**Andreja Rudolf*,**
**Metka Zadravec,**
**Zoran Stjepanović**

# Investigations Regarding the Effects of Simulating Parameters During 3D Garments' Drape Simulations

**DOI:** 10.5604/12303666.1221749

**Institute of Engineering Materials and Design, Faculty of Mechanical Engineering, University of Maribor,**
Smetanova 17, 2000 Maribor, Slovenia
*E-mail: andreja.rudolf@um.si,

**Abstract**
*This paper presents research into simulating parameters effects on 3D garment drape simulations with the aim of examining influential parameters regarding the accuracies of the appearances of virtual garments. The effects on the modified appearances of 3D virtual garments due to the simulated parameters, i.e. the solver setting, soft bending and resolution were investigated. Drape simulations of fabrics and garments were analysed by using the OptiTex 3D commercial CAD system for different fabrics, of which low-stress mechanical properties were measured by using the FAST measuring system and drape parameters by a Cusic Drape Tester. A comparison between the orthogonal projections of the real and virtual fabric drapes based on the Cusic method was performed and between the appearances and dimensions of the real and 3D virtual garments. The simulation parameters observed influence drape simulations of the 3D virtual fabrics and 3D garments depending on the fabric properties and pattern piece sizes. The results reveal that there is still a fundamental problem regarding the introduction of real fabric physical and seam properties during garment drape simulation. Therefore further consistent studies are needed for resolving limitations in this area on the synergistic effects of simulation parameters on 3D garment drape simulation.*

**Key words:** *fabric drape, garment drape simulation, low-stress mechanical properties, simulation parameters.*

## Introduction

Virtual garment simulations have received much attention over the past decade by the fashion industry as a tool during the product development process for shortening the production time and product time to market. The advantage of virtually prototyping garments is evaluating their appearances and fit without producing real prototypes. It is important that the shapes of virtual garments and fabric drapes appear to be the same as those of real fabrics. Therefore the properties of real fabrics must be accurately reflected in those of the virtual fabric in order to realistically express the shapes of the virtual garments. There are several commercial clothing CAD software packages providing 3D virtual simulation modules, such as V-stitcher by Browzwear of Gerber Technology, Modaris 3D Fit by Lectra, 3D by OptiTex etc. that enable predictions of garment appearances.

The appearances of garments are influenced by the essential characteristics of fabrics and their drapabilities. Drape is an important component of aesthetic garment appearance and affects comfort and fit [1 - 3]. Fabric drapes and, consequently, the resulting shapes and appearances of garments depend on the interactions between fabrics' mechanical (tensile, bending, shear) and physical properties (weight, thickness, yarn density and count), as well as on the fabric weave type. For this reason there is an essential property to be considered when selecting a fabric for a particular garment design and its final use.

Virtual prototyping of garments and thereby drape simulations of flat pattern pieces made into 3D virtual garments and their fittings within virtual environments depend on numerous factors. It reflects and combines the characteristics of garment styles, garment pattern designs, virtual 3D body models, and the mechanical properties of fabrics depending on the mechanical simulation models used. Drape simulation of a particular fabric is challenging especially from two aspects: (a) the mechanical simulation model, (b) the mechanical properties of the fabric. There have been many studies on the development of efficient mechanical simulation models that can accurately reproduce specific mechanical properties, and the particle-based physical method is widely accepted for the virtual prototyping of garments [4 - 8]. The well-known industry software for 2D and 3D CAD/CAM fashion design is OptiTex. It is a commercially-available software package for garment simulation based on an interactive particle modelling approach developed by Choi and Ko [9]. In order to enhance the accuracies of drape simulation investigations on the effects of low-stress mechanical properties measured by KES-FB or the FAST measuring system on a fabric's drape and/or garment appearance, many researches have been carried [2, 10 - 15], which have shown that for effective garment drape simulations, it is necessary to take into account the low-stress mechanical properties measured. In addition, studies have also shown that garment drape simulations can be successful when accurate virtual 3D human body models for simulating garment appearance and fit are fully taken into account [16, 17]. The drape behaviour of fabrics with different radial and circular seams in terms of the drape coefficient and fold numbers has been investigated within many studies [18 - 21]. Lim and Istook [13] studied the effect of fabric properties on drape simulations and appearances of virtual garments when applied to virtual avatars. This research was based on low-stress mechanical properties measured using the FAST measuring and OptiTex software systems for virtual 3D simulations of garments. The results showed that fabric properties including bending, thickness, stretch and shear affect the drape stiffness, silhouettes and fittings of virtual garments. Kim and Na [2] performed an investigation into the effects of bending properties (measured by the KES-FB and FAST systems) and drapabilities according to wool fibre blending ratios on the hands and appearances of real and virtual garments. The results showed that the wool-blending ratio affected the appearances of the real garments whilst it had no effect on the appearances of the 3D virtual garments. It should be noted that CAD 3D simulation programs offer default and adjustable simulation parameters that have been excluded in the studies of any article. When carrying out garment simulations at the default simulation parameters depending on the low-stress mechanical properties of fabrics measured, we encountered discrepancies in the appearances of garments expected. For this reason, it is imperative to investigate the accuracies of 3D garment drape simulations in a completely different and until now unexplored approach with regard to simulation parameters.

In this study, the effects of simulation parameters on 3D fabric and garment drape simulations were analysed for different fabrics, of which the real properties were measured by using the FAST measuring system and a Cusic Drape Tester. The main aim of this research was to examine the influence of parameters on the accuracy of the 3D garment drape simulation and thus achieve the most possible realistic appearances of virtual garments.

## Experimental

### Materials

Three different woven fabrics were used for this study, differing in fibre content, weave type, linear density of warp/weft yarns, yarn density, fabric thickness, and weight. The physical parameters of the fabrics are presented in ***Table 1***.

***Table 1.*** *Physical parameters of fabrics.*

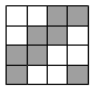
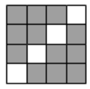
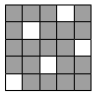
| Fabric code | Fibre content | Weave type | Linear density, tex | | Yarn density, thread/cm | | Fabric thickness, mm | Fabric weight, gm-2 |
|---|---|---|---|---|---|---|---|---|
| | | | warp | weft | warp | weft | | |
| FB1 | 100% wool | Cirkas batavia twill  | 23.2 | 28.7 | 32 | 24 | 0.42 | 175 |
| FB2 | 100% cotton | Twill  | 109.3 | 103.1 | 24 | 17 | 0.99 | 506 |
| FB3 | 100% polyester | Satin  | 3.7 | 6.8 | 115 | 43 | 0.16 | 76 |

***Table 2.*** *Low-stress mechanical properties measured by the FAST measuring system.*

| Fabric code | | Mechanical parameters | | | |
|---|---|---|---|---|---|
| | | Extensibility E100, % | Bending rigidity B, μNm | Shear rigidity G, Nm-1 | Surface thickness ST, mm |
| FB1 | Warp | 2.0 | 5.0 | 30 | 0.148 |
| | Weft | 13.5 | 3.7 | | |
| FB2 | Warp | 0.7 | 862.6 | 1054 | 0.226 |
| | Weft | 0.6 | 621.3 | | |
| FB3 | Warp | 2.5 | 2.0 | 20 | 0.036 |
| | Weft | 6.7 | 1.4 | | |

***Table 3.*** *Drape coefficients and drape parameters measured using a Cusic Drape Tester.*

| Fabric code | Drape coefficient | | | Node number | | | Minimum amplitude | | | Maximum amplitude | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | x | s | CV, % | x | s | CV, % | x, cm | s, cm | CV, % | x, cm | s, cm | CV, % |
| FB1 | 0.244 | 0.0164 | 6.73 | 7 | 0.00 | 0.00 | 8.90 | 0.09 | 0.98 | 13.45 | 0.18 | 1.33 |
| FB2 | 0.918 | 0.0140 | 1.52 | 9 | 1.00 | 11.11 | 13.94 | 0.19 | 1.38 | 15.05 | 0.09 | 0.60 |
| FB3 | 0.304 | 0.0142 | 4.68 | 8 | 0.00 | 0.00 | 8.82 | 0.22 | 2.46 | 13.66 | 0.32 | 2.36 |

### Measurements of low-stress mechanical properties and drape parameters

The fabrics' low-stress mechanical properties including tensile, shear, bending, surface and compression properties were measured by using the FAST measuring system, shown in ***Table 2***. The surface thickness (ST) is the difference in thickness of a fabric measured at a pressure of 0.196 kNm$^{-2}$ and 9.81 kNm$^{-2}$, thus differing from the fabric thickness measured according to Standard ISO 5084 [22, 23]. The mechanical properties of the fabrics determined were converted using the Fabric Converter programme of the OptiTex 3D software system and used for the purpose of 3D fabric and flared skirt drape simulations.

The Cusic Drape Tester (James H. Heal & Co. Ltd., Halifax, England) was used to measure the fabric drape coefficients and drape parameters, such as the number of nodes and maximum and minimum node amplitudes of three-dimensional drapes, using the Drape Analyser software. The diameter of the inner pedestal of the Drape Tester was 18 cm and that of the fabric samples 30 cm. Orthogonal projections of the fabric drapes were captured using a digital camera. Each sample was tested with its face upwards and five repetitions were carried out. The mean values ($x$), standard deviations ($s$) and coefficients of variations ($CV$) were calculated for the drape coefficients ($DC$) and drape parameters, shown in ***Table 3***. The orthogonal projections of the draped fabrics captured were contoured in or-


***Figure 1.*** *Presentation of measuring draped real flared skirts' lengths; a) front, b) back, c) right, d) left.*

der to compare them with projections of the fabrics' drape simulations using the OptiTex 3D.

All measurements were carried out under standard testing conditions, i.e. a temperature of 20 ± 2 °C and 65 ± 2% relative air humidity.

### Drapes of real flared skirts and drape simulations of 3D fabrics and flared skirts

During this research, the pattern design of a flared skirt was constructed according to a dressmaker dummy's dimensions and waist girth of 18 cm, respectively. The skirt length was 50 cm. A 2D pattern design of the flared skirt was made using the OptiTex PDS software system.

The real flared skirts manufactured were draped over a dressmaker dummy. The skirts were photographed from all four sides: the front, back, left and right sides, respectively. In addition, the lengths of the draped real skirts were measured on the front and back centres, as well as the lengths of the left and right seams, shown in ***Figure 1***. The skirts' lengths were measured without belts. The skirts' codes were the same as those for the fabrics used, shown in ***Table 1***.

In order to ensure as equivalent a draping as possible of the flared skirts within the virtual environment, the dressmaker dummy was scanned using the ATOS II 3D optical scanning system. Scanning was performed over three stages:

- calibration of the measuring system and labelling of the dummy with circular reference points,
- scanning of the dummy from different angles and heights in order to digitise the complete dummy and
- individual scans were polygonised within a global coordinate system.

A 3D dummy model and 3D pedestal model with a diameter of 18 cm were then imported into the OptiTex 3D simulation programme. Drape simulations of the 3D virtual flared skirts and fabrics with a diameter of 30 cm were performed at default simulation parameters [24] at a resolution of 1.5, and by varying the simulation parameters (solver setting, soft bending, resolution), as shown in ***Figure 2***, taking into account the low-stress mechanical properties of the real fabrics measured and converted.

The simulation parameters *solver setting* and *soft bending* are part of the dialogue box *Simulation properties,* whilst *resolution* is part of the dialogue box *3D*. When the solver setting *Hybrid IMEX* is used, the solver begins simulation using the *Explicit solver* and after a few iterations switches to the *Implicit solver*. This is the default type for fabric simulation in OptiTex 3D. Solver setting *Implicit Only* is more accurate than the *Explicit solver* but also consumes more computational time. Solver setting *Explicit Only* can be selected for faster but less accurate simulations. The *Soft Bending* option is used for simulating soft fabrics compared to more rigid ones used for hats, bags, etc. In the 3D viewer each pattern piece and fabric, respectively, is represented by a mesh of triangles. *Resolution* determines the size of the triangle's edges measured in cms. High resolution means smaller triangles for representing the fabric of the pattern piece and thus more accuracy in representing complex curved lines, folds and wrinkles, and vice versa for low resolution [24]. It is for this reason, in the section 'Results with discussion' that during the discussion we used the term *Resolution value*.

It should be mentioned that the effect of simulation parameters such as Time-Step and Iterations per Frame were also preliminarily investigated. Any significant influence of the default values of these parameters on the 3D garment drape simulations was not found, and therefore excluded from this study. A fully repeatable appearance of the fabric drape was achieved for the Time-Step between 0.02 and 0.03 (default value 0.2), whilst for the lower and higher values - inaccurate or non-feasible fabric drape simulation. A fully repeatable appearance of the fabric drape was achieved between 20 and 30 iterations per frame (default value 20), but it was inaccurate for the lower ones.

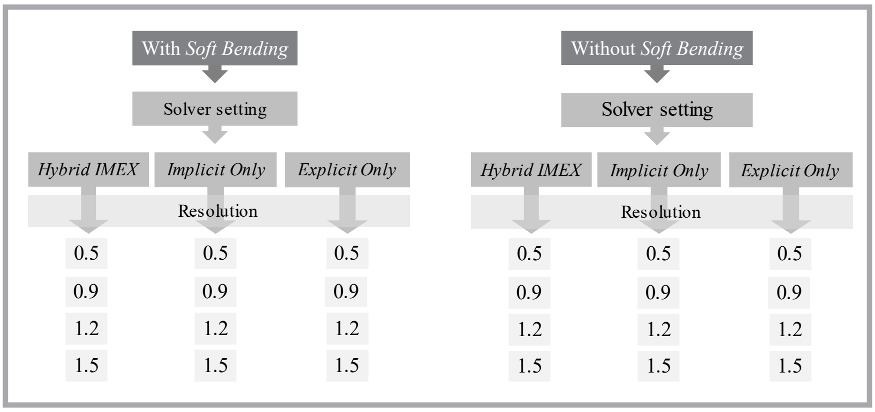



***Figure 2.*** *Variations in the simulation parameters for the 3D fabrics' and flared skirts' drape simulations.*

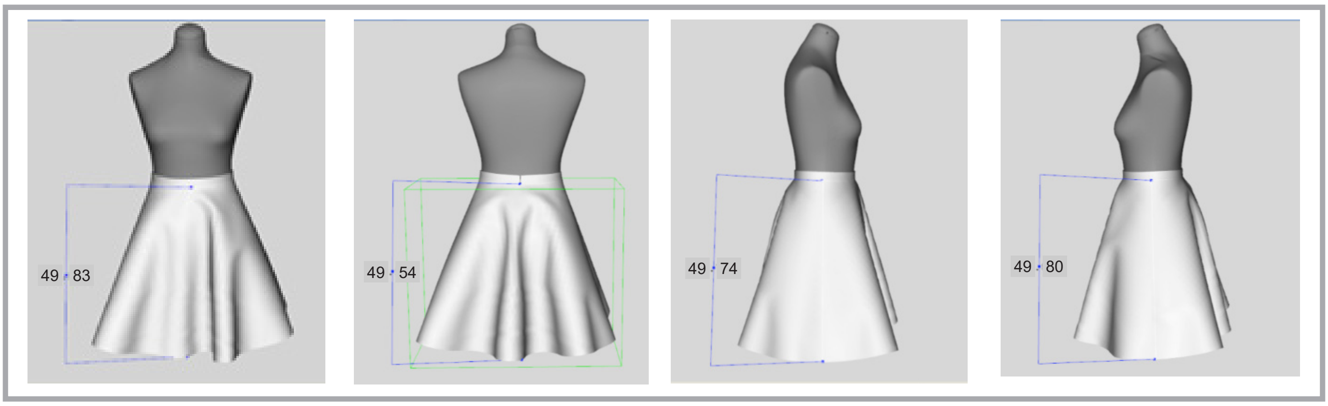



***Figure 3.** Presentation of measuring the draped 3D virtual flared skirts' lengths; a) front, b) back, c) right, d) left.*

When performing drape simulations of the 3D virtual fabrics and flared skirts the positions of all pattern pieces were the same for all simulations.

After the end of each fabric drape simulation, its orthogonal projection was captured in order to compare it with the Cusick Drape Tester's orthogonal projection.

After the end of each drape simulation of the 3D virtual flared skirts their images were captured from all four angles, and the lengths of the skirts without belts were measured by using the measuring tool of the OptiTex 3D software system, shown in ***Figure 3***.

A comparison between orthogonal projections of the real and 3D virtual fabrics and the appearances and dimensions of the real and 3D virtual flared skirts was performed in order to investigate the effects of the simulation parameters on the accuracies of the drape simulations of the 3D virtual flared skirts.

## Results with discussion

### Low-stress mechanical properties and drape parameters

The low-stress mechanical properties of the fabrics measured using the FAST measuring system, necessary for 3D fabric and flared skirt drape simulations, are presented in ***Table 2***. Differences were observed between the fabrics' low-stress mechanical properties. The fabric coded FB2 showed the more expressive low-stress mechanical properties, which were expected according to the tactile characteristics of this fabric. It had the lowest extensibility (E100-1 = 0.7%, E100-2 = 0.6%) and the highest bending (B-1 = 862.6 μNm, B-2 = 621.3 μNm) and shear rigidity (G = 1054.0 $Nm^{-1}$), as well as surface thickness (ST = 0.226 mm) and weight (506 $gm^{-2}$). The lowest surface thickness (ST = 0.036 mm) and weight (76 $gm^{-2}$) was by the fabric coded FB3, which also had the lowest bending (B-1 = 2.0 μNm, B-2 = 1.4 μNm) and shear rigidity (G = 20.0 $Nm^{-1}$) as well as a similar extensibility to fabric FB1 in the warp direction. Fabric FB1 had the highest extensibility in the weft direction (E100-2 = 13.5%) and higher bending and shear rigidities, surface thickness and weight when compared to fabric FB3.

The drape coefficient (DC) and drape parameters measured showed differences between the fabrics analysed, shown in ***Table 3***. The fabric coded FB2 had the highest drape coefficient ($DC_{FB2}$ = 0.918) and that coded FB1 the lowest ($DC_{FB1}$ = 0.244). This means that the worst drapability was shown by the fabric coded FB2 and the best the fabric coded FB1. The fabric coded FB3 had a drape coefficient of 0.304. The fabric coded FB2 with the highest drape coefficient, also had the maximum number of nodes while the fabric coded FB1, with the lowest drape coefficient, had a minimum number of nodes. When observing the orthogonal projection of draped fabric FB2, it clearly expressed high bending rigidity and barely visible nine nodes to the eye, as shown in ***Figure 4***. Fabric FB1 had seven nodes, which were evenly distributed and had more uniform shapes compared to fabric FB3, which had eight nodes.

Comparable results between the bending rigidities and drape coefficients were expected for the fabrics researched, shown in ***Tables 2*** and ***3***. Namely the fabrics with higher bending rigidity and shear rigidity and lower extensibility usually have higher drape coefficients and vice versa [1, 25], which was also observed for fabric FB2, which had the highest for both the bending rigidity and drape coefficient, shown in ***Tables 2*** and ***3***. Fabric FB1 had a lower drape coefficient compared to fabric FB3, with even bending and shear rigidities being higher than for fabric FB3. Behera and Pattanayaka [1] discovered that higher extensibility favours the folding and hanging of fabric at the edges of the platform; thus a smaller shadow is formed, giving a lower drape coefficient. Therefore it can be concluded that the high extensibility of fabric FB1 in the weft direction provoked a lower number of nodes and drape coefficient.

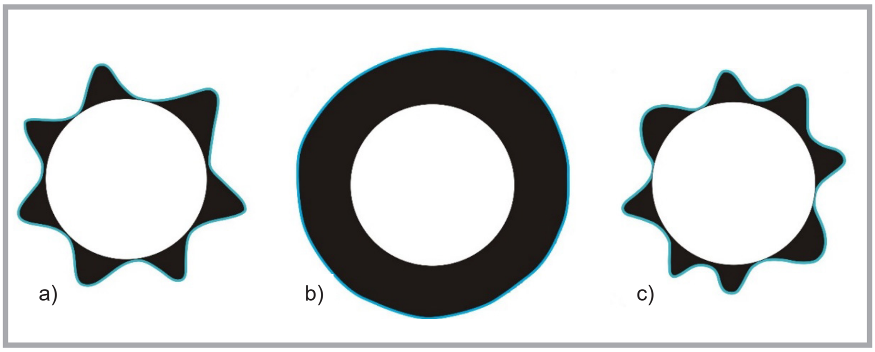



***Figure 4.** Orthogonal projections of the draped fabrics using the Cusick Drape Tes ter; a) FB1, b) FB2, c) FB3.*

*Table 4. Lengths of the draped real flared skirts.*

| Skirt code | Skirt length (cm) | | | |
|---|---|---|---|---|
| | Front centre | Back centre | Right seam | Left seam |
| FB1 | 49.0 | 49.0 | 50.0 | 50.0 |
| FB2 | 51.0 | 50.8 | 50.3 | 50.0 |
| FB3 | 50.0 | 49.0 | 51.0 | 55.0 |

### Appearances and dimensions of the draped real flared skirts

Drape is defined as the extent to which a fabric will deform when it is allowed to hang under its own weight, and is dependent on a large number of variables including fabric properties, the shape of the object over which it is draped, and environmental conditions [11]. These influences were observed for the low-stress mechanical properties of the fabrics used on the drape variations of the flared skirts. The lengths of the draped real flared skirts measured are collated in ***Table 4***. When observing the appearances of the draped real flared skirts, it could be seen that they corresponded to the bending and shear rigidities of the fabrics measured, which was to be expected. The highest bending rigidity was exhibited by skirt FB2 and the lowest by skirts FB1 and FB3.

The result after draping was that skirt FB1 was soft, equally shaped and with arranged folds, which coincided with the orthogonal projection of fabric FB1, shown in ***Figure 4***. The bottom edge of this skirt appeared to be straight, and even the lengths of the front and back centres measured were somewhat shorter, shown in ***Table 4***. When draping skirt FB3, unevenly shaped and deeper folds originated on the sides of the skirt. The orthogonal projection of fabric FB3 also showed unevenly shaped folds, shown in ***Figure 4***. The length of this skirt was uneven and extended on both sides, which also showed in the lengths measured, shown in **Table 4.** This could be attributed to the very low shear and bending rigidities of this fabric. The length of the left seam, into which the zipper was sewn, was longer than that of the right seam. It was assumed that the additional weight of the zipper and the increased rigidity of this seam could also have contributed to extending it. It should be noted that deviations between the lengths of the skirts' patterns and the skirts produced may also have arisen during the technological processes of the skirts' manufacture. The appearance of skirt FB2 clearly reflected the effects of higher bending and shear rigidity as well as the lower extensibility of the fabric. Its form had a smaller number of rigid folds that spread out the flared skirt, which was not in accordance with the orthogonal projection of this fabric, which had the highest number of nodes. The reason for this was the small deflection length when draping very rigid fabric using the Cusick Drape Tester, and hence poorly visible folds. Therefore it is supposed that the Drape Analyser software detected any deviation from the circle and, consequently, the nine nodes calculated. A slightly longer length of this skirt was measured in the centre, shown in ***Table 4***.

Based on this part of the research, we can conclude that the mechanical properties of the fabrics used influenced the drapes and appearances of the real fabrics and flared skirts.

### Comparison between the real and 3D virtual fabrics' drapes

Results of the fabrics' real drape (contoured lines of the orthogonal projections - Cusic Drape Tester) and drape simulations of the 3D virtual fabrics at the default simulation parameters at a resolution value of 1.5, and by varying the simulation parameters are presented in ***Figures 5 - 7***.

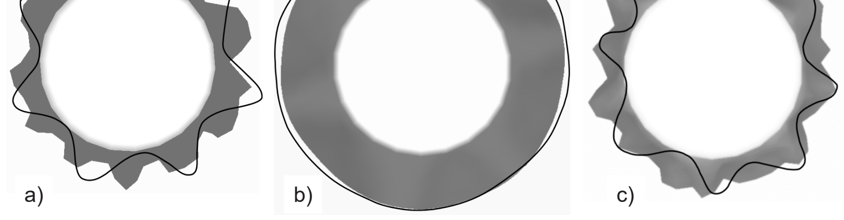



***Figure 5.*** *Comparison between the fabrics' real drape and virtual drape simulations at default simulation parameters; a) FB1, b) FB2, c) FB3.*

When comparing the fabrics' real and virtual drape simulations at the default simulation parameters, it was clearly visible that the fabrics' drapes differed, ***Figure 5***. The number of folds for real fabric FB1 was 7 and that of the virtual 12, the fabric FB3 - 8 real folds and at least 13 virtual that could be counted, whilst for fabric FB2 with nine real folds determined it was difficult to count the number of virtual folds.

Based on these research results, we can conclude that inaccurate drape simulation was obtained using the default simulation parameters *Hybrid IMEX* and *Soft Bending*.

Seventy-two drape simulations of the 3D virtual fabrics were carried out by varying the simulation parameters. Therefore the more important results are presented in ***Figures 6*** and ***7***.

The influence of the simulation parameter *Soft Bending* on the fabrics' drape simulations was found to be very important. Namely, without its use at all solver settings and resolution values the simulation results were completely different compared to the real fabric drapes, especially for fabrics FB1 and FB3 at all solver settings. The drape simulation for fabric FB2 had different shape compared to the real fabric drape only at solver setting *Explicit Only*. As an example, fabric drape simulations at a resolution value of 0.9 are presented in ***Figure 6***.

When using the simulation parameter *Soft Bending, a* greater number of folds originated than without its use. In general, by increasing the *Resolution value* up to 1.5, a decrease in the fold number was observed. For instance, when draping fabrics at solver setting *Explicit only,* fabric FB1 had at resolution values (RV) of 0.5 twenty one folds, at RV 0.9 fourteen folds, at RV 1.2 nine folds, and at RV 1.5 eight folds. The last simulation had one fold more than the real fabric, shown in ***Figure 7***. At the same solver setting fabric FB3 had at RV 0.5 nineteen folds, at RV 0.9 twelve folds, at RV 1.2 ten folds, and at RV 1.5 eight folds. For the latter, the number of folds was the same as for the real fabric, shown in ***Figure 7***. The more comparable results with the real fabrics' drapes were achieved for fabrics FB1 and FB3 when draping with solver setting *Explicit Only* and for fabric FB2 with *Hybrid IMEX* and *Implicit Only*.

Based on these research results, we can conclude that a more accurate and realistic drape simulation can be obtained by using the simulation parameter *Soft Bending* at the highest *Resolution value*, whilst solver settings *Hybrid IMEX* and *Implicit Only* were found to be more suitable for draping rigid fabric and *Explicit Only* for soft and flexible fabrics.

**Comparison between real and 3D virtual flared skirts' drapes**

When comparing the real and 3D virtual draped flared skirts at the default simulation parameters, the skirt coded FB2 had a similar appearance to the draped real flared skirt on the front and back. Greater deviation in appearances was observed when comparing the virtual and real skirts coded FB1 and FB3. Namely their shapes, numbers, depths and distributions of folds differed.

Seventy-two drape simulations of the 3D virtual flared skirts were carried out by varying the simulation parameters. When virtual drapes were carried out without using the simulation parameter *Soft Bending,* similar inappropriate results as for the fabric drape simulations were also achieved for the 3D virtual flared skirts. Therefore it can be concluded that performing garment drape simulation without the parameter *Soft Bending* resulted in inaccurate drape simulations of the fabrics and garments.

When virtual drapes were performed using the simulation parameter *Soft Bending,* the effect of the solver setting *Explicit Only* on the skirts' appearances was clearly visible. These skirts had completely different shapes and appearances than the real skirts. In addition, these results were in contrast to those of the virtual drapes of fabrics FB1 and FB3, which achieved more comparable results with the real fabric drapes when using solver setting *Explicit Only*. It may be assumed that using the solver setting *Explicit Only* is accurate when draping fabric pieces of smaller surface areas and inappropriate when draping garment pattern pieces of greater surface areas.

In general, it could be stated that the appearances of the draped 3D virtual flared skirts differed depending on the mechanical properties of the fabrics when using solver settings *Hybrid IMEX* and *Implicit Only*. The highest rigidity was exhibited by skirt FB2 and the lowest by skirts FB1 and FB3, which was also noted in the draped real flared skirts.

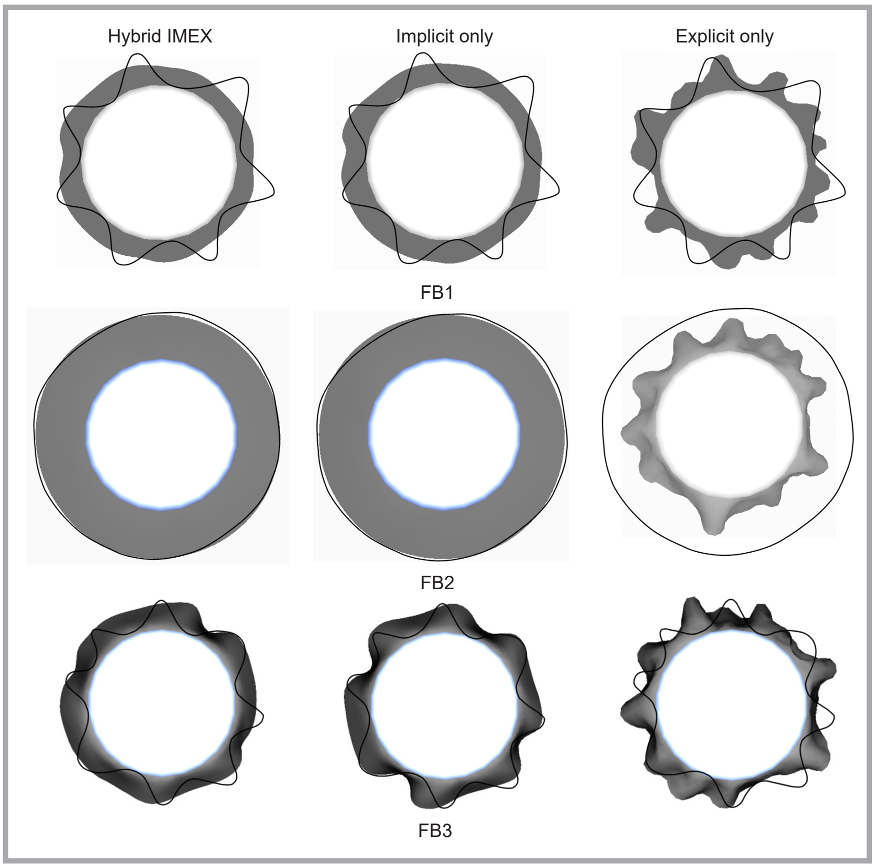



***Figure 6.** Comparison between the fabrics' real drape and virtual drape simulations without using Soft Bending and by varying the solver settings at a resolution value of 0.9.*

When comparing the appearances of the draped 3D virtual flared skirts between simulation parameters *Hybrid IMEX* and *Implicit Only* at *Soft Bending* parameters, there were different shapes, numbers, depths and positions of the folds originated. This was particularly evident for the draped 3D virtual flared skirts coded FB2 and FB3 at a *Resolution value (RV)* of 0.5. Increasing the *RV* affected the appearances of the draped 3D virtual flared skirts regarding the shapes of the skirts, as well as the number and increases in the folds' depths, and their redistributions. In addition, any increase in the *RV* led to a decrease in the fold number at a *Resolution value* of 1.5. The same was also found for the virtual fabrics' drape.

When comparing the shapes of the real and 3D virtual flared skirt FB1, a similar appearance but greater number of folds was achieved when using the simulation parameter *Soft Bending* for both *Hybrid IMEX* and *Implicit Only* solver settings, and for *Resolution values* 0.5 and 0.9. *Resolution values* 1.2 and 1.5 influenced a similar number of folds, but was slightly worse regarding the FB1 skirts' shapes.

The drape simulation of 3D virtual flared skirt FB2 showed that a comparable appearance to that of the real skirt was achieved using simulation parameters *Soft Bending*, *Implicit Only* and *Resolution value 1.2*. Namely similar shapes for both real and virtual skirts as well as for the fold numbers, arrangements and depths were achieved when using those simulation parameters. It could be concluded from this example that the drape simulation of the mechanical behaviour of the very rigid fabric FB2 was carried out very successfully within that combination of simulation parameters. The result was a very realistic appearance of the virtual skirt.

Results of the drape simulation of 3D virtual flared skirt FB3 showed that accurate simulation of the real mechanical behaviour of a fabric with very low surface weight and low bending and shear rigidities is difficult to achieve. More comparable appearances to those of the real

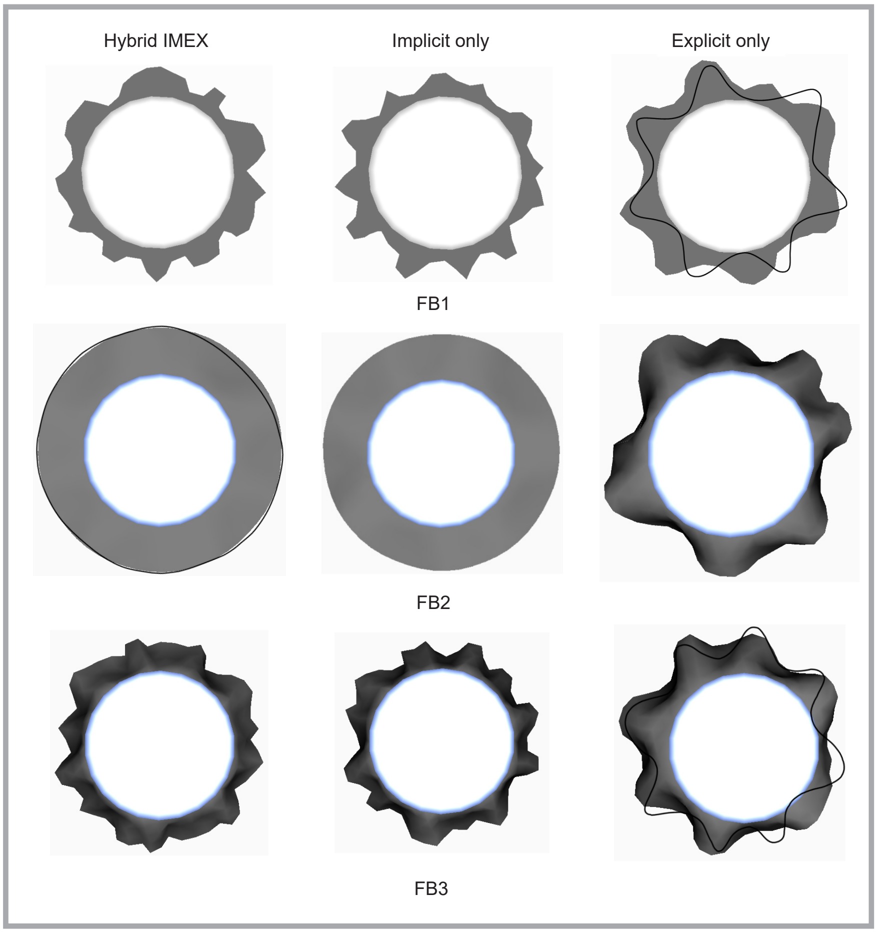



***Figure 7.*** *Comparison between the fabrics' real drape and virtual drape simulations using Soft Bending and varying the solver settings at a resolution value of 1.5.*

skirts were achieved using simulation parameters *Soft Bending, Implicit Only* and *Resolution value 1.2*.

When comparing the lengths of the real and virtual 3D flared skirts, exact correlations between values were not found regarding the simulation parameters, shown in ***Table 5***, in which the calculated differences between the real and virtual skirts' lengths ($\Delta_{R-V}$) are presented. The lengths of the real skirts were affected by technological processes during garment manufacturing, as well as by the structures of the skirts with zippers, and the mechanical behaviour of the real fabric. Any significant correlation between simulation parameters and the skirts' lengths was not observed. When comparing the lengths of the real and virtual skirts, which were simulated at parameters *Implicit Only*, *Soft Bending* and *Resolution value* 1.2, it was seen that all the real lengths of the right and left seams were longer compared to the virtual ones, ***Table 5***. As the most realistic appearances of the virtual skirts were found at these simulation parameters, we can assume that a virtual reproduction of seams is insufficiently realistic. This is particularly significant for skirt FB3, of which the real seams are stretched due to low fabric bending and shear rigidities, especially the left seam regarding the weight and rigidity of the zipper.

Based on the results of this study, it could be concluded that simulation parameters have a great influence on the accuracies of drape simulations of 3D virtual fabrics and flared skirts and their appearances. It is well-known that an exact realistic appearance of 3D virtual garments is difficult to achieve [2, 11 - 13], which is also confirmed by the results from our study. However, this research showed that more realistic appearances of 3D virtual garments could be achieved with proper selections of simulation parameters. The results showed that when performing drape simulations of different fabrics and fabric properties, respectively, we have to select different simulation parameters in order to achieve the most realistic appearances of the fabric's 3D virtual orthogonal projections and 3D virtual garments. Their selection depended on the mechanical properties of the real fabric and the sizes of the surface areas of the draped fabric and skirt pattern pieces, respectively.

During this study, it was found that when performing drape simulations without the parameter *Soft Bending*, inaccurate drape simulations were obtained for both the fabrics, irrespective of the Cusic method, and garments. More accurate and realistic fabric drape simulation was obtained irrespective of the Cusic method using the simulation parameter *Soft Bending* at the highest *Resolution value*. Solver settings *Hybrid IMEX* and *Implicit Only* were found to be more suitable for virtual draping of rigid fabrics and *Explicit Only* for soft and flexible ones. On the other hand, a negative influence was proved for solver setting *Explicit Only* on the 3D garment drape simulations. These findings were in accordance with Hayler et al [26], who stated that explicit integration is not a particularly stable method regarding large numbers of particles, whilst implicit integration estimates the next particle position and uses that in a calculation to see if the prediction is correct. With respect to this, it is a more stable method for a large number of particles, as can be found in the garments pattern pieces. Therefore it could be concluded that drape simulations of soft and flexible fabrics with shorter draping lengths and smaller surface areas should be performed using solver setting *Explicit Only*

***Table 5.*** *Lengths of the real and draped skirts at simulation parameters Implicit Only, Soft Bending and Resolution value 1.2.*

| Skirt code | Skirt length, cm | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Front centre | | | Back centre | | | Right seam | | | Left seam | | |
| | Real | Virtual | $\Delta_{R-V}$ | Real | Virtual | $\Delta_{R-V}$ | Real | Virtual | $\Delta_{R-V}$ | Real | Virtual | $\Delta_{R-V}$ |
| FB1 | 49.0 | 50.0 | (-1.0) | 49.0 | 49.8 | (0.8) | 50.0 | 49.7 | (0.3) | 50.0 | 49.6 | (0.4) |
| FB2 | 51.0 | 49.8 | (1.2) | 50.8 | 50.0 | (-0.8) | 50.3 | 49.9 | (0.4) | 50.0 | 49.8 | (0.2) |
| FB3 | 50.0 | 51.0 | (-1.0) | 49.0 | 51.2 | (-2.2) | 51.0 | 48.7 | (2.3) | 55.0 | 48.3 | (6.7) |

and for very rigid fabrics with *Hybrid IMEX* and *Implicit Only,* whilst for pattern pieces of longer draping length and greater surface area solver setting *Implicit Only* for any mechanical properties of the fabrics is used. This means that the mechanical simulation model as used by the software package OptiTex 3D carried out successful drape simulations of smaller fabric pieces when solving a mathematical problem using the solver *Explicit Only*, whilst for greater fabric pieces and very rigid fabrics this was when using solvers *Implicit Only* and *Hybrid IMEX*. In addition, realistic appearances of the virtual fabrics and flared skirts were achieved at higher resolution values whilst at the same time enabling a shortening of the simulation time. There was also a problem with realistic representations of the garment seams. Therefore there is a need to perform further studies regarding simulation of the mechanical behaviour of seams and additional materials that make up the garment, such as the zipper weight and rigidity, and other fasteners.

## Summary and conclusions

This study investigated the effects of simulation parameters on drape simulations of 3D virtual fabrics and flared skirts for different fabrics, of which the low-stress mechanical properties were measured using the FAST measuring system and drape parameters by using a Cusic Drape Tester. Drape simulations of 3D virtual fabrics and flared skirts, due to the simulation parameters, i.e. the *Solver setting*, *Soft Bending* and *Resolution value* were performed using the powerful OptiTex 3D software with the aim of examining the influences the parameters have on the accuracy of 3D garment drape simulation and thus the achievement of more possible realistic appearances of virtual garments. The results of the study represent an important contribution for those professionals/researchers who deal with virtual developments and simulations of garment pattern designs, and for those who are engaged in software development.

During this investigation, it was found that:

- when performing drape simulations without the parameter *Soft Bending*, inaccurate drape simulations were obtained for both the fabrics irrespective of the Cusic method and garments,
- drape simulations of soft and flexible fabrics with shorter draping lengths and smaller surface areas should be performed using solver setting *Explicit Only* and for very rigid fabrics *Hybrid IMEX* and *Implicit Only,*
- 3D garment drape simulation and pattern pieces of longer draping length and greater surface area, respectively, should be carried out using solver setting *Implicit Only* for any mechanical properties of fabrics,
- more realistic appearances of virtual fabrics and flared skirts could be achieved at higher resolution values that, at the same time, enable shortening of the simulation time,
- there is a need to perform further studies regarding simulation of the mechanical behaviour of seams and additional materials that make up a garment, such as the zipper weight and rigidity, and other fasteners,
- there is still a fundamental problem in the introduction of real fabrics' physical and seams properties into drape simulation. It was found that the algorithms used for solving mathematical problems do not allow completely accurate drape simulations of fabrics and garments, such as the complex architectures of pattern pieces with seams and additional materials that make up the garment. Therefore it is difficult to determine suitable simulation parameters for any new fabric by using the Cusic drape method within a virtual environment for performing drape simulations of garments. Hence further consistent studies are needed to resolve the limitation in this area regarding the synergistic effects of simulation parameters on 3D garment drape simulations depending on the influential factors of the virtual environment.

## References


1. Behera B K and Pattanayak A K. *Indian J Fibre Text Res* 2008; 33: 230.
2. Kim H S *and* Na M H. *Fiber Polym* 2013; 14: 2148.
3. Lee M S and Kim E K. *J Korean Soc Cloth Tex* 2006*,* 30: 1723.
4. Kim S and Park C K. *Fiber Polym* 2006, 7: 436.
5. Eberhardt B and Weber A. *IEEE Comput Grapics and Appl* 1996*,* 16: 52.
6. Volino P, Thalmann N M, Jianhua S and Thalmann D. *IEEE Comput Graphics and Appl* 1996; 16: 42.
7. Breen D E, House D H and Wozny M J. *Textile Res J* 1994; 64, 663.
8. Carignan M, Yang Y, Thalmann N M and Thalmann D. *ACM Siggraph Comput Graph,* 1992; 26: 99.
9. Choi K J and Ko H S. *ACM Trans Graph* 2002; 21: 604.
10. Kenkare N, Lamar T A M, Pandurangan P and Eischen J. *J Text Inst* 2008; 99: 211.
11. Pandurangan P, Eischen J, Kenkare N and Lamar T A M. *J Text Inst* 2008; 99: 219.
12. Sanad R, Cassidy T, Cheung V and Evans E. *JFBI* 2013; 6: 1.
13. Lim H and Istook C L. *Fiber Polym* 2011; 12: 1077.
14. Ng S F, Hui C L and Tam F Y. *Res J Text App* 2003; 6, 65.
15. Hu J L and Chan Y F. *Textile Res J* 1998; 68: 57.
16. Stjepanović Z, Rudolf A, Jevšnik S, Cupar A, Pogačar V and Geršak J. *Bulletin of the Polytechnic Institute of Iasi* 2011; 57: 17.
17. Rudolf A, Cupar A, Kozar T and Stjepanović Z. *Fiber Polym* 2015; 16, 1177.
18. Yang Y. *Fiber Polym;* 2014, 15: 2217.
19. Hu J L and Chung S P., *Textile Res J;* 1998, 68: 913.
20. Hu J L. *Structure and mechanics of woven fabrics*, (Woodhead publishing in Textiles, Cambridge) 2004; 210.
21. Jevšnik S and Lojen D Ž. *Fiber Polym;* 2007, 5: 550.
22. De Boss A. *The FAST System for Objective Measurement of Fabric Properties, Operation, Interpretation and Application.* (CSIRO Division of Wool Technology, Sydney), 1991.
23. ISO 5084:1996, Textiles - Determination of thickness of textiles and textile products.
24. 3D:Simulation Properties, OptiTex Help www: http://www.optitex.com/Help/en/index.php/3D:Simulation_Properties
25. Okur A and Cihan T. *Textile Asia* 2002; 33: 28.
26. Hayler G, Bangay S and Lobb A. Available on (15.11.2015): http://www.cs.ru.ac.za/research/groups/vrsig/pastprojects/052cloth/paper03.pdf.


***Received 20.04.2016 Reviewed 06.07.2016***