Egypt. J. Chem. **Vol. 67** No. 3 pp. 537- 545 (2024)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Towards a new method for assessment of fabric drapeability through a virtual flared skirt

Basma A. Ashmawi[a], Giulia Dalla Fontana[b], Rania F. El-Newashy[a], Roberta Peila[b], and Hosam El-Sayed[c*]

[a]*Clothing & Knitting Industries Research Department, Textile Technology Research Institute, National Research Centre, Cairo, Egypt, Affiliation ID: 60014618*

[b]*CNR-STIIMA (National Research Council - Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing), Corso Giuseppe Pella 16, 13900 Biella, Italy*

[c]*Proteinic and Man-made Fibres Department, Textile Technology Research Institute, National Research Centre, Cairo, Egypt, Affiliation ID: 60014618*

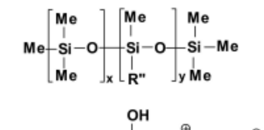
Abstract

By virtue of its polar groups-rich chemical structure, cotton is one of the most favorable textile substrates for the manufacture of garments in view of the comfortability of the final product. The fabric drape is an important element that determines the aesthetic properties of textile products. Herein, an easy accurate method was proposed for evaluating the garment drapeability on a mannequin. Six light- and medium-weight cotton and polyester fabrics, as well as cotton/polyester (50/50) blended fabrics, were used in this study. The mechanical properties of the fabrics were evaluated using the Kawabata Evaluation System (KES), and the data were inserted into the DC Suite software program. The same fabrics' properties were digitalized using the *CLO3D* system and fed into its software program. The fabric drape coefficient was also evaluated using the conventional method, both virtually and physically. Using a flared skirt, the effect of the applied low mechanical forces on the fabric drapeability and the silhouette areas was monitored. A standard virtual mannequin was used to facilitate spreading the proposed strategy within the industrial sector. The flared skirt (FS) was worn on the virtual mannequin; the evaluated skirt was assembled using the 90° circular FS method in 54 cm length. In the virtual environment, the FS's images were captured from front, side, and bottom views. The image analysis was used to assign the extents of different fabrics drapeability on the virtual mannequin. The results revealed that there is no appreciable discrepancy between the fabrics' drapeability in both real and virtual methods of analysis. No significant correlation was found between the FS worn on virtual mannequin and the fabric thickness, the warp and weft bending, and compression in the *CLO3D* system. On the other hand, the DC Suite FS did not meet all the fabric's mechanical properties.

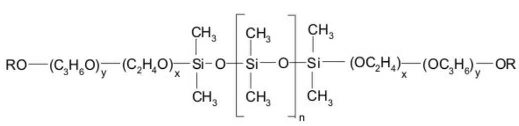
Keywords: Fabric, drapeability, *CLO3D*, DC Suite, flared skirt, silhouette

1. Introduction

Fabric drape is the milestone of the comfort attributes of textile goods, and hence various chemical modifications have been applied to improve the fabric drapeability [1–3]. Silicon softeners have been widely used in the clothing field to decrease the fabric stiffness, and hence increase its drapeability. Examples of these textile auxiliaries are cationic quaternary ammonium salt softeners (Structure 1), silicone glycol with a block-like structure (Structure 2), aminofunctional silicone softener (Structure 3), and epoxy functional silicone softener (Structure 4) [4–6].



Structure 1: Structural formula of cationic quaternary ammonium salt softener



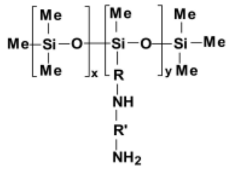
Structure 2: Structural formula of silicone glycol with a block-like structure

*Corresponding author e-mail: hosam@trdegypt.org (Hosam El-Sayed)

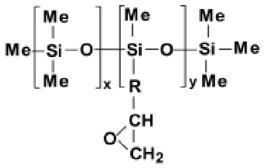
Receive Date: 16 September 2023 Revise Date: 02 November 2023 Accept Date: 26 November 2023

DOI: 10.21608/EJCHEM.2023.236681.8628

©2024 National Information and Documentation Center (NIDOC)



Structure 3: Structural formula of aminofunctional silicone softener



Structure 4: Structural formula of epoxy functional silicone

Within the last few decades, the digital fashion approach became a beneficial investment as the new 3D clothing software achieved reliable results and trustworthy estimated calculations [7]. The 3D simulation systems have been used for a long time by many famous brands. Among others, Optitex, Browzwear, *CLO3D*, and Modaris Lectra attempted to mimic the highest fidelity of the virtual garments to the real garments by developing the digitization of fabric into software [8].Recently, in the garment industry, it has become necessary for production retailers to quickly introduce a new fashion line in a wide variety at a minimum cost to appear at the desired levels of quality for competition superiority purposes [9]. This could not be achieved through typical methods. For this purpose, the fabric assessment methods must be modified [10]. The Japanese KES-system is the most common system in the field; it tests the low-load mechanical properties of fabric, from which the usage of fabric is inferred [11]. Apart from the dyeing and printing of textiles, which highly affect the performance attributes of the final product [12, 13], for different reasons, the fabric drapeability is considered a crucial aesthetic indicator [14]. The high fabric drapeability imparts better comfortability to the worn garment piece [15], as it reflects the effect of the applied finishing process [16, 17]. Also, the fabric drape coefficient gives a comprehensive idea of the different fabric properties and serves as a judgmental tool between the real and simulated 3D garments [18].

Technically, the conventional Cusick drape test is the most common one; it is being digitalized for more accurate results following the conventional test procedures [19]. Several trials were conducted to improve this method of stimulating the fabric acting on the human body. Mei et al. suggested a unidirectional drape test method to stimulate the fabric's falling performance on the human body. They concluded that the conventional fabric drape analyses are not sufficient to properly reflect the drape behavior of fabric worn in actual situations, according to the fabric direction falling [20]. In a previous study, a mini-scaled dummy was used instead of the cylindrical holder and a scaled flared skirt instead of the circular fabric specimen [21]. The obtained results were significant and could help to use a garment piece as an assessment specimen rather than the flat circular one. However, for the mechanical properties, it couldn't predict the final form of the garment accurately [19]. Buyukaslan et al. investigated the mechanical properties of three different plain weave fabrics, and they recorded some differences in bending and shear properties, and they observed that the fabrics drape profiles were significantly different among the three samples [22]. It was found that, despite some differences between the physical and virtual trials, they had similar appearances, which was in harmony with the fabric construction that and had an axial effect on the fabric drapeability [23]. Issa et al. developed a 3D drape meter, worked on the conventional drape tester concept using a garment sample instead of a flat fabric sample, and studied the factors that affected the drapeability in both real and virtual environments. The similarity between real and virtual methods was attained, and it was observed that there was no clear relationship between the different seams application on the fabric drapeability on both real and virtual trials [24].

The assumption of manipulation is that the 3D clothing simulation software works to stimulate the fabric appearance on the body. The flared skirt method could describe the fabric's drapeability as it must be. In their attempt to assign the effect of the fabrics' characteristics on the flared skirt hemline form, Ashmawi et al. applied the flared skirts using 3 different materials virtually, in different angles and lengths. They concluded that the area of the skirt hemline expressed clearly the variation between the different fabrics in the 180° and 90°skirts in the short length and was strongly correlated with the fabric drapeablility. The 90°flared skirt in long length achieved the strongest correlation with the fabric drape coefficient [25]. In another previous study, Ashmawi and coworkers attempted to clearly assign the way to analyze exactly the size of the measurable flared skirt and the procedures of measurements, in which 6 fabrics were grouped into 2 groups according to the weave structure. The authors found that the 90°skirt in 54 cm long exhibited the best fabric drapeability [8]. It has been reported that the different fabrics' properties in virtual environment may have similar form of virtual garment pieces [26].

Lee et al. analyzed the drapeability of fabrics with different physical parameters by image analysis virtually. The flared skirt was used to find out the relationship between the fabric profile and the final form of the garment. It is concluded that the categorization of fabrics according to fabric drapeability can improve the explanatory process of fabric on the human body. The garment's final form has no individual numerical value to explain the drapeability of fabric [27].

Power investigated the difference between the fabric digitization instruments Browzwear and the FAST system, in which he studied the effect of both systems on garment simulation. The mechanical properties, namely extensibility, shear rigidity, and bending rigidity, of the six knitted fabrics were evaluated, compared, and interpreted. It has been agreed that unification of the standard procedure for digitizing textile properties is of prime importance for the fashion industry to facilitate the garment design method for the garment designers [28].

Fabric selection for garment manufacturing is crucial and highly dependent on their compatibility for a definite fashion collection. For mass production and fast-street fashion, the conventional laboratory tests are very expensive and time-consuming steps. In this study, the virtual flared skirt was studied to find out whether the image analysis of flared skirt shape could be an appropriate tool to assign the fabric behavior in terms of its drapeability. This investigation is of prime importance for the garment industry, as it would offer a simple and accurate method for evaluating the garment's drapeability on a mannequin.

2. Experimental

2.1. Materials

Six plain 1/1 weave structure fabrics were collected from the local market. The used fabrics were 100 % cotton, 100 % polyester, and cotton/polyester blend (50% /50%) and of dissimilar yarns counts. The profiles of the used fabric were presented in Table 1.

The fabric drape coefficient was calculated according to the conventional method described elsewhere [14].

Table 1: The main characteristics of the used fabrics

	Material	Warp Yarns count	Weft Yarn count	Weight g/m^2	DC%
1	Cotton 100%	29	49	121	36.03464
2	Cotton 100%	12	16	193	29
3	Polyester 100%	24	34	112	34.96844
4	Polyester 100%	19	33	192	43.03366
5	Cotton/polyester (50/50)	27	28	126	48.36299
6	Cotton/polyester (50/50)	24	34	207	33.28

The mechanical properties of the fabrics were examined using KES, and the results were summarized in Table 2. All measurements are directional, except for compression, and are made in both the lengthwise direction (warp direction), and in the crosswise direction of the sample (weft direction). A standard specimen size of 20 x 20 cm was used and two replicates were performed for each sample and for each direction.

The properties measured include the compressional resilience (RC), thickness (at 50 gf/cm2 pressure), shear rigidity/stiffness (G), hysteresis of shear force at 0.5° shear angle (2HG), hysteresis of shear force at 5° shear angle (2HG5), bending rigidity (B), bending hysteresis (2HB), and extensibility (EMT).

2.2. Methods

2.2.1. Flared Skirt assembling method

The Flared skirt was assembled in the virtual environment. Flared skirts were assembled using circular geometric method in angel 90° and it was applied in 54 cm lengths. The skirt was virtually assembled using one seam line and one fabric layer [8].

Table2: The KES fabrics' mechanical properties

ID	RC [%]	Tm (mm)	G [gf/cm*degree]	2HG [gf/m]	2HG5 [gf/m]	MIU [-]	B [gf*cm2/c]	2HB [gf*cm/cm]	EMT [%]
1	0.268	0.268	0.54026	1.008788	2.112008	0.1667	0.0634751	0.05016825	10.495
2	0.442	0.413	0.573856	0.958848	1.912248	0.22	0.0834965	0.05271745	5.603
3	0.262	0.262	0.443104	0.742744	1.274832	0.1765	0.0394922	0.03477108	8.265
4	0.243	0.772	0.64014	1.242144	1.928592	0.1525	0.0665239	0.03579076	8.043
5	0.263	0.263	0.761812	1.363816	2.416188	0.1668	0.0452942	0.03793209	6.575
6	0.778	0.442	0.764536	1.696144	3.912572	0.2697	0.1393494	0.10115224	7.19

2.2.2. Simulation process

For fabric digitalization, the collected fabrics were digitalized into two 3D simulation software programs, namely *CLO3D* and DC Suite. The physical properties were inspected as per the procedures of each software program. Whereas in the *CLO3D* software, the specimen is digitalized through its own procedures [9], the DC suite software follows the KES values for the fabric digitization.

2.2.2.1. Conventional fabric drapeability test simulation process

The samples (25 cm in diameter) were draped on a cylindrical object with a 10 cm diameter in both systems (*CLO3D* and DC Suite). The DC Suite required a visual evaluation step to secure the similarity of the fabric between the real and virtual results, based on a fabric drape methodology using a disc holder. The fabrics were captured from the bottom and analyzed by the same procedures of image analysis as the conventional fabric drapeability test. The results were compared with those of the real fabric drapeability test.

2.2.2.2. The flared skirt in virtual environment

The flared skirt, assembled in one piece with a back middle seam line attached to a one-layer waste band, was simulated using both the *CLO3D* and DC Suite software programs, regardless of the sewing properties [25]. Both programs used the same object (a virtual mannequin, Figure 1) to ensure an accurate comparison between the two virtual results. The fabric simulation characteristics and rendering profiles were considered for both software programs individually.

A **B**

Fig. 1: (A) the front view (B) the side view of the used virtual mannequin

2.3. Analyses

2.3.1. The image analysis

The analysis method in this study is divided to two parts. The 1st part was the real and virtual fabric drapeability test, and the 2nd was the three positions of the flared skirt silhouettes. The image analysis was made using a Photoshop software program by obtaining the pixel ratio per area.

2.3.1.1. Analysis of the real and virtual fabric drapeability

The image analysis of the fabric's drapeability was done according to the conventional method (Figure 2). For comparison, the drapeability test was conducted in both real and virtual environments using the *CLO3D* (Version 7) and DC Suite (Version 5.0) software programs. The drape fabric images were captured for the fabric in the initial posture fixed on a smaller supporting disk, and then a photo of the draped sample appeared inside the initial circle area and was captured. For the virtual trial, the same steps as in the real trial were followed. The captured areas were calculated according to the following equation:

$$\text{DC}(\%) = \left[\frac{\textit{the initial shadow area per pixels} - \textit{the supportting Area disk per pixels}}{\textit{the fabric draped Area per Pixels} - \textit{the supported disk area per pixels}}\right] \times 100$$

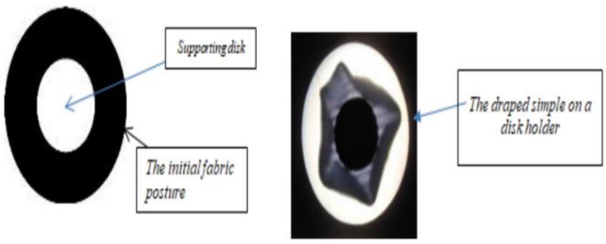


Fig. 2: The fabric drapeability conventional method

2.3.1.2. The virtual flared skirt image analysis

2.3.2. Statistical analysis

The statistical analysis was used to assess the difference between materials in terms of their appearance and drapeabilty. The relationship between mechanical properties of the fabrics was tested, and the similarity between fabric drapeability on real and virtual environments was studied, using the one-way ANOVA test. For the virtual flared skirt, the significance of differences between materials was tested on the obtained result. The correlation strength between fabric mechanical properties and virtual flared skirts results was assigned, and it was found that there was a strong correlation between the bending

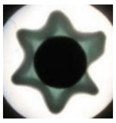
properties of the fabric, DC Suite virtual fabric drapeability trial, and *CLO3D* virtual skirts. All the statistical tests were done using the IBM SPSS software and Microsoft Excel

3. Results and Discussion

3.1. Drape coefficient measurements

The comparison between fabric drape coefficient (DC %) in both real and virtual environments is an essential step to adjust the virtual flared skirt assessment procedures. As shown in Table 3, the comparison between the real and the virtual (in both *CLO3D* and DC Suite) draped fabric was conducted in terms of their drape coefficient. On the other hand, Figure 3 shows the drape coefficient values of the six fabrics measured in reality and virtually using *CLO3D* and DC Suite software program. It is clear that there is a remarkable variation, even within a limit, in the drape coefficient of the six fabrics measured using the adopted different methods. This variation was approved by the ANOVA test (Table 4) as indicated by the p-value, which is higher than the significant level.

Table 3: The real and virtual fabric drapeability simulation results for both systems DC suite and *CLO3D* software

Situation	Real	DC Suite	CLO3D
DC %			

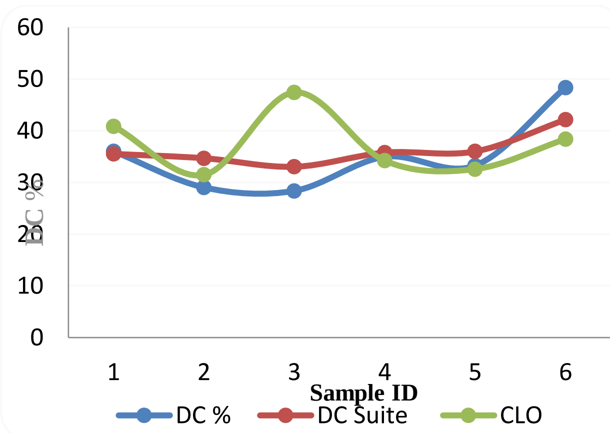


Fig. 3: Fabric drape coefficient for real and virtual for both systems DC Suite and CLO3D

Table 4: The one-way ANOVA, single factor test to test the significance of differences between real and virtual drape coefficient

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F- crit*
Between Groups	29.23849632	2	14.61925	0.400259	0.677095	3.68232
Within Groups	547.8670459	15	36.52447			
Total	577.1055422	17				

Whereas SS= Sum of squares, the sum of the squared deviations from the expected value of the real and virtual drape coefficients, DF= Degree of freedom or the number of the samples - 1, * MS= Mean square, F= F- statistics which is the ratio between the mean squares of the real and virtual drape coefficient, P-Value= the probability of obtaining an F statistic at least as extreme as that observed when the null hypothesis is true, .F-Crit = the critical F Value[29].

3.2. The virtual flared skirt assessment

Tables 5 and 6 show the two trials for the visual comparison of the virtual simulation for both systems, *CLO3D* and DC Suite. These tables also contain the real fabric drapeability samples photos, and virtual fabric drapeability images, as well as the flared skirt in the three positions (hemline view, front view, and side view) prepared for the image analysis process. Regarding the fabric drapeability, the difference between the real and virtual results appeared visually, whereas the DC Suite exhibited dissimilitude in the pattern of the fabric drapeability, as illustrated in Table 5. Figure 3, on the other side, showed that there is harmony between the results of the drape coefficient of both the DC Suite trial and the real one. Similar trend was encountered in case of the *CLO3D* trial, as indicated in Table 6.

Concerning the fabric drapeability of the flared skirt on a virtual mannequin, it is obvious from the data in Tables 5 and 6 that the DC Suite virtual flared skirt trial is more impressive than the *CLO3D* trial. Visually, the flare count of the virtual flared skirts was displayed on Figure 3, and the number of flares differed as approved in a previous study [26].

3.3. Comparison between the DC Suite and CLO3D virtual flared skirts

The flared skirts were simulated using an angel 90° pattern block, as it was confirmed that wider flared skirt angles produced similar results and abolished the differences between fabrics. Table 5 shows the simulated flared skirts on the three positions (front, side, and bottom views) for DC Suite software, whereas Table 6 abridges the same simulated flared skirts on the same poses for *CLO3D* software. For the same fabric, although the number of flares is the same in both programs, the shapes and areas of the hemlines are different within the two adopted programs. Moreover, in the *CLO3D* virtual trial, the fabrics seem to be stiffer than in the DC Suite trial.

Figure 4 represents the main values of the 3 positions of the flared skirt areas per pixel of the image analysis for both programs. There are clear visual discrepancies between the DC Suite and *CLO3D* in terms of the area per pixel of the flared skirts in the three positions. This finding was verified by using a one-way ANOVA, test as shown in Table 7, in which there is a significant difference between the *CLO3D* and DC Suite statistically with a P-value much less than 0.001.

Table 5: DC Suite virtual attempt for fabric drape coefficient in both real and virtual environments and the flared skirt in three positions (front, side, and bottom views)

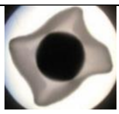
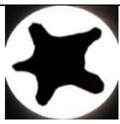
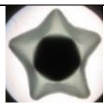
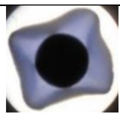
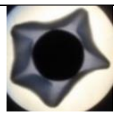
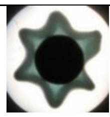
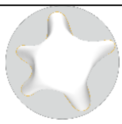
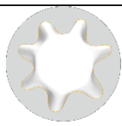
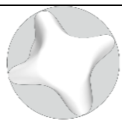
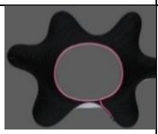
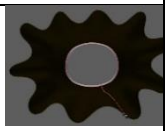
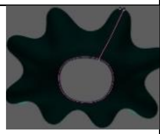
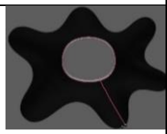
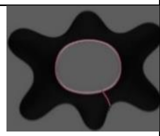
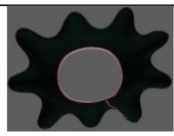
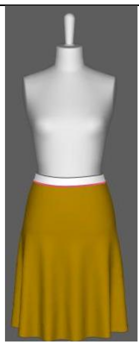
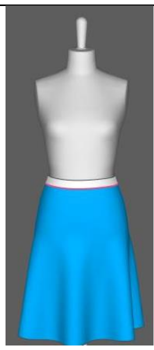
FABRIC	1	2	3	4	5	6
FABRIC Drape						
DC Suite						
DC Suite						
Front view DC Suite						
Side view DC Suite						

Fig. 6: *CLO3D* virtual trial for fabric drape coefficient in both real and virtual environments and the flared skirt three positions (front, side and bottom views)

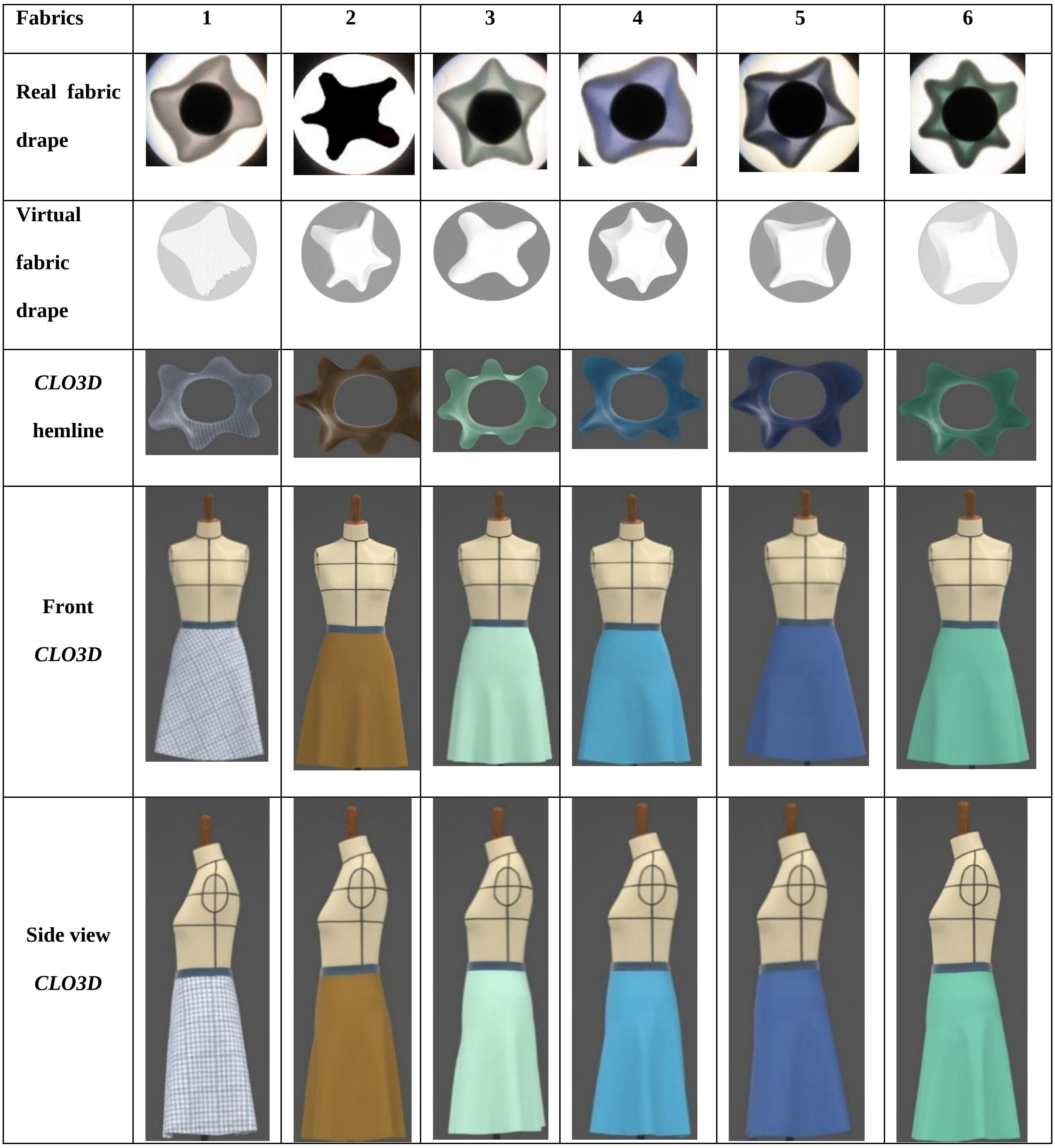


Table 7: The oneway ANOVA test to test the differences between the DC Suite and *CLO3D* virtual trials

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F- crit.***
Between Groups	1.56E+12	11	1.42E+11	10.1612	1.43E-06	2.216309
Within Groups	3.36E+11	24	1.4E+10			

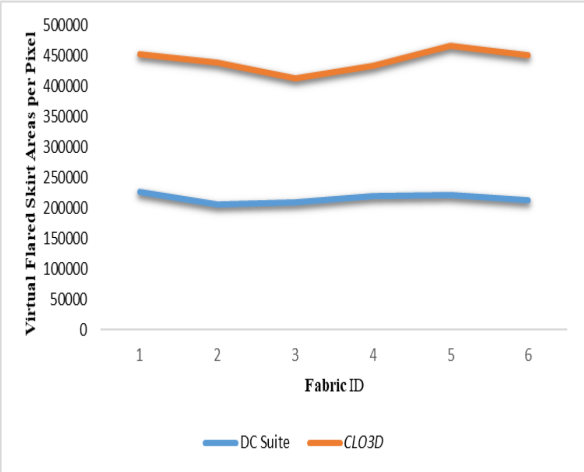


Fig. 4: The flared skirt area per pixel for the tested fabrics using *CLO3D* and DC Suite softwares

3.4. The correlation between mechanical properties and the flared skirts

Finding a correlation between KES mechanical properties, DC%, and the areas of the flared skirts three positions is of prime importance to expressing the fabric drapeability through flared skirts. According to the results of the examined samples, it is clear from the data in Table 8 that the fabric drape coefficient was strongly correlated with the surface friction properties of the KES (MIU) and RC% with a P-value less than 0.05.The DC Suite fabric drapeability simulation test revealed a strong correlation among the different Kawabata mechanical properties, namely the thickness, the surface friction, and the bending properties. This finding could be attributed to the dependence of the DC Suite software on the Kawabata system for fabric digitalization. On the other hand, the *CLO3D* virtual drape test had no correlation with all the properties of the KES. Moreover, for the flared skirt virtual trial, the DC Suite was not correlated with the KES, whereas the *CLO3D* had a strong correlation with a P-value less than 0.001 with the bending properties, despite the fact that the *CLO3D* digitalization procedures were different from those of the KES. This would bring us to a new effective and reliable method for fabric drapeability assessment based on a worn garment piece rather than the conventionally used flat specimen fabric method.

Table 8: The relationship between real fabric drapeability, the virtual fabric drapeability for both systems DC Suite, *CLO3D*, and the KES using IBM SPSS Software

			Correlation				
			DC %	DC Suit DC %	*CLO3D* DC %	DC Suit Flared Skirt	*CLO3D* Flared Skirt
RC%	Pearson correlation		-.873*	-.379	-.584	-.319	.120
	Sig.(2-tailed)		.023	.459	.223	.538	.821
MIU-	Pearson correlation		.841*	.861*	.022	-.300	-.772
	Sig.(2-tailed)		.036	.028	.967	.564	.072
B gf*cm^2	Pearson correlation		.618	.900*	-.035	-.309	-.924**
	Sig.(2-tailed)		.191	.015	.948	.552	.008
2HB gf*cm	Pearson correlation		.797	.925**	.141	-.146	-.827*
	Sig.(2-tailed)		.058	.008	.789	.782	.042
Thickness	Pearson correlation		.476	.889*	-.169	-.537	-.993**
	Sig.(2-tailed)		.340	.018	.749	.272	<.001
	N		6	6	6	6	6
	Bootstrap^c	Bias	-.135	-.229	-.023	-.111	.026
		Std. Error	.608	.462	.473	.256	.190
		95% confidence Interval Lower	-.995	-.586	-.925	-.999	-1.000
		95% confidence Interval Upper	1.000	.999	.967	-.356	-.943

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
C Unless otherwise noted, bootstrap results are based on 1000 bootstrap sample

4. Conclusions

Based on the above findings, it is concluded that the conventional method of measuring fabric drapeability is not the proper choice to express the worn garment's aesthetic properties. The flared skirt, as a fabric drapeability assessment method, is more appropriate for a larger sample size in the form of a garment piece. Although the DC Suite software required a visual evaluation step, which is based on a comparison between the simulation and the real methods using a fabric draped on a disc holder, yet the flared skirt method was not suitable to reflect the mechanical properties of the examined fabric. The use of *CLO3D* software in the flared skirt simulation properly reflected the behaviour of the worn fabric in terms of the fabric's mechanical properties. Accordingly, a new effective and reliable method for fabric drapeability assessment based on a worn garment piece rather than the conventionally used flat specimen fabric conventionally, was proposed. This method would pave the road for a new garment drapeability assessment standard method. Further investigations are currently being conducted in our laboratories to optimize the proposed procedures.

5. Acknowledgement

The authors are indebted to the TG3D Studio, DC Suite, South Korea for extending the license of DC Suite software to complete this work.

6. References

[1] A. A. Almetwally. Alkaline hydrolysis of polyester woven fabrics and its influence thermal comfort properties. Egyptian Journal of Chemistry, 65(12):259–274 (2022). https://doi.org/10.21608/EJCHEM.2022.122214.5508

[2] M. Abou Taleb, H. El-Sayed. Preparation and characterization of lanolin-based condensate and its utilization as a nonionic softener for wool fabric. Journal of Applied Research and Technology, 19(5):508–520 (2021). https://doi.org/10.22201/icat.24486736e.2021.19.5.1443.

[3] H. El-Sayed. Novel approach for antisetting of wool fabric during dyeing. Coloration Technology, 122(1):57–60 (2006). https://doi.org/10.1111/j.1478-4408.2006.00004.x

[3] J. J. Chru´sciel. Modifications of textile materials with functional silanes, liquid silicone softeners, and silicone rubbers—A Review. Polymers, 14:4383 (2022). https://doi.org/10.3390/polym14204382.

[4] M. Abou Taleb, A. Hussien, A. El-Fiky, H. El-Sayed. Preparation of fatty acid-amino diol condensate and its utilization in improving comfort characteristics of PAN fabrics. Heliyon, 8(6):e09741 (2022). https://doi.org/10.1016/j.heliyon.2022.e09741.

[5] H. El-Sayed, M. Abou Taleb, S. Mowafi. Potential applications of textile wastes and by-products in production of textile auxiliaries. Egyptian Journal of Chemistry, 64(8):4429–4443, 2021. https://doi.org/10.21608/EJCHEM.2021.79398.3899.

[6] H. Lee, Y. Xu, Y. Classification of virtual fitting room technologies in the fashion industry: from the perspective of consumer experience. International Journal of Fashion Design, Technology and Education, 13(1):1-10 (2020)). https://doi.org/10.1080/17543266.2019.1657505.

[7] B. A. Ashmawi, A. G. Hassouna, N. Nasr Eldine, and R.F. El-Newashy. The relationship between FAST mechanical properties, fabric drape coefficient and 3D simulated flared skirt. Journal of Textiles, Coloration and Polymer Science, 19 (2): 321-329 (2022). https://doi.org/10.21608/jtcps.2022.160479.1135

[8] Emulator – How can we help you? (clo3d.com) May, 2022.

[9] K. Arzu. Comparison of CAD and manual system efficiency in pre-production preparation process. Textile and Apparel, 29 (1):73–84 (2019). https://doi.org/10.32710/tekstilvekonfeksiyon .

[10] S. Kawabata, M. Niwa. Fabric performance in clothing and clothing manufacture. The Journal of the Textile Institute, 80(1):18-50 (1989). https://doi.org/10.1080/00405008908659184.

[11] K. Haggag, A. A. Ragheb, I. Abd El-Thalouth, S. H. Nassar, H. El-Sayed. A Review article on enzyme and their role in resist and discharge printing styles. Life Science Journal, 10(1):1646–1654 (2013).

[12] K. Bekiroğlu, G. Özcan, P. Altay. Improvement in pilling property of viscose/PET blended knitted fabric after garment dyeing. Journal of the Textile Institute, 113(6):971–982 (2022). https://doi.org/10.1080/00405000.2021.1912953

[13] R. F. El-Newashy, H. El-Sayed. Adopting *CLO3D* simulation system for evaluation of fitting and stretch-ability of selected bio-treated knitted polyester/Lycra fabrics. Egyptian Journal of Chemistry, 65(8):779–789 (2022). https://doi.org/10.21608/EJCHEM.2022.150365.6512.

[14] H. Bilgic, F. Turemez. Determining production fabric with three dimensional modeling system (V-Stitcher). International Journal of Scientific and Technological Research, 5(1):63-70 (2019).

[15] M. Abou Taleb, S. Mowafi, H. El-Sayed, R. F. El-Newashy. Facile development of electrically conductive comfortable fabrics using metal ions. Journal of Industrial Textiles, 51(7):1100–1120 (2022). https://doi.org/10.1177/1528083719893713.

[16] H. El-Sayed, S. Mowafi, A. Basuoni (2022). One-pot multifunctional finishing of wool fabric using reactive nonionic softener. Heliyon, 8:e10985 (2022). https://doi.org/10.1016/j.heliyon.2022.e10985

[17] X. Zheng, C. Liu, W. Wei. Investigation into evaluation of wearing bagging behavior for woven garments. Journal of the Textile Institute, 113(7):1479–1486 (2022). https://doi.org/10.1080/00405000.2021.1933805

[18] M. A. El-Gamal, A. G. Hassouna, R. F. El-Newashy, M. Shawky, B. A. Ashmawi. Prediction of garment appearance from FAST mechanical properties and fabric drape. Life Science Journal, 11(12):1054-1059 (2014).

[19] Z. Mei, W. Shen, Y. Wang, J. Yang, T. Zhou, and H. Zhou. Unidirectional fabric drape testing methods. 10(11):e0143648 (2015). https://doi.org/10.1371/journal.pone.0143648.

[20] S. H. El Gholmy. Predicting the appearance of garment for E-marketing. The 6th World Conference on 3D Fabrics and their Applications, Raleigh, NC, USA, 26-28 (2015).

[21] E. Buyukaslan, S. Jevsnik, F. Kalaoglu. Drape of virtual garments on body models: Impact of mechanical properties of the fabrics. Proc. of 6th Int. Conf. on 3D Body Scanning Technologies, Lugano, Switzerland, 127-133 (2015). https://doi.org/10.15221/15.127 .

[22] M. Matusiak. Influence of the structural parameters of woven fabrics on their drapeability. Fibres & Textiles in Eastern Europe, 25:56-64 (2017). http://doi.org/ 10.5604/12303666.1227883.

[23] M. Issa, S. Elgholmy, A. Sheta, M. N. Fors. A new method for measuring the static and dynamic fabric/garment drape using 3D printed mannequin. The Journal of the Textile Institute, Taylor & Francis, 113(6):1163-1175 (2022). https://doi.org/10.1080/00405000.2021.1917803

[24] B. A. Ashmawi, A. G. Hassouna, N. N. Eldine, R. F. El-Newashy. CLO3D simulation versus real drape test for assessment of garment drape coefficient. Journal of Textiles, Coloration and Polymer Science, 18(2): 263-271 (2021).

[25] C. Sujoung. A study on comparing evaluation of external appearance between real and 3D simulation of flared skirt focused on flare volume and length. Journal of Fashion Business, 18(6):38-56 (2014). https:// /doi.org/10.12940/jfb.2014.18.6.38.

[26] E. Lee, H. Park. 3D virtual fit simulation technology: strengths and areas of improvement for increased industry adoption. International Journal of Fashion Design, Technology and Education, 10:1-12 92016). http://doi.org/10.1080/17543266.2016.1194483.

[27] J. Power. Fabric objective measurements for commercial 3D virtual garment simulation, International Journal of Clothing Science and Technology, Bradford 25(6):423-439 (2013). http://dx.doi.org/10.1108/IJCST-12-2012-0080 .