Virtual Simulation of Apparel Draping

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ABSTRACT

The influence of two groups of factors related to physical and mechanical properties and structural parameters of a textile sample on its drape in a virtual environment was investigated. The tests were carried out using a gravity-based drape testing scheme on a test stand with a special configuration that replicates the supporting surface of the human figure. Samples from two interconnected geometrical primitives had variable dimensional parameters, adapted to features of the volume-silhouette form of a garment and its shaping on a surface of a human figure. It was found that the drape of material samples depends primarily on their design parameters and less on property parameters. Thus, the new form of sample for drape testing allows to imitate the behaviour of real clothes.

Keywords: drape, sample shape, physical and mechanical properties, 3D simulation, virtual clothing.

INTRODUCTION

The drape (D) of fabrics refers to their ability to sag or form folds under their own weight, which is an important characteristic for modelling the volumetric and spatial shape of garments and controlling their visual appeal. This property allows fabrics to form aesthetically pleasing, curved surfaces and ensures good fit of garments on the human figure (Yu, Bao, & Wu, 2004 and pp.242-304). Studies emphasise the impact of drape on the appearance and sensory appeal of fabrics, as fabrics with good drape abilities increase the visual satisfaction of wearers (Pavlinic & Geršak, 2003, and pp. 231–240; Geršak, 2004, and pp. 238–251). Traditional methods of measuring drape are based on the deformation of a sample in a horizontal position under the influence of gravity, while the sag of a garment is not defined by a horizontal plane.

LITERATURE REVIEW

Historical background and key finding

The seminal work on drape of fabrics was initiated in the 1930s by Pearce (1930, and pp.T377–T416) who established the relationship between drape and fabric stiffness and proposed the use of stiffness and bend length as measures of mechanical properties to assess drape. Further studies on drape were continued by Grosberg (1980, and pp.197-209), Lindberg (1961, and pp.99-122), Bere (1961, and pp.8-99), Dahlberg (1961, and pp.94-99), and Skelton (1980, and pp.211-226), For example, Grosberg included a new factor, friction between main and weft yarns, to improve the accuracy of the drape description. Lindberg's research established a close relationship between shear, bending and drape. Skelton and subsequent researchers confirmed these findings by establishing the importance of mechanical property indices including bending and shear.

Following these seminal studies, Cusick (1968, and pp.253-260) found a high correlation between bend length, shear modulus and drape coefficient. Later, Moroka (1976, and pp.67-73) studied more comprehensively and systematically the relationship between drape coefficient (DC) and mechanical property indices of fabrics and obtained multivariate regression equations.

Recent developments in drape analysis

Most modern methods of drape research are based on flat models, and the factors used are mainly indicators of the physical and mechanical properties of the textile material. The study of drape of textile fabrics is carried out using two types of samples - real and virtual.

In the first case, studies are carried out using material flat samples, traditional methods of measuring drape, and schemes to analyse the relationships between fabric property indicators and drape.

The type of fabric structure was found to have a high correlation with drape. Sadugi et al. (2020, and pp.145-152) found that the highest correlation between fabric structural characteristics and drape, bend and shear exist for plain weave, followed by twill weave, and increasing the linear density in the weft of the fabric leads to higher DC.

Another point is that the flexural and shear properties of fabrics are also related to weave structure and weft density. Ahmed B. (2022, and pp.321-329) conducted experiments with flared skirts and confirmed the strong relationship between fabric structure and DC. However, it is clear from these studies that fabrics have different mechanical property indices depending on the weave structure, so more studies have been done with mechanical property indices. For example, Al-Gaadi et al. (2011, and pp.502-512) analysed the effect of twist direction on drape of fabrics and found that different yarn twists can change the mechanical stiffness, which can have different effects on drape. M Messiri (2019, and pp.416-423) investigated the effect of different weft densities and weave structures and found that DC has a high correlation with fabric flexural stiffness and other structural properties of the fabric. Jong Hwa Kim (2024, and pp.1-20) found that flexural stiffness and surface density affect DC, and flexural stiffness is the decisive parameter.

S Wein et al. (2023, and p.160) found that the DC coefficient had a good positive correlation with both bending length and bending stiffness, and the correlation with bending length was higher than that with bending stiffness. Hu et al. (2023, and p.100020) found that the dynamic drape of silk fabric was influenced (in descending order) by weft extensibility, shear index, and bending stiffness index. A Basma (2023, and pp.537-545) found that DC of fabric is closely related to surface friction properties and compressibility resistance. Praveen Ukey (2023, and pp.99-102) studied the shear properties of fabrics with different surface densities (linen, cotton, blended polyester and cotton, denim and corduroy) at different angles and confirmed the existence of high correlation between drape and shear indices of fabrics. Yang (2019, and pp.442-459) used a cantilevered circle segment model with infinite shear stiffness (upper limit) and a cantilevered strip radial deflection model with zero shear stiffness (lower limit) to analyse the effect of fabric size on drape deformation.

The listed studied indicators of fabric properties can be divided into structural, mechanical and physical. Summarising the studies performed, we can arrange all the identified factors in descending order of their influence on drape:

- fabric structure (weave),
- type of yarn and its linear density,
- shear force,
- surface density,
- bending stiffness,
- yarn count,
- thickness,
- extensibility,
- compression properties,
- surface properties,
- twist direction.

Obviously, it is more convincing to use indices of mechanical properties rather than yarn properties and structure to study drape. Therefore, in this paper also physical and mechanical property indicators will be selected for experiments: thickness, surface density, bending stiffness, extensibility and deformation strength.

In the second case, drape studies are carried out in a virtual environment using digital and virtual doubles of tangible fabrics. With the growing interest in 3D virtual garment styling, more and more researchers are getting involved in the study of virtual drape due to the unlimited possibilities of this method. Feng (2022, and pp.104-109) pointed out that flexural strength and fabric density are the key factors affecting virtual drape of fabric in CLO3D. Buyukasla (2015, and pp.127-133) investigated real and virtual drape of fabrics with similar composition but different yarn counts using

FAST and found significant differences between real and virtual drape images. Virtual studies still use flat specimens and flat test beds, ignoring the fact that in a real garment, the fabric does not come in contact with a flat but convex-curved surface of the human body.

Another area of research is the use of existing or development of new testing equipment and sample moulds. The KES-FB complex was used by Shim (2022, and pp.47156-47164) to relate physical properties to draping and found strong effects of thickness, extensibility, bending stiffness and shear resistance. F Kalalau (2018, and pp.12-15) applied simulations using Optitex software to observe virtual draping of FAST-tested fabrics. Buyukasla (2017, and p.162002) and others used similar setups to compare real and virtual sample images using image analysis software. RYKLIN (2022, and pp.114-119) presented a 3D scanner for capturing 3D images and measuring drape indices. Studies by Ashmawi (2021, and pp.263-271) and Duong (2024, and p.102077) investigated virtual drape and evaluated drape performance in CLO3D and other digital platforms.

Experimental variations and equipment innovations

Some studies modify test patterns to improve measurement accuracy. Ju Eunjung (2020, and pp.195113-195121) and colleagues investigated cylindrical holders for both round and square tissue samples. Bottino (2001, and pp.63-70) presented spherical, square and rectangular mounts for different sample shapes. In an effort to realistically simulate draping on real clothes, recent research has shifted the focus from round fabric tests to measurements on real mannequins (Asano C, 2014, and pp.811-819). For example, Issa (2021, and pp.1163-1175) developed a drape measurement mannequin using 3D printing technology, which allows dynamic measurements of drape and investigates the effect of seam lines on drape behaviour. Kuzmichev (2024, and pp.83-95) presented a test device modelling the shoulder girdle to simulate the interaction with the human body and proposed a new approach to assess drape.

Aim of this study

This study of fabric draping can be conducted more flexibly in a virtual environment, which is very convenient for documenting and speeding up the processing of results. In our study, Style3D software will be used as a virtual experimental environment. The thickness, surface density and mechanical properties -- bending, tensile and flexural stiffness - are chosen as indicators of fabric properties. A new sampling form with two geometric primitives will be used, allowing both fabric properties and design parameters to be taken into account. The ultimate goal of fabric draping research is to optimize the fit and style of garment, which is determined by different design decisions. This paper presents a new method for predicting the properties of textile fabrics in virtual clothing, aiming to deepen the understanding of how these parameters affect the appearance of clothing, the results of which will help balance virtual and real clothing testing. The method and algorithm can better predict and create contoured realistic shapes for "avatar + garment" systems in virtual environments, bridging the gap between digital twins and their material prototypes.

METHODOLOGY

The study utilised a drape test bench (KUZMICHEV & Chen, 2024, and pp.83-95), which significantly modifies the traditional testing scheme. The study was divided into five stages. Firstly, the test bench was set up and the trial patterns with variable parameters were developed. Second, virtual tissue doubles were generated. Third, the samples were tested, to select the best sample that allows a clearer differentiation of the draping abilities of the materials. Fourthly, equations were developed to obtain the drape index. Finally, in the fifth step, validation of the results obtained was carried out using other fabrics.

Materials

Three woven fabrics were used to investigate the correlation between mechanical and structural material properties and drape: fabric 1 was denim fabric (97% cotton and 3% spandex), fabric 2 was faux acetate fabric (97% polyester and 3% spandex), fabric 3 was Tencel-poplin (100% cotton). These fabrics were commercially available and have different properties as shown in Table 1. The physical and mechanical properties of the fabrics are provided by the fabric manufacturers.

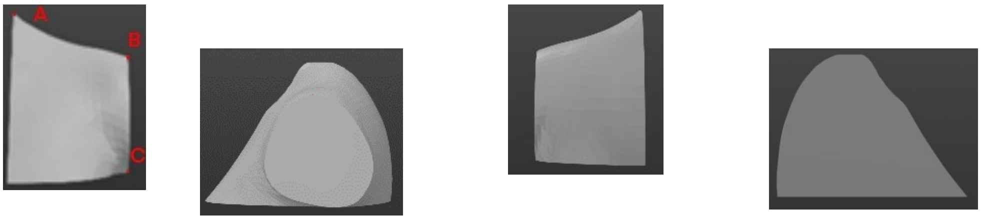
Table 1. Indicators of physical and mechanical properties of experimental materials

Fabric code	Weights, g/m^2	Thicknesses, mm	Tensile, g/s^2			Bending stiffness, g·mm^2/s^2/rad			Deformation strength		
			War p	Weft	Bias	War p	Weft	Bias	War p	Weft	Bias
1	147	0.38	66	43	28	45	34	39	100	100	100
2	194	0.38	66	33	22	40	29	35	0	0	0
3	103	0.17	66	66	52	24	14	19	20	20	20

Similar fabrics with the same chemical composition were selected from the Style3D software fabric library, and their physical and mechanical property parameters were modified to ensure that the properties of the virtual fabrics matched those of the real fabrics.

Sample and stand for drape

The drape stand was derived from 3D avatars of human bodies (KUZMICHEV & Chen, 2024, and pp.83-95). The virtual stand was modelled using Style3D and Rhino 7. The dimensions of the booth are based on the Chinese standard for women's clothing sizes (Chen, C.Y, Li, Y and Xue, J.P, 2023, and pp.17-27) and correspond to the parameters of the upper support surface of a typical 160/84A figure. Figure 1 shows the appearance of the stand.

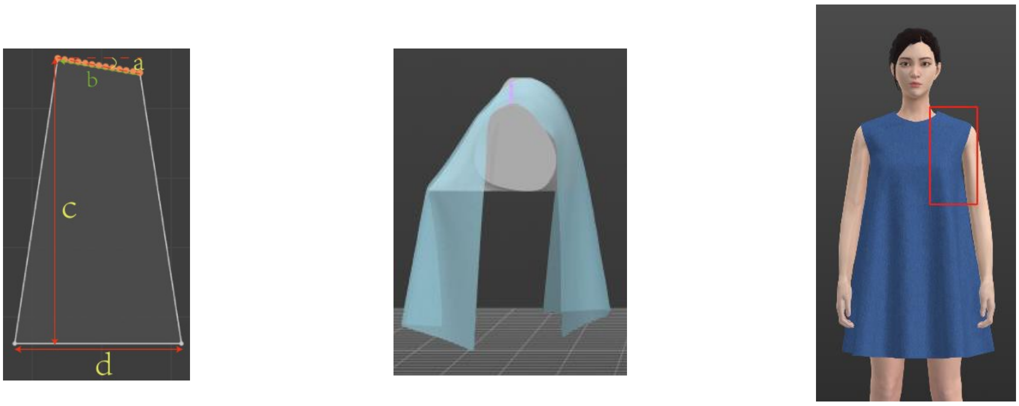


(a) (b) (c) (d)

Fig. 1 Drape test stand:
(a) front, (b) profile left, (c) back, (d) profile right

In Fig. 1, the following notations are used: *A* - cervical point from the side, *B* - shoulder point, *C* - anterior corner of the axilla.

For the new bench, a sample of two geometric primitives was designed, which were connected to each other with a thread stitching, simulating the shoulder seam of a garment. The sample shape is shown in Figure 2 and its dimensions are shown in Table 2. Figure 2(b) shows the position of the sample placed on the test stand and Figure 2(c) shows how it mimics a garment on the support surface of the human body.



(a) (b) (c)

(d) (e) (f)

Figure 2. Shape of sample part (a), sample simulation (b), virtual dress (c), and shoulder seam types: Flat S1 (d), Overlaid S2 (e), Overlock Stitch S3 (f)

No.	Parameter, unit	Symbol	Reference	Величина
1	The sum of the shoulder angles of the front and back patterns, degree	*a*	Liu R.P. (2005)	Variable 20 ... 40°
2	The shoulder length, cm	*b*	Chen et al. (2023)	Stable 12 cm
3	The sample length, equal to SNP-waist length, cm	*c*	Chen et al. (2023)	Stable 45 cm
4	The size was calculated using (0,25...0,5) BG, BG - bust circumference, cm	*d*	Chen et al. (2023)	Variable 21 .... 42cm

Table 2. Sample pattern parameter

The sample consists of two identical pieces sewn on the short side. According to Table 2, *a* is the angle which is similar to the slope of the shoulder line of the pattern. According to (Liu R.P, 2005) the sum of the angles of the shoulder sloped lines of the front and the back is 20°... 40°, so the same interval was chosen for the sample; *b* is the length of the shoulder line, which was taken as 12 cm; *c* is the length of the sample, which is equal to the distance from the neck point at the side to the waist and was chosen constant 45 cm; *d* is the sample width, calculated as (0.2 .... 0.5) of the chest circumference: the minimum value is 21 cm and the maximum is 42 cm.

In order to establish the influence of the shoulder seam on drape, as thread seams have different effects on drape (Chu, Cummings & Teixeira, 1950, and pp.539-548), the study used one-piece samples in parallel, i.e. without shoulder seam. Three variants of seamless samples were studied: without bottom hemming (W1), with bottom folded edge (W2), and with bottom hemming seam (W3). Fig. 3 shows the variants of one-piece samples with a seamless shoulder section.

(a) (b) (c)

Figure 3. One-piece samples without folding bottom W1(a), with bottom folded edgeW2(b), with bottom hemming seamW3(C)

Methods of measuring drape

In contrast to traditional test methods (Chu, Cummings & Teixeira, 1950, and pp.539-548; Jeong, 1998, and pp.59-69; Frydrych, Dziworska and Architecture, 2003, and pp.31-37), this experiment utilises a new method for measuring the drape coefficient (KUZMICHEV & Chen, 2024, and pp.83-95) and the specific scheme is shown in Figure 4.

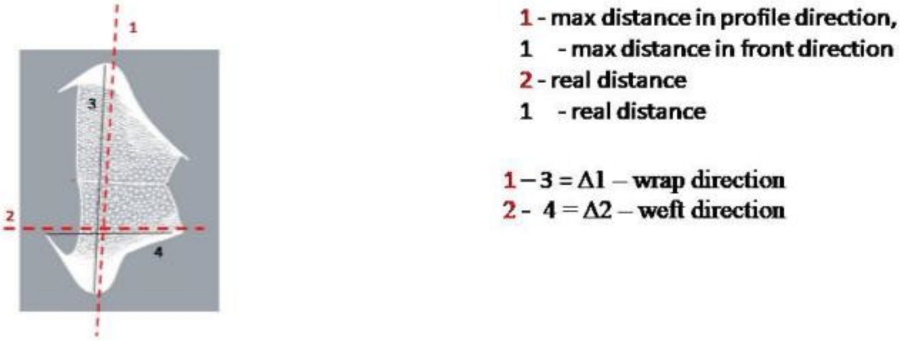


Fig 4. Test schemes The drape coefficient was calculated according to the Eq:

$DC = \frac{\Delta 2}{\Delta 1}$, (1)

where $\Delta 1$ is the difference between the maximum distances between the front and the back of the sample before *1* and after *3* simulations, and $\Delta 2$ is the difference between the mean sample width before 2 and after 4 simulations.

Statistical analysis

A total of 810 samples were formed, differing in the type of fabric, shoulder seam construction, direction of cutting, width and angles of slit cuts imitating the shoulder seam. The results of drape coefficient measurements were statistically analysed using SPSS27 software with correlation and regression analysis.

RESULTS AND DISCUSSIONS

Justification of sample size and design

The coefficient of variation was calculated for each sample using the equation:

$CV = S/\bar{x} \times 100\%$, (2) where S is the standard deviation of the sample group, and $\bar{x}$ is the mean value of the drape coefficient. The results of the CV calculation for the DC of each sample group are shown in Table 3.

Table 3. Coefficient of variation of DC for each group of samples

Sample cutting	F1			F2			F3		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Warp	0.70	0.38	0.72	0.50	0.54	0.69	0.33	0.64	0.83
Weft	0.65	0.64	0.74	0.56	0.52	0.72	0.51	0.59	0.79
Bias	0.37	0.66	0.75	0.58	0.53	0.58	0.59	0.60	0.80

From Table 3, it can be seen that different types of stitches cause different degrees of variation in DC, the maximum difference in coefficient of variation of samples with S1 is 0.33, while the maximum difference in coefficient of variation of samples with S2 and S3 is 0.28 and 0.14 respectively. Samples with S1 had the highest CV and were more sensitive to the drape of the samples. Therefore, this seam was selected for further studies to investigate the effect of cutting direction on DC. Figure 5 shows the change in CV for each group of samples with different cutting direction.

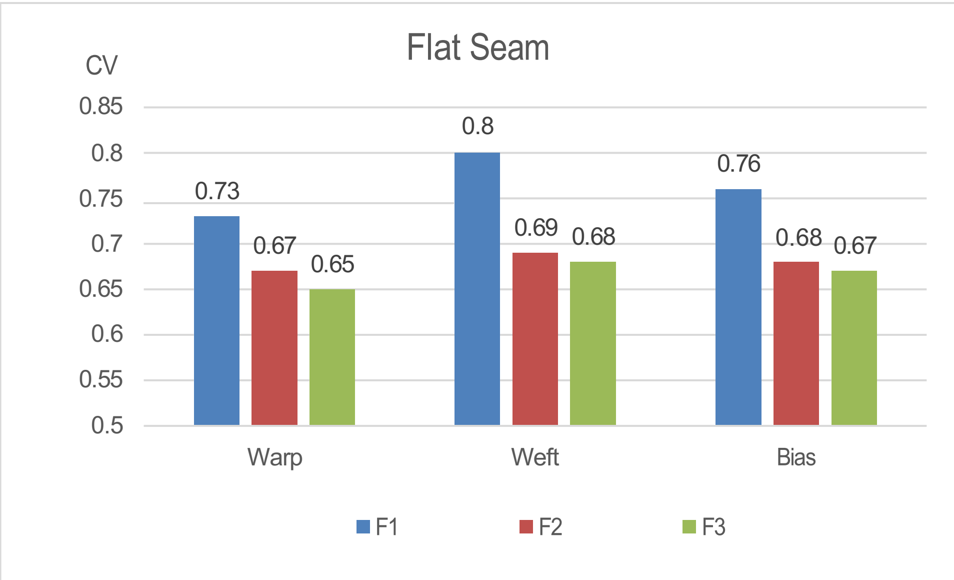


Figure 5. CV for each group of samples with different cutting direction

According to the histogram in Fig. 5, it can be seen that the coefficient of variation has a maximum difference of 0.12 for weft cutting, greater than for base cutting (0.08) and angled cutting (0.09). The reason for this variation is that the samples cut in the weft direction are more compressed in the transverse direction. Therefore, further analyses were continued with samples cut along the weft yarn.

The DC measurement results of samples cut along the weft yarn and parts of which are joined by flat seam with open cuts are shown in Table 4.

Table 4. Three kinds of fabric DC

Sample width, см	DC for different angles and different fabrics														
	20°			25°			30°			35°			40°		
	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3
21	0.09	0.15	0.17	0.04	0.10	0.13	0.02	0.07	0.09	0.02	0.06	0.08	0.01	0.03	0.06
25.2	0.18	0.24	0.35	0.15	0.19	0.19	0.10	0.17	0.18	0.10	0.11	0.12	0.07	0.10	0.12
29.4	0.31	0.40	0.41	0.29	0.35	0.31	0.22	0.28	0.29	0.19	0.24	0.20	0.15	0.19	0.20
33.6	0.50	0.56	0.65	0.47	0.52	0.60	0.34	0.43	0.46	0.31	0.34	0.34	0.23	0.28	0.27
37.8	0.78	0.81	0.87	0.66	0.80	0.82	0.56	0.62	0.68	0.50	0.53	0.49	0.38	0.47	0.46
42	0.98	0.96	0.95	0.86	0.91	0.99	0.78	0.77	0.86	0.73	0.74	0.70	0.61	0.67	0.64
AV	0.47	0.52	0.57	0.41	0.48	0.51	0.34	0.39	0.43	0.31	0.34	0.32	0.24	0.29	0.29

According to Table 4, it can be seen that the average value of drape coefficient is higher when the sample angle is 20°: it is 0.47 for F1 fabric, 0.52 for F2 fabric, and 0.57 for F3 fabric. At other shoulder cut angles, the drape coefficient is lower. Therefore, the best drape effect is achieved when the sample angle is 20°.

The difference in drape of samples with and without seams was compared at a sample angle of 20°. The results of the comparison are shown in Figure 6.

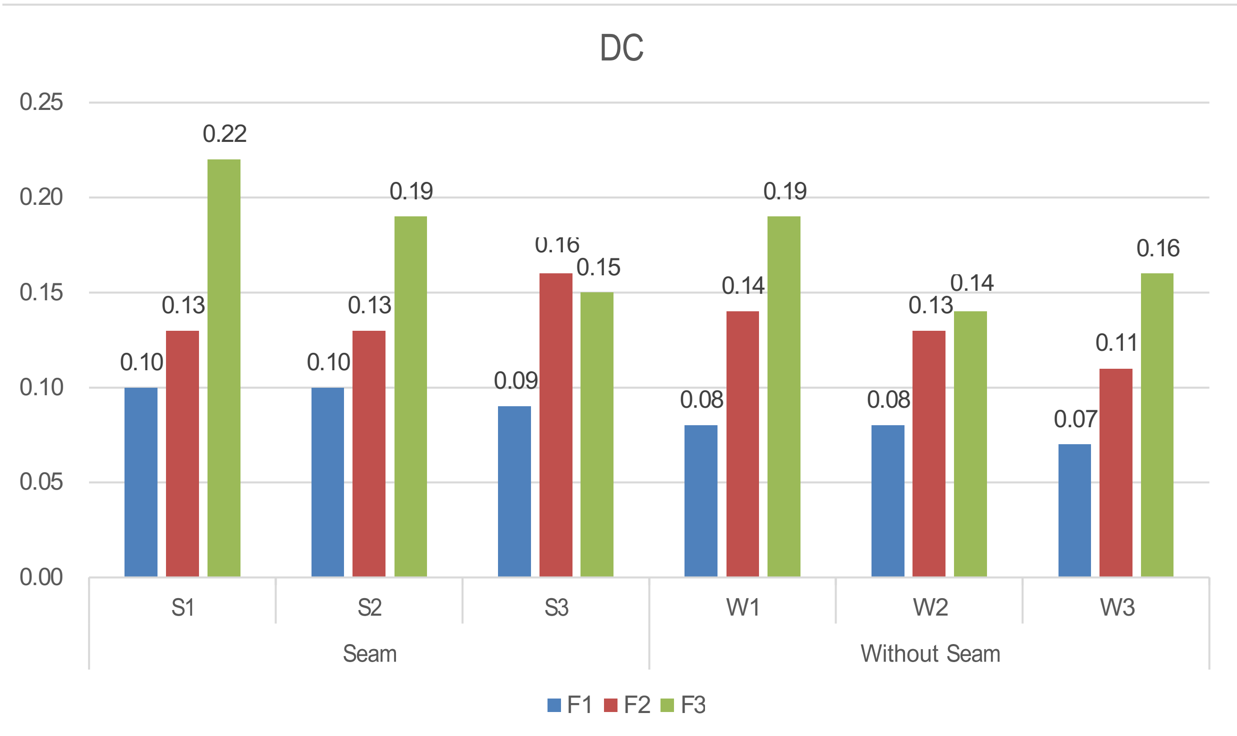


Fig. 6 Effect of seam design on DC

Important conclusions follow from Figure 6. 1) Samples whose parts are joined by flat seam with open cuts (S1) has the highest variability of drape from 0.1 to 0.22; 2)

Overlock stitch (S3) reduces the drape of fabrics; 3) W2 and W3 show that Style 3D could not react on bottom seam. In real practice, each seam along the bottom increases the stiffness and decreases the draping.

Because no effect on the DC, that means that Style 3D cannot simulate the bottom seam influencing. Due to the limitation of Style 3D, this factor was not included in the future experiment; 4) The addition of a seam that mimics a shoulder seam results in a slight increase in the DC for all fabrics when using the S1 seam.

Thus, the final requirements for the sample were formed as: the angle imitating the shoulder cut is 20°; cutting direction - along the weft; the pieces should be joined with an overlapping seam with open cuts, the bottom cut must not be hemmed.

Effect of different parameters on drape

Correlation and regression analyses of the test results were performed to further investigate the significance of the influence of factors - structural and those related to the physical properties of fabrics. The number of samples totalled 270, differing in cutting directions (three), width (six), angles (five) and fabric type (three).

The following variable factors were included in the experiment: tensile (X1), bending stiffness (X2) and deformation strength (X3), and the design parameters of the sample - an angle (X4) and a width (X5).

The correlation coefficients between the selected factors and the DC are shown in Table 5.

Table 5. Correlation coefficients (n=270)

	X1	**X2**	**X3**	**X4**	**X5**	**DC**
X1	1					
X2	-0.211**	1				
X3	-0.045	0	1			
X4	0	0	0	1		
X5	0	0	0	0	1	
DC	0.044	-0.049	-0.079	-0.306**	0.920**	1

The results of the correlation analysis in Table 5 show that X5 - the sample width (correlation coefficient 0.920) and X4 - the angle simulating shoulder cut (correlation coefficient -0.306) have the greatest influence on the DC. According to the data, it is obvious that the physical property factors X1, X2 and X3 have no strong influence on drape because its correlation coefficients of 0.044, -0.049 and -0.079 respectively not significant.

Before starting the regression analysis, the linear relationship between drape factors of the three fabrics and DC was tested. The results are shown in Figures 7 and 8.

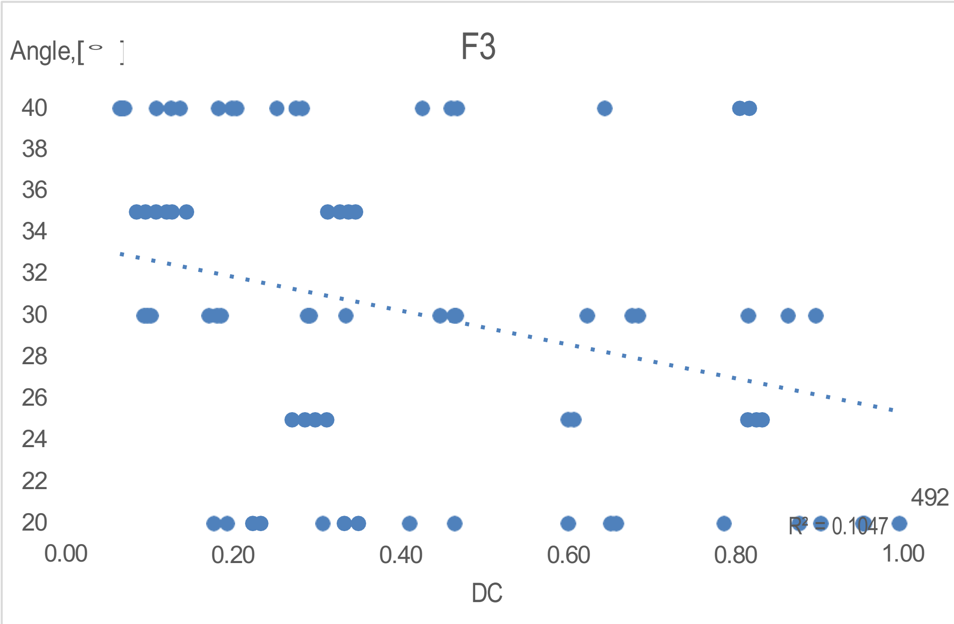


Fig. 7 Relationship between drape factor X4 and DC for F3

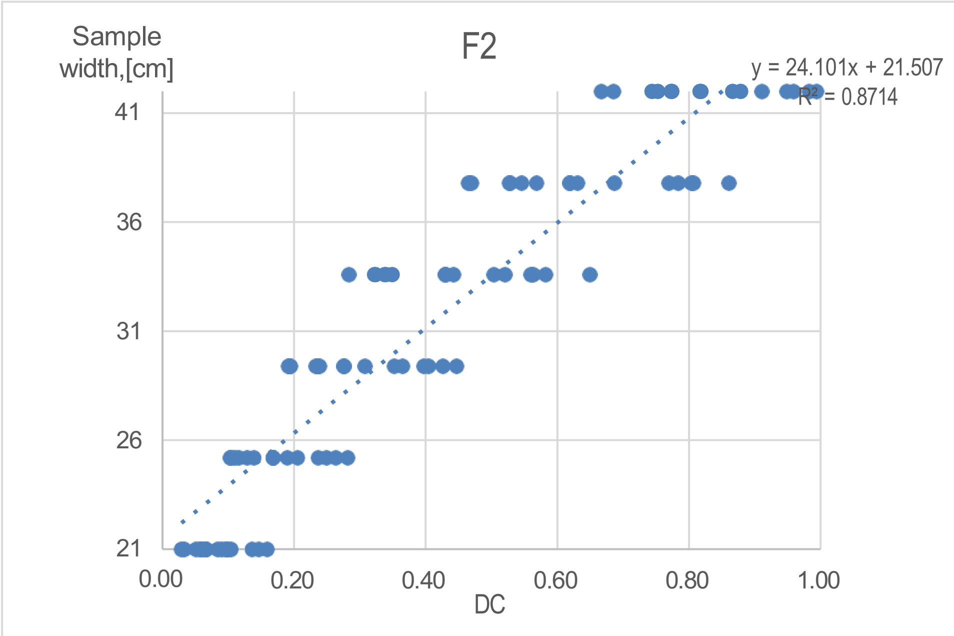


Fig. 8 Relationship between drape factor X5 and DC for F2

The equations describing the relationships between sample design parameters and drape coefficients are adequate and are of the form:

$$DC = -8.16X4 + 33.492, \text{ correlation coefficient } 0.306; (3)$$
$$DC = 24.1X5 + 22, \text{ correlation coefficient } 0.920, (4)$$

where DC is the drape factor, X4 is the angle; and X5 is the width. For X4, X5 correlation coefficients R>0.248 indicate that a linear relationship between factors X4 and X5 and DC are existing.

Regression two-factor analysis was performed using the design parameters of the sample. Equation (5) was obtained to predict the DC:

$$DC = -0.369 - 0.012X4 + 0.036X5 \ (5)$$

Equation (5) shows that it is the design parameters of the sample that have a greater influence on DC when the flat sample transitions to the three-dimensional state. In this study, the samples mimic the behaviour of the garment when it is worn on the shoulders of a person. The inclusion of these factors in the model for prediction is consistent with the shaping of the garment on the shoulder girdle of the figure. In the case of clothing, the greater the angle of the shoulder lines, the more the left and right shelves overlap; in the case of a sample, the smaller the DC becomes.

In the case of clothing, the greater the width of the shelves, the more vertical folds appear on them; in the case of a sample, the greater the DC becomes.

Prediction of drape coefficient

To validate the experimental results and the equation 5, we added other fabrics for DC prediction. Three other control fabrics - twill (F4), polyester (F5) and canvas (F6) - were selected from the Style3D library. The DC was measured in the virtual environment using Eq. 1 and the fabrics were predicted using Eq. 5 and the respective values were given and the test results are shown in Table 6.

Table 6. Fabric properties and DC of three additional woven fabrics

NO.	Materials	Angle	Width	DC	
				virtual measurement by Eq.1	Virtual prediction by Eq.5
F4	twill	20	30	0.50	0.47
F5	polyester	20	34	0.60	0.61
F6	cotton	28	34	0.54	0.52

According to Table 9, the samples were made with different angles and widths to test equation (8) and the results obtained were more satisfactory. DC measured by new method and DC predicted for all three tissues are within ±5%.

Table 7 shows the results of statistical verification of measured and predicted values using the method of comparing two averages.

Table 7. Difference between virtual measurement and Virtual prediction DC for additional woven fabrics.

DC	Average	Standard Deviation	*t-Student*	*p*
measured	0.5467	0.0507	0.268	0.799
predicted	0.5333	0.0701		

Table 7 shows the results of the *t*-test for control samples. *t* is 0.268 at a 95% confidence level? so there is no significant difference between the mean of measured DC values and the mean of predicted DC values. The *p*-value 0.799 is significantly higher than the commonly used significance level of 0.05. Therefore, is it possible to say that there is no difference between measured and predicted DC.

CONCLUSION

1. It is shown that the new scheme of the calculating of drape coefficient is allow to investigate the influence of direction of fabric cutting, presenting of thread

seams, samples design contours (width and angle) due to it approaches to real conditions of designing and shaping of clothes putting on a human body.

2. It is established that the rational parameters of the sample are:the angle which imitating the shoulder cut is 20°; cutting direction - along the weft; the pieces must be joined with an overlaid seam with open cuts.
3. Using correlation analysis, it was found that the design parameters of the sample have a stronger influence on the DC than the physical and mechanical property of textile fabrics.
4. A two-factor regression equation for predicting DC, which adequately allows to calculate of the drape coefficient with an error of ±5%, is obtained.
5. This paper presents a new method for predicting the properties of textile fabrics in virtual clothing, aiming to deepen the understanding of how these parameters affect the appearance of clothing, the results of which will help balance virtual and real clothing testing. The method and algorithm can better predict and create contoured realistic shapes for "avatar + garment" systems in virtual environments, bridging the gap between digital twins and their material prototypes.

Limitations and future research within one month.

One of the limitations of the study was to obtain physical and mechanical properties of real fabrics. Therefore, more research needs to be done using more fabrics of different purposes. Over the next month, measurements of drape coefficient will be made using real samples, and real test benches will be set up using 3D printing technology. Comparisons will be made with traditional drape testing methods; protocols will be developed for real samples to standardise measurement steps and reduce errors. Validation of the results with fabrication of real dresses will be performed.

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