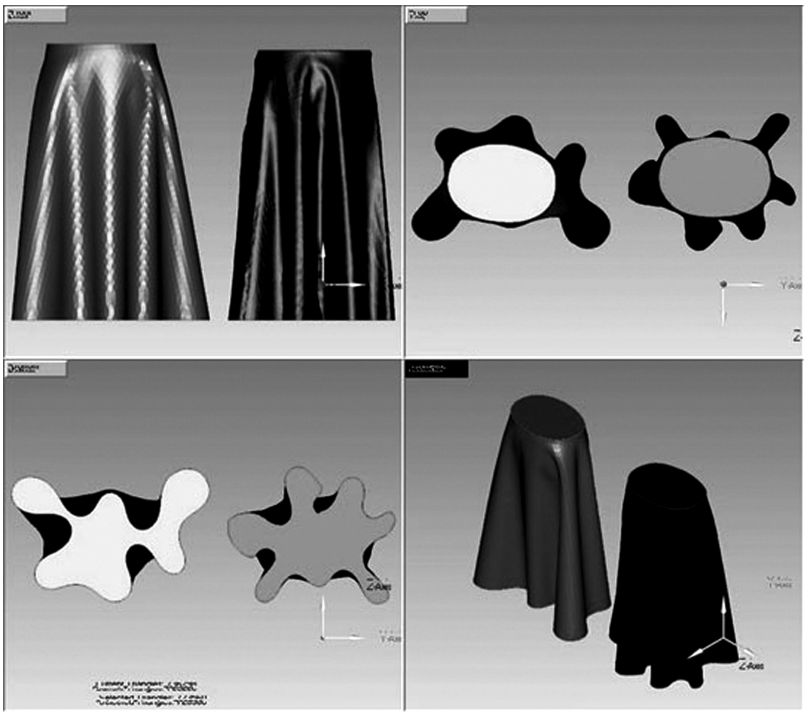

Figure 9 Scan (always on left, lighter shade) and simulation of a skirt.

Table 2 **Comparison of scan and simulation for skirt in Figure 9**

	Scan		Simulation		
Fabric	Target number of nodes	Target volume (cm^3)	Number of nodes obtained	Volume obtained (cm^3)	Percent difference between target and actual volumes
Lawn	7	65,064	6	65,008	0.09

Table 3 **Input parameters for simulation in Figure 9 (obtained from previously derived relationship)**

Parameter	Value
Bending stiffness	3,000 dyne-cm
Stretching stiffness	$X = 1{,}500,\ Y = 1{,}000$ g/cm
Shear stiffness	300 dyne-cm
Damping	0.01 cm/s
Shrinkage	$X = 0,\ Y = 0$
Weight	95 g/m^2
Resolution	1.5 cm
Friction coefficient	0.25
Thickness	0.05 cm

Figures 7 and 8 compare the scan and simulation of the skirt shown in Figure 6 constructed of different fabrics. In all cases, the established criteria were satisfied.

Figure 9 shows different views of the scan and simulation of the skirt made from one fabric (Lawn). Table 2 compares the scan and simulation of the skirt made of the same fabric, in this case Lawn, shown in Figure 9, using the established criteria.

The bending stiffness of the Lawn fabric measured by the KES is 69 dyne-cm and its weight per unit area is 95 g/m^2. From the plot in Figure 3, the bending stiffness to be input into Modulate^{TM} was obtained as 3,000 dyne-cm. Table 3 shows the input parameters used to simulate the skirt made of Lawn, shown in Figure 9.

CONCLUSIONS

Evaluation of the other two garments produced similar results lending credence to the validity of the stiffness relationship. All the simulations done were classified as acceptable matches to the scans based on the developed criteria. In most cases, the simulations fell well within the limits defined by the criteria. Overall the resemblance of the simulations based on the developed relationship to the actual garment scans was quite good. Further research will seek to improve the accuracy of virtual representation with the inclusion of other mechanical properties, garment designs, and fabric varieties.

In simulating the drape of fabrics, it must be remembered that fabrics do not drape the same way each time. Hence, there is no precise target for a fabric or garment simulation to achieve. Fabric drape is dependent on a large

number of variables such as fabric properties, shape of the object over which it is draped, and environmental conditions. Each of these is in turn dependent on more variables. It would be extremely difficult and an ineffective use of computational time to predict each of those precisely in order to simulate fabric drape. The practical approach to simulating fabric drape is to minimize the number of variables in simulations without compromising the resemblance of a simulation to reality. This is the approach that has been followed in our research. Using bending stiffness and weight as the only variables, keeping other variables as constants, fabric drape simulations done by using the Modulate™ software were shown to be very good representations of actual fabrics. In circumstances where KES testing may be unavailable, a calculated bending stiffness derived from bending length as obtained from cantilever testing could be used.

This work also demonstrated the successful application of the 3D body scanner to evaluation of garment drape. We found that a 3D body scanner can be used successfully to quantify drape parameters of entire draped garments by capturing the image of the draped garments and processing the image in the Geomagic™ software. This capability allows for expanding investigation of drape behaviour beyond study of circular samples to the complex, three-dimensional drape of garments supported by the human form.

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