Fashion and Textiles

RESEARCH Open Access

Multidimensional analysis for fabric drapability

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Abstract

This study analyzed fabric drapability in one, two, and three dimensions to provide an assessment method reflecting real conditions. One-dimensional analysis of drapability involved observing the fabric movement by reciprocating motion. The movement appeared differently depending on the fabric characteristics, and the shape and location of the node showed differently, which were considered to be influenced by the weight of the sample along with the drape coefficient. Two-dimensional analysis identified the significant factors for the drape information. This examination confirmed that, even if drape factors were similar, differences in draped shape were observed based on the factors related to node shapes. Three-dimensional analysis, using a 3D scanner, involved the use of the mean distances between draped samples and the standard truncated cone, their standard deviation, and the coefficient of variation. The coefficient of variation was high in the groups wherein the shape of the drape was irregular. In the 3D analysis, the distances between samples and the standard truncated cone were expressed in colors to intuitively deliver the drape information. To determine a factor that could indicate drapability among the factors derived from each dimension, the existing drape coefficient was employed for correlation analysis. Three pairs of samples with similar drape coefficients but different drape shapes were selected to verify the above results. In conclusion, one-dimensional node location, two-dimensional standard deviation of node severity, and three-dimensional coefficient of variation were shown to effectively demonstrate the drape characteristic that the drape coefficient could not indicate.

Keywords: Fabric drapability, Multidimensional analysis, Drape coefficient, Drape shape, Node

Introduction

Fabric drapability is a three-dimensional shape by its self-weight—an important factor that decides the appearance of the garment, along with the color, luster, and texture (Sanad et al., 2013). The fiber composition, yarn type, fabric structure, and finishing type of a textile determine its drapability (Abdin et al., 2013; Glombikova & Zdenek, 2014; Loien & Jeysnik, 2007). The drape coefficient (DC), which is calculated using the draped area, is generally used to evaluate a fabric drapability. However, the same drape coefficient between two fabrics may produce different drape shapes; this is because the measurement is only based on fabric's projected area. To correctly quantify drapability, it is desirable to propose a parameter that implies drape shape along with drape area. One solution is using the number and shape of nodes (Chu et al., 1950, 1960; Jeong, 1998; Kalaoglu et al., 2018; Mah & Song, 2010; Robson & Long, 2000). Kim (2011) suggested a method to express the drape shape using the angle and radius in the outline. Along these studies, Ghith et al. and's (2015) study on dynamic drapability was able to predict fabric drapability using an artificial neural network (Ghith et al., 2015).

It is difficult to distinguish the internal shape because the drape coefficient only uses the shape determined by outlines. To overcome such difficulties, a 3D scanner can be used to examine the internal angles, which are formed as the fabric is draped; this technique provides additional three-dimensional drape information (Kenkare et al., 2008; Kim et al., 2020; Pandurangan et al., 2008; Rudolf et al., 2016; Stylios & Wan, 1999; Yang et al., 2021). The frequency, angle, depth, and extended outline of the sample can be measured automatically and analyzed in 3D. Studies have also attempted to obtain several cross-sections according to the total length of the textile for a three-dimension analysis (Al-Gaadi et al., 2012; Carrera-Gallissà et al., 2017; Glombikova & Zdenek, 2014; Mah & Song, 2010). However, compared with existing methods of drapability measurement, there remain efficiency concerns regarding three-dimension drapability measurement using a 3D scanner. The popularity of fashion technologies that employ 3D necessitates to develop an innovative method for measuring drapability to realistically illustrate actual fabric in a three-dimensional garment simulator. By extension, it is also required for an evaluation method that reflects actual drapability when the garment is worn (Capdevila & Carrera-Gallissà, 2016; Hussain, 2020).

This study examines the drape characteristics of fabrics by subdividing them into 1D, 2D, and 3D to obtain drape shape information and improve the accurate measurement of fabrics of various characteristics. After conducting a correlation analysis that employs every dimensional factor used to evaluate drapability, the factors were compared with existing drape coefficients.

Methods

Materials

710 samples widely used in the market were collected with the assistance of the Korea Textile Trade Association, and their average drape coefficient (%) was 33.15, with a minimum value of 3.64 and a maximum value of 95.31 (Kim et al., 2021; Kime et al., 2020). To use fabrics having various drape characteristics, these samples are classified into 10 groups according to their rank of drape coefficient; two samples per group, 20 samples in total, are chosen for multidimensional analysis. Then, three pairs of samples with similar drape coefficients and different drape shapes are chosen for verification. Table 1 reports the characteristics of the 26 samples.

One-dimensional measurement of drapability using reciprocating motion

As shown in Fig. 1, we tried to analyze one-dimensional fabric drapability by tracking the movement of the side of a hanging fabric. Since the fabric thickness (hundreds of

Table 1 Physical characteristics of fabric samples

Group	Sample	Fabric constructure	Drape coefficient (%)	Weight (g/m^2)	Thickness (mm)
D1	a	Knit	7.66	157	0.37
	b	Knit	8.51	160	0.38
D2	a	Woven	11.68	122	0.23
	b	Knit	11.62	143	0.51
D3	a	Woven	16.77	168	0.39
	b	Knit	14.93	251	0.43
D4	a	Woven	17.86	238	0.61
	b	Woven	18.94	268	0.81
D5	a	Woven	28.16	191	0.52
	b	Woven	29.18	81	0.17
D6	a	Woven	32.05	162	0.28
	b	Woven	30.20	292	0.64
D7	a	Woven	47.56	165	0.26
	b	Woven	41.10	85	0.10
D8	a	Woven	49.96	104	0.19
	b	Woven	51.43	335	0.62
D9	a	Woven	60.15	132	0.20
	b	Woven	68.31	193	0.28
D10	a	Woven	91.55	334	0.48
	b	Woven	74.29	241	0.42
R6	a	Woven	37.78	289	0.70
	b	Woven	37.64	68	0.12
R7	a	Woven	43.58	125	0.22
	b	Woven	44.04	55	0.13
R8	a	Woven	55.30	199	0.36
	b	Woven	55.46	39	0.05

micrometers) is very small value compared to the fabric length (90 cm), it is expressed as one-dimension. One-dimension drapability is examined by reciprocating a 90 cm $\times$ 15 cm sample at 180 rpm using a device equipped with a reciprocating motion system. Reciprocating motion is chosen considering the walking situation of a person wearing pants or skirts. Considering the average walking speed (70.64 m/min) and stride length (76.2 cm) (Kilic et al., 2021), the force by walking is about 1.3 times stronger than that by the reciprocating motion in this study.

A digital camera (Canon EOS M100, Canon, Japan) is used to record the movement of the samples for five seconds; in total, 250 frames are analyzed. The movements of the samples in the video are tracked using TEMA Motion-Outline Tracker (Image Systems Co., Ltd., Sweden). To quantify the movement, the center of the hanger is set as the origin, and an XY coordinate system is created using two points that can reflect actual distance. The outlines of 250 frames are accumulated for analysis of fabric drapability. The number and location of nodes are examined using the XY coordinate system. As shown in Fig. 1, the node in 1D refers to the joint created from the movement of the sample, and node location is measured from the top of the sample. When several nodes are created, the node location is measured using the node at the very top.

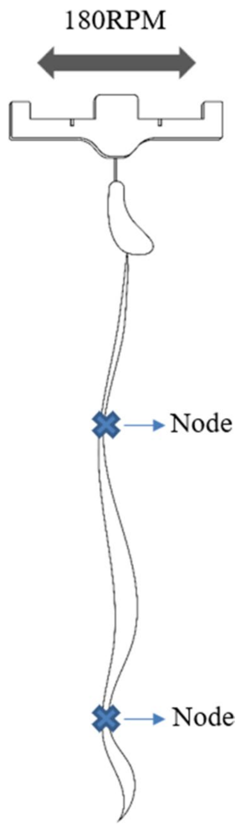


Fig. 1 A schematic diagram of a device for reciprocating motion of a sample

Two-dimensional measurement of drapability by drape coefficient and drape shape factors

Using a Cusick Drapemeter (Han Won Soway Testing, Korea), draped area and shape are observed by placing samples that are 30 cm in diameter on a round plate that is 18 cm in diameter (Cusick, 1968; International Organization for Standardization, 2008; Shin et al., 2021). The distance between a sample and the camera is set to 80 cm for taking draped images. After obtaining the area according to the draped outlines by Image J, the drape coefficient is calculated using Eq. (1):

$$\text{Drape coefficient }(\%) = [(A - S_1)/(S_2 - S_1)] \times 100 \quad (1)$$

where A is the draped area by the fabric (cm^2), S_1 is the area of the supporting disk (cm^2), and S_2 is the area of the fabric (cm^2).

Along with drape coefficient, the circularity of the draped sample (CIRC), node number (NN), standard deviation of peak angles (SDPA), node severity (NS), mean node severity (MNS), and standard deviation of node severity (SDNS) are considered as factors that indicate drape shape information. They are calculated following Eqs. (2–8) (Buyukaslan et al., 2018). Node in 2D refers to the part that is folded, and it was determined when the difference between a fold peak and a neighboring valley fold was greater than 2 mm. Peak angle refers to the angle between neighboring nodes (Buyukaslan et al., 2018).

$$CIRC = \frac{4\pi A}{P^2} \tag{2}$$

$$SDPA = \sqrt{\frac{1}{n}\left[\left(\propto_1 - \frac{360}{n}\right)^2 + \left(\propto_1 - \frac{360}{n}\right)^2 + \cdots + \left(\propto_n - \frac{360}{n}\right)^2\right]} \tag{3}$$

$$NH_i = \frac{\ell_{peak,i} + \ell_{trough,i}}{2} \tag{4}$$

$$NW_i = \frac{P \times \frac{\alpha_{peak,i} - \alpha_{trough,i}}{2}}{360} \tag{5}$$

$$NS_i = \frac{NH_i}{NW_i} \tag{6}$$

$$MNS = \frac{NS_1 + NS_2 + \cdots + NS_n}{n} \tag{7}$$

$$SDNS = \sqrt{\frac{1}{n}\left[(MNS - NS_1)^2 + (MNS - NS_2)^2 + \cdots + (MNS - NS_n)^2\right]} \tag{8}$$

In the above equations, P is the perimeter of the draped sample, A is the area of the draped sample, α is the angle between neighboring peaks, $\updownarrow_{peak,i}$ is the distance (in cm) of the i^{th} fold to the center, and $\updownarrow_{trough,i}$ is the distance (in cm) of the i^{th} trough to the center (Buyukaslan et al., 2018).

Three-dimensional measurement of drapability using 3D scanner

For the three-dimensional measurement, a draped fabric is scanned using a 3D scanner (Thor3D, Russia) after a sample, 30 cm in diameter, is placed on a round plate that is 18 cm in diameter (see Fig. 2). For accurate scanning, a rotatable pedestal is placed below the round plate. Markers are attached for recognition of the flat surface before scanning. The scanned files are converted into three-dimensional image files using Calibry Nest (Thor3D, Russia). The scanned drape shape is converted into an STL file. The standard truncated cone is obtained from the average of 30 datasets from each

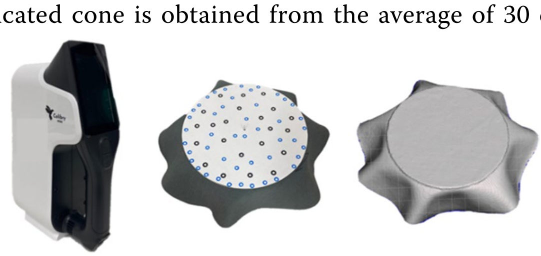


Fig. 2. 3D Scanner, a draped sample, and its scanned image

drape group (i.e., D1 to D10). The 30 datasets here include 20 samples used for drapability analysis. Then, the three-dimensional drapability is examined using the average of the distance from the standard truncated cone to the draped sample, standard deviation, and coefficient of variation. The distances to the standard truncated cone were measured at more than 40,000 locations to examine the drape characteristics at all locations of the fabric.

Correlation analysis and verification of multidimensional drape factors

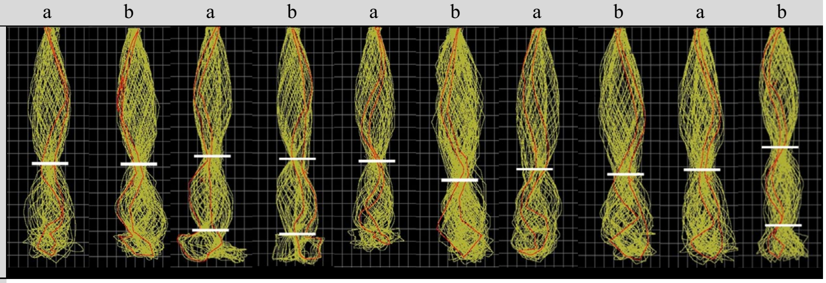
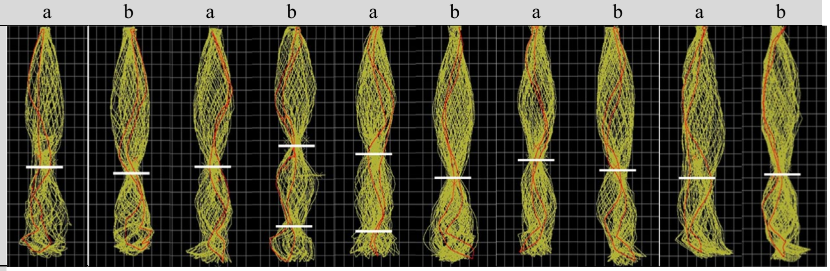
IBM SPSS Statistics are used to check the correlation of multidimensional drape factors. To verify the usefulness of the multidimensional drape factors, three pairs of samples with similar drape coefficients and different drape shapes are chosen and then examined through multidimensional measurement methods to confirm if they can overcome the drawbacks of the conventional drape coefficient.

Results and Discussion

One-dimensional analysis of fabric drapability

Table 2 shows the one-dimensional drapability results of a total of 20 samples, each figure exhibits the accumulation of motions in 250 frames for 5 s. Because two samples in

Table 2 One-dimensional drapability by reciprocating motion

Group	D1		D2		D3		D4		D5	
Sample	a	b	a	b	a	b	a	b	a	b
Image										
Number of node	1	1	2	2	1	1	1	1	1	2
Node location (cm)	52.71	53.74	50.30 77.84	50.50 80.79	51.30	58.14	53.48	57.59	52.27	46.88 77.12
Group	D6		D7		D8		D9		D10	
Sample	a	b	a	b	a	b	a	b	a	b
Image										
Number of node	1	1	1	2	2	1	1	1	1	1
Node location (cm)	52.20	57.35	52.01	45.27 75.48	48.35 76.01	56.34	51.83	56.13	58.75	57.74

D2 group have low drape coefficients and are comparatively lightweight, they have two nodes. D5b is thin and light (81 g/m^2), so its movement is active, resulting in the formation of two nodes with a high location of the first node. However, D3b and D4b exhibit low locations of the node owing to their heavy weight (251 and 268 g/m^2). D7b and D8a have two nodes owing to their light weight, although they have a drape coefficient of 41.10 and 49.96, respectively, indicating that they are relatively stiff samples.

One-dimensional drapability shows that fabrics that are lightweight and have small drape coefficients deliver reciprocating motion well, resulting in the elevation of node location, which consequently increases the number of nodes to two. However, this result does not align with the existing measurement of the drape coefficient, that is, the movement analysis through reciprocating motion could supplement the drape information that the drape coefficient could not express.

Two-dimensional analysis of fabric drapability

Figure 3 shows the drape shapes of all samples and Table 3 shows the factors that can indicate drape shape along with drape coefficient (Buyukaslan et al., 2018; Lojen & Jevsnik, 2007). CIRC is small in drapery samples such as D1 and shows a larger value close to 1 in stiff samples like D10. NN tends to be more in drapery samples, and D1 shows the largest node number, at 13 and 11 nodes. Regarding SDPA, D7b shows the highest value owing to its small NN, and the coexistence of large and small nodes.

MNS is small in D8–D10, and among them, D10a is the smallest, at 0.12. The samples in the D8–D10 groups hardly fold, have a long node width, and consequently have small

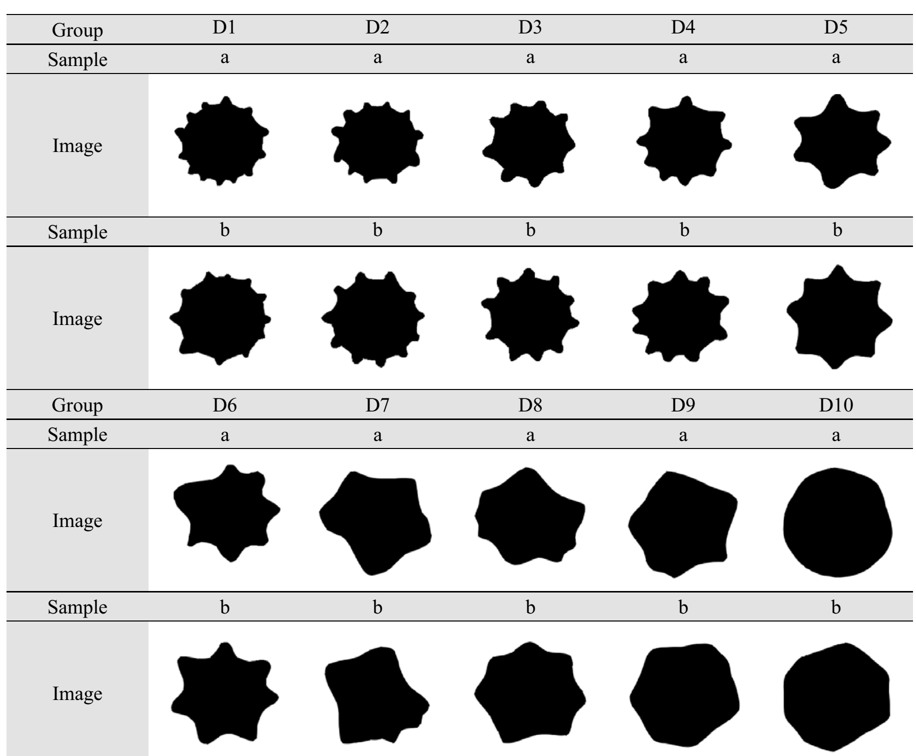


Fig. 3 Two-dimensional drape shape

Table 3 Two-dimensional analysis for fabric drapability with drape shape factors

Group	D1		D2		D3		D4		D5	
Sample	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
P	764	737	787	778	796	811	818	814	862	852
A	29179	29174	30692	30747	31530	31509	32878	32865	38245	39621
CIRC	0.63	0.67	0.62	0.64	0.63	0.60	0.62	0.62	0.65	0.69
NN	13	11	11	11	9	10	9	10	7	8
SDPA	5.63	6.76	5.45	3.36	3.56	4.14	7.50	7.36	6.84	3.68
MNS	0.52	0.46	0.52	0.48	0.58	0.56	0.46	0.45	0.49	0.46
SDNS	0.055	0.090	0.066	0.071	0.098	0.053	0.047	0.047	0.033	0.037
Group	**D6**		**D7**		**D8**		**D9**		**D10**	
Sample	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
P	859	857	847	849	863	854	860	872	915	881
A	40730	37406	46477	43716	48685	49083	50847	56897	65907	58839
CIRC	0.69	0.64	0.81	0.76	0.82	0.85	0.86	0.94	0.99	0.95
NN	7	7	5	6	8	7	6	7	8	8
SDPA	11.62	10.57	11.32	25.16	18.48	10.16	17.01	15.12	18.41	15.25
MNS	0.46	0.51	0.41	0.39	0.30	0.33	0.32	0.21	0.12	0.18
SDNS	0.049	0.034	0.056	0.100	0.074	0.036	0.077	0.061	0.027	0.055

All abbreviations in the table can be found in the 'List of Abbreviations'

NS. Regarding SDNS, D10a is the smallest at 0.027, because it has the most uniform ratio of nodes when it is draped, with the smallest MNS mentioned above. D7b shows the largest SDNS of 0.100, which may be owed to the effect of non-uniform nodes. These drape shape factors may be used to deliver and analyze the drape shape information in more detail.

Three-dimensional analysis of fabric drapability

Based on the standard truncated cone created by the drape shape dataset of 30 samples, the distances of the 20 samples to the standard truncated cone are analyzed by color. Figure 4 reports the results thereof. The scale bar on the right side of Fig. 4 indicates the color extent according to the distance, and it has different size scales for each sample. As the distance from the standard truncated cone increases, the colors change to red and pink, and as the distance decreases, the color changes to green.

Table 4 shows the mean distance from the standard truncated cone, standard deviation, and coefficient of variation. D1a had the largest negative value of mean distance, at − 13.27, meaning that its drape shape is deep in the standard truncated cone. As the number of groups increases, the distance from the truncated cone decreases, yielding the positive mean distance from D7. D10a has almost no folding, so drape shape forms outside the standard truncated cone. It has the largest positive value of mean distance, at 13.57. The standard deviation of the distance from the standard truncated cone is relatively small in D6–D8. This is because they have the most similar position with respect to the standard truncated cone. However, it increases when close to both ends of D1 and D10. Note that the size of the mean can affect the standard deviation. In other words, fabrics in D1 and D10 have large standard deviations

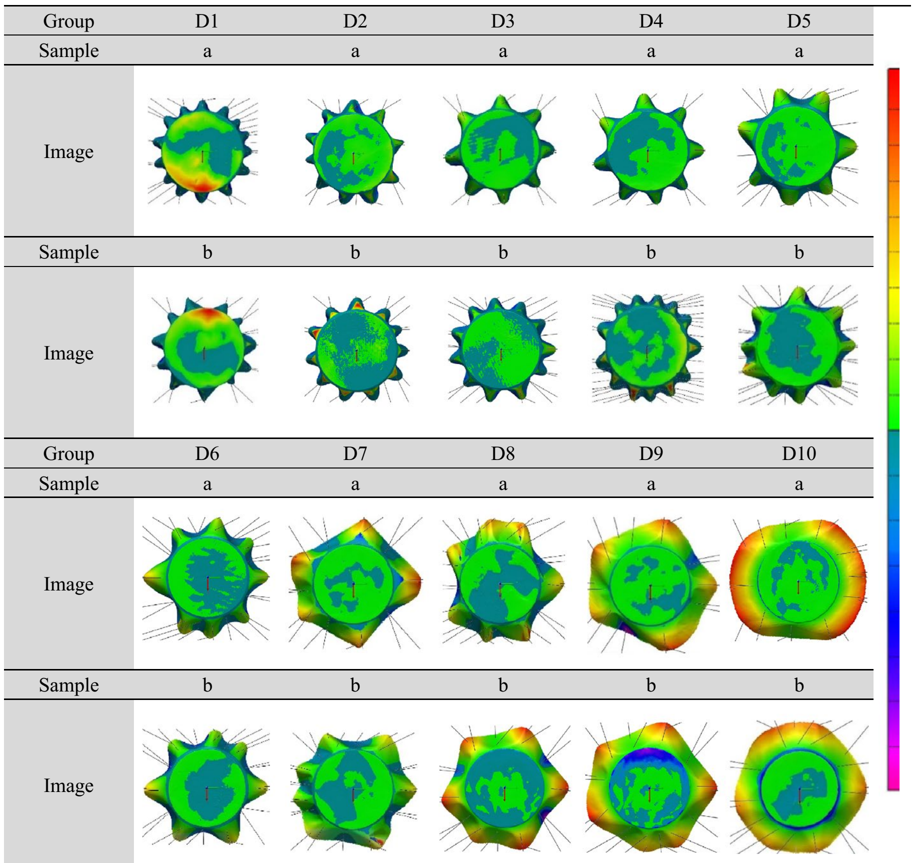


Fig. 4 Three-dimensional drapability with the distance from the standard truncated cone in color

Table 4 Three-dimensional analysis for drape shape

Group	D1		D2		D3		D4		D5	
Sample	a	b	a	b	a	b	a	b	a	b
Mean distance (cm)	− 13.27	− 9.61	− 11.58	− 9.27	− 10.45	− 9.65	− 9.83	− 8.33	− 5.53	− 2.48
SD	16.24	13.19	16.37	13.26	16.40	12.62	15.06	12.84	12.73	10.01
CV	1.22	1.37	1.41	1.43	1.57	1.31	1.53	1.54	2.30	4.04
Group	**D6**		**D7**		**D8**		**D9**		**D10**	
Sample	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Mean distance (cm)	− 2.28	− 1.51	4.23	2.86	2.67	6.48	6.07	9.48	13.57	9.29
SD	10.78	8.82	9.60	8.71	10.22	8.80	12.19	10.19	14.66	12.25
CV	4.73	5.85	2.27	3.04	3.83	1.36	2.01	1.07	1.08	1.32

owing to the larger values of their distance from the standard truncated cone. Thus, after dividing the standard deviation by the mean distance, its absolute value (coefficient of variation, or CV) is used. Regarding CV, D5–D7 have the highest value, likely because of the uneven shape of the draped node. However, CV decreases in both ends of D1 and D10 because the node shapes in the fabric are similar. As discussed earlier, the three-dimensional factors (mean distance, standard deviation, and CV) could represent different information from the drape coefficient, allowing one to distinguish fabrics that have similar drape areas but different drape shapes.

Correlation analysis between multidimensional factors

To develop a more precise method for drapability evaluation, the correlation between drape coefficient and the outcome of multidimensional analysis is examined. Table 5 shows the results.

Node location, a one-dimensional factor, is weakly correlated with drape coefficient, possibly because the actual clothing size is reflected upon 1D-measurement, unlike the circular fabric used to measure the drape coefficient. Note that the node location is employed to represent dynamic drapability.

The drape coefficient is highly correlated with CIRC, NN, SDPA, and MNS in the two-dimensional drape factors. Especially, the drape coefficient and CIRC are highly correlated, showing a value of 0.960, while MNS shows a high negative correlation of − 0.933, indicating that such factors yield drape information that is similar to the drape coefficient. Only SDNS reveals a weak correlation with the drape coefficient in the two-dimensional factors. SDNS is considered the most suitable factor to deliver drape shape information because it can exhibit the deviation of the ratio of nodes.

In the three-dimensional results, the mean distance is highly correlated, showing a value of 0.975, while SD and CV have no significant correlation at a significance value of 0.01. Thus, in the middle groups, such as D6–D8, which are not usually discriminated by drape coefficient, the fabric drapability could be well discriminated using SD and CV.

These results necessitate verification of whether the drape information that cannot be expressed by the drape coefficient can be delivered by the factors that are weakly correlated with the drape coefficient.

Verification of correlation analysis results of each dimensional factor

To verify the results of the correlation analysis of each dimensional factor, samples with similar drape coefficients (difference of less than 1.00%p) and different drape shapes are chosen. The closer to the D1 group, which has drapery feature, the large the number of narrow nodes created, showing similar drape shapes. As D9 and D10 have fewer folds and draped almost to a circular form, their drape shapes reveal no differences. However, from D6 to D8, some samples have different drape shapes but similar drape coefficients; three pairs of samples are chosen from these groups, namely, R6, R7, and R8, and their drape coefficients and shapes are shown in Table 6.

Table 7 shows the results of the one-dimensional analysis. The samples from the same group exhibit different aspects. There exists a difference between samples within the same group in the number of nodes excluded from the correlation analysis, as all their values are 1 or 2. The node location having a weak correlation with the drape coefficient

Table 5 Correlation coefficients between one, two, and three-dimensional factors

Var			1	2	3	4	5	6	7	8	9	10
1	1D	Node location	1									
2	2D	DC	0.274	1								
3		CIRC	0.225	0.960**	1							
4		NN	0.040	− 0.655**	− 0.544*	1						
5		SDPA	− 0.089	0.750**	0.730**	− 0.564**	1					
6		MNS	− 0.279	− 0.933**	− 0.960**	0.425	− 0.723**	1				
7		SDNS	− 0.515*	− 0.239	− 0.092	0.172	0.172	0.168	1			
8	3D	Mean	0.205	0.975**	0.950**	− 0.730**	0.774**	− 0.901**	− 0.206	1		
9		SD	0.105	− 0.378	− 0.347	0.699**	− 0.472*	0.273	0.129	− 0.555*	1	
10		CV	− 0.128	0.540*	0.661**	− 0.258	0.652**	− 0.617**	0.372	0.546*	− 0.157	1

Significance level: **0.01

* 0.05

All abbreviations in the table can be found in the 'List of Abbreviations'

Table 6 Samples with similar drape coefficient (DC) and different drape shape

Group	R6		R7		R8	
Sample	a	b	a	b	a	b
DC	37.78	37.64	43.58	44.04	55.30	55.46
Image						

Table 7 One-dimensional verification with reciprocating motion

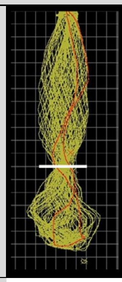
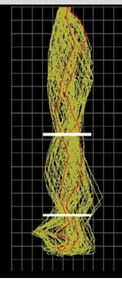
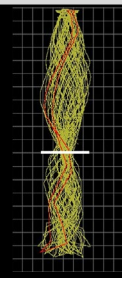
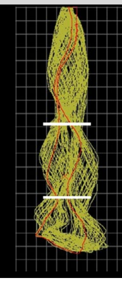
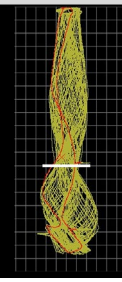
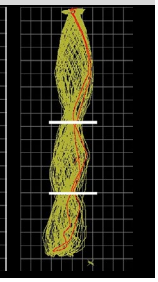
Group	R6		R7		R8	
Sample	a	b	a	b	a	b
Image						
Number of node	1	2	1	2	1	2
Node location (cm)	59.56	45.87 78.39	51.96	43.46 70.51	58.35	41.32 71.62

Table 8 Two-dimensional drape characteristics of samples with different drape shape

Group	**R6**		**R7**		**R8**	
Sample	**a**	**b**	**a**	**b**	**a**	**b**
P	863	831	858	842	857	854
A	43957	40599	46489	45709	49346	49787
CIRC	0.74	0.74	0.79	0.81	0.84	0.86
NN	7	4	7	5	7	8
SDPA	11.53	4.99	15.16	9.11	23.53	19.23
MNS	0.41	0.57	0.37	0.43	0.24	0.26
SDNS	0.051	0.031	0.069	0.049	0.065	0.071

All abbreviations in the table can be found in the 'List of Abbreviations'

also reveals a clear difference between samples in the same group. In the one-dimensional analysis using the reciprocating motion, factors such as weight, along with the drape coefficient, affect the movement of fabrics. This result was interpreted to mean that such drape information is not expressed by the drape coefficient. Combined with the results in Table 2, it is possible to conclude that the node location has a discriminative ability for samples with different drape shapes, even if the drape coefficients are similar.

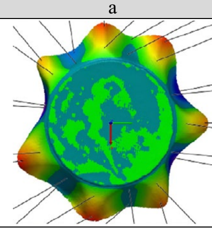
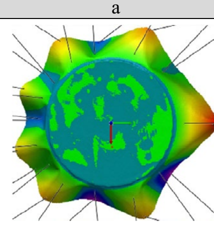
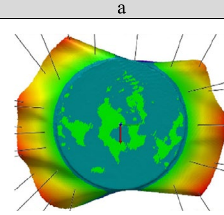
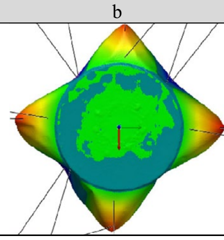
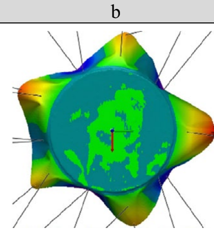
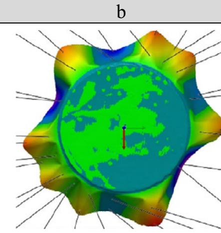
Table 8 shows the two-dimensional results. The samples in R6 and R7 have a similar drape coefficient and circularity, but R6b and R7b have fewer node numbers than R6a and R7a, respectively. Hence, their node intervals are uniform, exhibiting a small SDPA. R6b and R7b have a larger and more uniform NS than R6a and R7a, indicating a large MNS and a small SDNS. Between the two samples in R8, R8a has a larger SDPA, at 23.53, indicating irregular node intervals. This irregularity is thought to be affected by relatively non-uniform folds owing to its stiffness. Thus, the two-dimensional analysis confirms that the node in the drape shape is an important factor that explains the drape characteristics and that the information that the drape coefficient cannot express can be explained using the factors related to nodes.

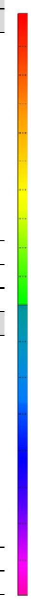
Table 9 shows the results for surface color image and analysis results for three-dimensional drape shapes. Not only the coefficient of variation and standard deviation, which show weak correlation with drape coefficient, but also the mean distance also shows differences in drape shapes in the samples from the same group. Although the mean distance is highly correlated with the drape coefficient, that the in-sample differences could be distinguished using the mean distance is attributed to the different NN and shape in the two samples. Considering these results, the three variables derived from three-dimension analysis are considered suitable for explaining the drape shape that the conventional drape coefficient could not express.

Conclusions

Drapability is one of the most significant factors that express the characteristics of a garment. However, the drape coefficient, which is conventionally used for its measurement, is only based on the draped area, thus distorting real fabric drape. This limitation warrants the search for a better evaluation method to reflect drapability that is closer

Table 9 Surface color images of three-dimensional drape shape and their analysis results

Group	R6	R7	R8
Sample	a	a	a
Image			
Mean distance (cm)	2.02	4.31	4.29
SD	7.71	8.16	13.09
CV	3.83	1.89	3.05
Sample	b	b	b
Image			
Mean distance (cm)	2.48	0.88	2.27
SD	11.59	10.32	8.26
CV	4.67	11.79	3.64



to the real garment. In this study, by categorizing and analyzing fabric drape in multi-dimensions, evaluation methods were reviewed to convey information that the existing drape coefficient cannot cover. In the one-dimensional analysis, fabric movement was examined based on reciprocating motion, which replicated real walking conditions. The resulting one-dimensional drapability showed different tendencies from the drape coefficient, which was confirmed through the NN and location. The one-dimensional drapability was affected by how the force generated at the top was transmitted to the bottom of the fabric, which is thought to be affected by the weight of the sample along with its drape coefficient. The two-dimensional analysis incorporated the drape shape along with the conventional area. To deliver the exact drape information, nodes by folding as well as the draped area were employed as critical factors. The nodes were presented by NN, SDPA, MNS, and SDNS. The three-dimensional analysis was performed using a 3D scanner. The surface color image according to the distance of the draped shape, mean distance, standard deviation, and CV were devised to explain the drape feature. Among them, SD and CV were found to suitably represent fabric drapability in 3D. A correlation analysis of the multidimensional drape factors derived in this study and the drape coefficient revealed that the one-dimensional node location could reveal drape information different from the conventional drape coefficient. In the two-dimensional analysis using the node shape, SDNS had the lowest correlation with the drape coefficient. Further, the three-dimensional drapability was successfully expressed through the SD and CV of the distance from the standard truncated cone. Then, three pairs of samples with similar drape coefficients but different drape shapes were selected to verify that the information that the drape coefficient could not express could be expressed discriminatively using the multidimensional drape factors. In conclusion, by categorizing drapability in 1D, 2D, and 3D, the study meaningfully reviewed a new measurement method that can complement established methods. However, this is a fundamental study on multidimensional drapability; a more precise verification based on more samples and conditions is the next step.

Abbreviations

CIRC	Circularity of the draped sample
DC	Drape coefficient
MNS	Mean node severity
NH	Node height
NN	Node number
NS	Node severity
NW	Node width
SDNS	Standard deviation of node severity
SDPA	Standard deviation of peak angles

Acknowledgements
Not applicable.

Authors' contributions
BS conceived the ideas, experimental design, performed the experiments, collected the data, interpretation of the results, and drafted the manuscript of the analysis. CY supervised on the experimental design, experimental results, and manuscript preparation. All authors read and approved the final manuscript.

Funding
This paper was conducted with the support of the Industrial Technology Innovation Infrastructure Project of Korea Institute for Advancement of Technology in 2022 (No. P0014711).

Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent and participate
Not applicable.

Competing interests
The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Received: 1 March 2023 Accepted: 9 July 2023
Published online: 05 September 2023

References

Abdin, Y., Taha, I., El-Sabbagh, A., & Ebeid, S. (2013). Description of draping behaviour of woven fabrics over single curvatures by image processing and simulation techniques. *Composites Part B: Engineering, 45*(1), 792–799. https://doi.org/10.1016/j.compositesb.2012.06.004
Al-Gaadi, B., Goktepe, F., & Halasz, M. (2012). A new method in fabric drape measurement and analysis of the drape formation process. *Textile Research Journal, 82*(5), 502–512. https://doi.org/10.1177/0040517511420760
Buyukaslan, E., Jevsnik, S., & Kalaoglu, F. (2018). Comparative analysis of drape characteristics of actually and virtually draped fabrics. *International Journal of Clothing Science and Technology, 30*(3), 286–301. https://doi.org/10.1108/IJCST-06-2017-0085
Capdevila, X., & Carrera-Gallissà, E. (2016). Application of discriminant analysis to parameters describing the drape for two types of woven fabrics. *The Journal of the Textile Institute, 107*(6), 784–790. https://doi.org/10.1080/00405000.2015.1061784
Carrera-Gallissà, E., Capdevila, X., & Valldeperas, J. (2017). Evaluating drape shape in woven fabrics. *The Journal of the Textile Institute, 108*(3), 325–336. https://doi.org/10.1080/00405000.2016.1166804
Chu, C. C., Cummings, C. L., & Teixeira, N. A. (1950). Mechanics of elastic performance of textile materials: part V: a study of the factors affecting the drape of fabrics—the development of a drape meter. *Textile Research Journal, 20*(8), 539–548. https://doi.org/10.1177/004051755002000802
Chu, C. C., Platt, M. M., & Hamburger, W. J. (1960). Investigation of the factors affecting the drapeability of fabrics. *Textile Research Journal, 30*(1), 66–67. https://doi.org/10.1177/004051756003000109
Cusick, G. E. (1968). 21-The measurement of fabric drape. *The Journal of the Textile Institute, 59*(6), 253–260. https://doi.org/10.1080/00405006808659985
Ghith, A., Hamdi, T., & Fayala, F. (2015). Prediction of drape coefficient by artificial neural network. *Autex Research Journal, 15*(4), 266–274. https://doi.org/10.1515/aut-2015-0045
Glombikova, V., & Zdenek, K. U. S. (2014). Drape evaluation by the 3D drape scanner. *Textile and Apparel, 24*(3), 279–285.
Hussain, A., Zhong, Y., Naveed, T., Yu, Z., Xi, Z., & Ge, W. (2020). A new approach to evaluate fabric hand based on three-dimensional drape model. *Autex Research Journal, 20*(2), 155–167. https://doi.org/10.2478/aut-2019-0011
International Organization for Standardization. (2008). ISO 9073–9:2008 Textiles - Test methods for nonwovens - Part 9: Determination of drapability including drape coefficient. Retrieved from https://www.iso.org/standard/41375.html
Jeong, Y. J. (1998). A study of fabric-drape behaviour with image analysis part i: measurement, characterization, and instability. *The Journal of the Textile Institute, 89*(1), 59–69. https://doi.org/10.1080/00405009808658597
Kalaoglu, F., Buyukaslan, E., & Jevsnik, S. J. (2018). Psychophysical testing of virtual fabric drape. *Journal of Fashion Technology & Textile Engineering,* (S4), Article S4-017. https://doi.org/10.4172/2329-9568.S4-017
Kenkare, N., Lamar, T. A., Pandurangan, P., & Eischen, J. (2008). Enhancing accuracy of drape simulation part i: investigation of drape variability via 3D scanning. *The Journal of the Textile Institute, 99*(3), 211–218. https://doi.org/10.1080/00405000701489222
Kilic, G. B., Demir, M., & Kilic, M. (2021). Dynamic drape behaviours of wool woven suiting fabrics considering real-time use. *International Journal of Clothing Science and Technology*. https://doi.org/10.1108/IJCST-11-2020-0173
Kim, H. J., Youn, S., Choi, J., Kim, H., Shim, M., & Yun, C. (2021). Indexing surface smoothness and fiber softness by sound frequency analysis for textile clustering and classification. *Textile Research Journal, 91*(1–2), 200–218. https://doi.org/10.1177/0040517520935211
Kim, J., Kim, Y. J., Shim, M., Jun, Y., & Yun, C. (2020). Prediction and categorization of fabric drapability for 3D garment virtualization. *International Journal of Clothing Science and Technology, 32*(4), 523–535. https://doi.org/10.1108/IJCST-08-2019-0126
Kim, S. (2011). Determination of fabric physical properties for the simulation of Cusick drapemeter. *Fibers and Polymers, 12*(1), 132–136. https://doi.org/10.1007/s12221-011-0132-2
Lojen, D. Z., & Jevsnik, S. (2007). Some aspects of fabric drape. *Fibres and Textiles in Eastern Europe, 15*(4), 39–45.
Mah, T., & Song, G. (2010). An investigation of the assessment of fabric drape using three-dimensional body scanning. *The Journal of the Textile Institute, 101*(4), 324–335. https://doi.org/10.1080/00405000802417122
Pandurangan, P., Eischen, J., Kenkare, N., & Lamar, T. A. (2008). Enhancing accuracy of drape simulation. Part II: optimized drape simulation using industry-specific software. *The Journal of the Textile Institute, 99*(3), 219–226. https://doi.org/10.1080/00405000701489198
Robson, D., & Long, C. C. (2000). Drape analysis using imaging techniques. *Clothing and Textiles Research Journal, 18*(1), 1–8. https://doi.org/10.1177/0887302X0001800101
Rudolf, A., Zadravec, M., & Stjepanovič, Z. (2016). Investigations regarding the effects of simulating parameters during 3D garments' drape simulations. *Fibres & Textiles in Eastern Europe, 6*(120), 143–150. https://doi.org/10.5604/12303666.1221749

Sanad, R., Cassidy, T., Cheung, V., & Evans, E. (2013). Fabric and garment drape measurement—part 2. *Journal of Fiber Bioengineering and Informatics, 6*(1), 1–22. https://doi.org/10.3993/jfbi03201301
Shin, B., Yu, D., Lee, S., Youn, S., Shim, M., & Yun, C. (2021). Development of a simple drape measurement method for 3D virtualization. *Journal of the Korean Society of Clothing and Textiles, 45*(5), 881–891. https://doi.org/10.5850/JKSCT.2021.45.5.881
Stylios, G. K., & Wan, T. R. (1999). The concept of virtual measurement: 3D fabric drapeability. *International Journal of Clothing Science and Technology, 11*(1), 10–18. https://doi.org/10.1108/09556229910258070
Yang, L., Kim, K., & Takatera, M. (2021). Measurement of local shear deformation in fabric drape using three-dimensional scanning. *Textile Research Journal, 91*(7–8), 885–898. https://doi.org/10.1177/0040517520963347

Publisher's Note

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