Determination of used textiles drape characteristics for circular economy

DOI: 10.35530/IT.074.01.202241

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ABSTRACT – REZUMAT

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In the present work, the drape characteristics of second-hand textile fabrics were determined. The results can be used to implement the concepts of the circular economy. Automated software tools have been adapted and researched to apply the proposed methods and procedures for digital image analysis of used textile drape, which will be utilized to describe their shapes and predict their characteristics, as well as their classification into groups and assessment of classification accuracy in recognizing their elements. A radius-vector function was used to determine the main drape characteristics, such as the number of peaks, their size, and their location. Analytical models have been created for automated forecasting of the drape characteristics from used textiles, which can be applied to predict changes in these characteristics. It obtained an accuracy of 68–92% in the prediction of the main drape characteristics of used textiles. Due to changes in their main characteristics, the errors in classification and prediction increased by 10–15%. More complex computational procedures have been implemented to obtain a higher predictive power for second-hand textile fabrics. The results can be applied in the manufacture of new products such as curtains, tablecloths, napkins and fashion accessories.

Keywords: *used textile fabrics, drape coefficient, color digital images, regression analysis, fabric characteristics*

Determinarea caracteristicilor de drapaj ale textilelor uzate în contextul economiei circulare

În această lucrare, au fost determinate caracteristicile de drapaj ale țesăturilor second hand. Rezultatele pot fi folosite pentru implementarea conceptului în economia circulară. Au fost adaptate și cercetate instrumente software automatizate pentru a aplica metodele și procedurile propuse, în analiza digitală a imaginilor drapajelor textilelor uzate, care vor fi utilizate pentru a descrie formele și a preconiza caracteristicile acestora, precum și pentru clasificarea lor în grupuri și evaluarea acurateței clasificărilor în recunoașterea elementelor acestora. A fost utilizată funcția rază-vector pentru a determina principalele caracteristici de drapaj, cum ar fi numărul de falduri, dimensiunea și locația acestora. Au fost create modele analitice pentru prognoza automată a caracteristicilor de drapaj ale textilelor uzate, care pot fi aplicate pentru a preconiza modificările acestor caracteristici. S-a obținut o precizie de 68–92% din principalele caracteristici prevăzute inițial. Din cauza modificărilor acestor caracteristici, erorile de clasificare și predicție au crescut cu 10–15%. Au fost implementate proceduri de calcul mai complexe pentru a obține o putere de predicție mai mare pentru țesăturile second-hand. Rezultatele pot fi aplicate la fabricarea din textilele uzate a unor produse noi precum perdele, fețe de masă, șervețele și accesorii de modă.

Keywords: *deșeuri textile, coeficient de drapaj, imagini digitale color, analiza de regresie, caracteristicile țesăturii*

INTRODUCTION

In recent decades, there has been a worldwide interest in finding sustainable alternatives to the transition from a linear economy, based on a buy-use-throw model, to a circular economy. In the circular economy, a cycle takes place in which raw materials and materials considered waste are used for making new products, avoiding their storage or incineration. In this way, at the end of the product's life, the material is retained in the economy as many times as possible and can be reused, thus having an added value. Some authors have tried to define the circular economy. In 1990, McGregor [1] critically examined the traditional linear economic system and developed a new economic model. They use the term 'circular economy' to describe an economic system in which waste is transformed into raw materials at the extraction, production, and consumption stages. According to Kirchherr, Reike & Hekkert [2], the circular economy refers to three levels: material recovery, reuse, and recycling in the production, distribution, and consumption processes. In their article, Lieder & Rashid [3] emphasize the need for common support of all stakeholders for the successful implementation of the concept of a circular economy. They offer a framework for a circular economy as well as a workable plan for creating a regenerative economy and environment. The framework puts focus on a vision that combines three factors: resources, the environment, and economic rewards. In the circular economy, the implementation of the concepts of sustainability and competitiveness is encouraged. Johnston et al. [4]

estimate that about 300 definitions of sustainability will exist.

Few studies have been found in the available literature on the composition and properties of the used textile fabrics. For example, the second-hand clothes offered are sorted according to consumer demand and not in terms of the properties of textile materials and their reusability.

The drape of textile fabric is one of its main characteristics. It is related to its softness or hardness and it affects the way it falls, and folds, hence it plays a decisive role in the final shape of the fashion product. The standard test methods for drape analysis (such as the British Standard Institute BS5058/1974, called the Cusick Method) have some drawbacks. To make the measurements, paper disks are required, on which the silhouette of the drape is outlined. This procedure creates some errors arising from the meter's experience. The solution to this problem is the use of digital techniques for obtaining, processing, and analysing images. In addition to automating and refining the process of measuring the drape characteristics, the obtained digital images can be stored and organized in databases. The measurement of the drape characteristics using image-processing techniques is enshrined in the standard BS EN ISO 9073-9:2008. In addition to standardized methods, some other sources have been found in the available literature, which removes some limitations of standard methods.

In their papers, Sanad et al. [5, 6] conclude that the proposed automated methods for drape analysis have equivalent results, but in some cases, those results contradict each other. No uniform methods were proposed to determine the drape characteristics, which would ensure repeatability and allow standardization of measurements. The authors offered a modified method that partially eliminates the shortcomings of existing approaches to the automated determination of the drape characteristics of the fabric, non-woven, and woollen fabrics. Kenkare et al. [7], and also, Capdevila et al. [8], offer a method for determining the drape characteristics using image processing techniques. Using discriminant analysis, the authors achieved a classification accuracy of 76% in determining the woollen drape characteristics, with errors of 2–4%. Ragab et al. [9], offer a simplified method for figuring up the drape characteristics through their visual images. Also, Hussain et al. [10], offer a modified drape ratio. The accuracy of the proposed methods is 76–82%.

Pan et al. [11], propose to determine the drape properties on their digital images, to use the mass and thickness of the fabric, its linear density. The authors point out that the direct use of types of fibres utilized in textile fabrics cannot predict drape characteristics. They achieve a forecasting accuracy of 55–84%. Rudolf et al. [12], Han et al. [13], and Petrak et al. [14] made a comparative drape analysis obtained through 3D simulation software and those obtained by a standard method with image processing. Due to an incomplete correspondence between the real and the simulated drape, the authors show that the simulation models do not describe the real drape shape with sufficient accuracy. According to the authors, more research is needed to achieve effective methods for the analysis of drape simulation. To create a more accurate 3D shape of fabric drape [15, 16], it is necessary to determine the mechanical properties of textile fabric such as deformation, and mechanical strength. This indicates that the mesh density of the polygonal model is an important parameter for the results of the drape simulation.

But all the research in the available literature is mainly based on new fabrics. No reported results have been found to determine the drape characteristics made of used textile fabrics. Such analyses would help to determine the characteristics of textile fabrics before they are recycled and reused.

Waste is considered a valuable resource. It is very important to reduce the used materials, to reuse the textile products [17–20] to extend the life cycle of each product and to obtain new products with similar properties and characteristics. The main goal of this research is to add value to waste and to develop fashion products. Fabrics that are no longer used, and textile waste are to be used for making interior textile accessories such as curtains, upholstery, tablecloths, napkins, and blankets.

MATERIAL AND METHODS

In the present work, there were used second-hand clothing made of cotton knitted fabrics and cotton blends with polyester, elastane, and polyamide. These combinations of fibres are more common in second-hand clothing. To determine the drape, round samples with a diameter of 240 mm were prepared. The textile fabrics have not been analysed for surface structure or mechanical, physical, or chemical properties. The analyses were performed as soon as the samples were prepared. The captured images are on one side of the fabric only. A total of 90 textile fabrics were measured. The main composition of the samples is 50–100% cotton, 0–36% elastane, 45–100% polyester, and 0–55% polyamide.

Figure 1 shows in a schematic form the experimental setup used to obtain the colour digital images of the drape. It utilized a digital video camera with a USB interface – Trust Exis (Trust International B.V.). The maximum resolution is 640×480 pix. The light source for illumination of the sample below is a diode lamp VT-2017 (V-TAC Innovative LED Lighting) 6400 K, with white LEDs, with the highest intensity of light emitted at 450 nm. Its power is 17 W, power supply 220 V, 50 Hz, 141 mA. The light source is mounted in a cylindrical housing, 16 cm in height and 18 cm in diameter. The illumination of the shot scene from above is provided by diode lighting SMD3528-120/1, 6400 K white IP65 (V-TAC Innovative LED Lighting), with the highest intensity of emitted light at 450 nm. It is mounted in a domed part of a row.

The experimental setup is located in dimming housing, which reduces the influence of ambient light.

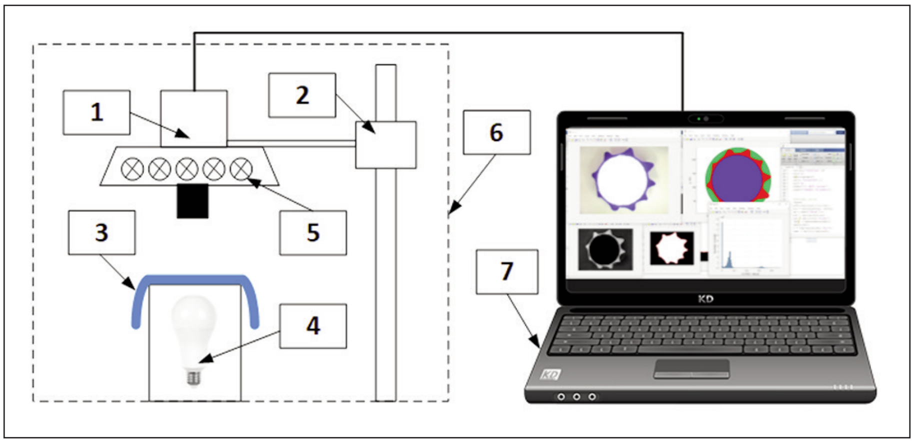


Fig. 1. Schematic of the experimental set-up used in the work: 1 – digit video camera; 2 – movable stand for changing the shooting height; 3 – measured sample; 4 – light source to illuminate the sample below; 5 – light source to illuminate the object from above; 6 – housing to reduce the influence of ambient light; 7 – personal computer

Images were captured with the camera 24 cm away from the sample. The pictures' resolution is 640×480 pix. To reduce the colour's influence of the sample on the accuracy of recognition of object areas, the background should be much lighter than textile fabric, expressed as values in the Lab colour model, $L_{background} >> L_{sample}$.

Mathematical formulas given by Sanad et al. [5] were used to determine the parameters of the drape, and the *DC* – Drape coefficient was taken from Alikhanov et al. [21]. This coefficient is used to determine the drapability of the fabric. *RD* represents the Drape distance ratio. The higher this ratio, the more flexible would be the fabric. *N* is the number of peaks. The flexibility of the textile fabric depends on this number. The number and positions of the peaks in the drape were determined by a radius-vector function.

$$DC = \frac{A_{fs} - A_{sd}}{A_o - A_{sd}} \cdot 100, \% \quad (1)$$

$$RD = \frac{R_o - R_{fs}}{R_o - R_{sd}} \cdot 100, \% \quad (2)$$

$$C = \frac{4\pi A_{fs}}{P_{fs}^2} \quad (3)$$

$$K = \frac{P_{fs}^2}{A_{fs}} \quad (4)$$

$$E = \frac{D_{fs}}{d_{fs}} \quad (5)$$

$$A_{mr} = d_{fs} D_{fs}; \quad AR = \frac{A_{fs}}{A_{mr}} \quad (6)$$

where *C* is Circularity. This is a descriptor of the complexity of the form and its sharpness. *K* – Coefficient of the form. It illustrates the connection between the drape's proportions and shape [22]. *E* – Eccentricity. It highlights how the drape's shape differs from an ideal circle. *AR* – Coefficient of the minimum rectangle. It indicates how closely the drape is to the minimum rectangle that describes it. The following parameters were used to determine these coefficients: A_{sd} – area of the supporting disk (f_s – fabric shadow); A_o – an area of the circle around the drape; A_{fs} – drape area; R_{fs} – average radius of the drape; R_{sd} – radius of the support disk; R_o – radius of the circle around the drape; d_{fs} – small diameter of the drape; D_{fs} – drape large diameter; P_{fs} – drape perimeter; A_{mr} – area of the drape's surrounding minimum rectangle as defined.

Table 1 describes the implementation's main stages of the method for figuring out the draping parameters. In Stage 4 and Stage 5, the parameters of the obtained contours are also determined by the *region props* function. This includes area, perimeter, and major and minor axis lengths of the object area.

Textile materials are divided into three classes, depending on the fabric's content of cotton. The content of cotton in the textile fabric was chosen as a criterion for division into classes. Because this material is a natural product, it creates "breathable" fabrics, and it is easily wrinkled. Synthetic fibres are added to improve the properties of the resulting textile fabrics. Therefore, they are not selected as the main criterion for classification. Table 2 shows the values of the parameters of these three classes of textile fabrics.

Table 1

ALGORITHM FOR DETERMINING THE DRAPE PARAMETERS

Stage	Description
Stage 1	Obtain an RGB image of the drape
Stage 2	Convert to HSV and extract the S component
Stage 3	Analysis of the image's histogram and identification of object areas
Stage 4	Defining the contour of the inner circle. Scope range of the S (HSV) component (Ssd1, Ssd2). Remove small objects with less than 3500 pixels. Contour noise filtering. Sealing the area in the contour. Defining the contour of the object area. Draw the contour of the object area.
Stage 5	Determining the drape contour. Same procedure as for Stage 4, but with a different range from the histogram of the S (HSV) component (So1-So2)
Stage 6	Scaling and visualization of the drape
Stage 7	Calculate the drape parameters. N, RD – from radius-vector function. The other parameters – according to the specified mathematical formulas

Table 2

CLASSES OF TEXTILE FABRICS			
Parameter \ Class	**Class 1 (C1)**	**Class 2 (C2)**	**Class 3 (C3)**
Cotton (%)	100	74.15±15.56	0
Polyester (%)	0	17.85±14.23	66.85±15.9
Elastan (%)	0	8.17±9.09	0
Polyamide (%)	0	0	33.15±15.9
N	6.64±1.84	7.64±1.46	7.07±0.71
DC	33.64±6.88	28.52±9.1	36.28±3.25
RD	36.8±17.06	42.02±12.12	31.11±7.18
C	0.7±0.44	1.53±0.7	1.01±0.37
K	16.54±8.04	19.5±8.93	41.15±21.37
E	1.1±0.05	1.35±0.23	1.25±0.16
AR	0.71±0.49	1.81±0.8	0.81±0.44

The geometric drape properties of used textiles were detected by using methods of successively improved assessments: ReliefF, FSNCA and SFCPP [21]. Using these methods, the number of the received features is reduced. These methods are suitable for taking into account features for both regression and classification of drape, depending on their parameters. These characteristics of the drape have been selected, and in all selection methods, the weight coefficient is above 0.6.

Principal Component Analysis [23–25] is used to decrease the amount of data (PC) and latent variables (LV). These methods are used because they create new sets of variables. The data obtained are significant and independent of each other. They contain important and useful information derived from raw data.

For classification, the following algorithmic tools were used: Naïve Bayesian Classifier (NB); k-Nearest neighbours (kNN); Discriminant analysis (DA) with linear (L) and quadratic (Q) separation functions; Support vector method (SVM) with linear (L), quadratic (Q) and radial basis function (RBF). These classification procedures were chosen because they are more commonly used in the analysis of textile fabrics, the drape obtained from them, and their characteristics [8].

The performance of the utilized classifiers was assessed by basic (ei), actual (gi), and total (e0) errors for the assessment of the classification results. The selection of appropriate methods for minimizing the amount of data from the drape characteristics was made utilizing a naïve Bayesian classifier as a reference.

The relationship between *RD* and *DC* of the drape has been assessed. For this purpose, it was creating a linear regression model such as:

$$y = f(x) \qquad y = b_1x + b_0 \qquad (7)$$

where: b is the coefficient of the model, x – the independent variable, and y – the dependent variable.

Regression prediction models have been developed to predict the *RD* and *DC* of drape by a feature vector containing easy-to-determine data such as the type of textile fibres used and the number of peaks.

The ability to predict *DC* and *RD* has been tested. The partial least squares regression (PLSR) method was used. This method was chosen because it yields the values of the latent variables to which the experimental data in the feature vectors are reduced.

It was used as an initial model [26, 27], to describe the correlation between selected drape properties such as:

$$z = f(x,y) \qquad z = b_0 + b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 \qquad (8)$$

where: x and y are the independent variables; z – the dependent variable, which corresponds to RD or DC; and b – the model coefficients. An analysis of the coefficients of the model depending on “p's” value, for each of them. The model rejects non-informative coefficients. The accuracy of the predictive models was evaluated based on statistical parameters. The developed models were evaluated using the following principles: coefficient of determination (R^2); Sum of squared errors (SSE); Root mean squared errors (RMSE); F-criterion; Standard error (SE); t-statistics (tStat); p-value. The residuals, or discrepancies between measured values and model values, were evaluated. The experimental data processing tools included Statistica 12 (Stat Soft Inc.) and Matlab 2017b (The Mathworks Inc.). All data were processed at a level of significance α = 0.05.

RESULTS AND DISCUSSION

The highest value of the weights, regardless of the method of selection, is the content of cotton in the fabrics which were used. Next is the content of elastane fibres. Finally, is the polyester content. The polyamide content does not significantly affect the drape properties. Equally high values of the weights (above 0.6) indicate the drape coefficient, the distance coefficient, the shape coefficient, and the eccentricity.

The following vector containing a total of 8 features has been selected:

$$FV_1 = [\%Cotton, \%Polyester, \%Elastan, N, DC, RD, K, E] \quad (9)$$

The vector of characteristics contains the percentage of fibres in the fabric – cotton, polyester and elastane, the number of peaks, the drape coefficient, the coefficient of distances, the coefficient of shape and eccentricity, having the highest values of weights, compared to other drape characteristics included in the selection. The required number of latent variables and principal components for reducing the volume of data in the obtained feature vectors has been determined. Two latent variables and two principal components are needed to describe over 95% of the variation in the experimental data. This number significantly reduces the amount of data from the feature vectors that describe the drape characteristics.

The results of a naïve Bayesian classifier (NB) classification are shown in table 3. Because some of the data do not fall within the relevant class, they cannot be recognized. NB also restricts classes to spherical boundaries. The boundaries of the classes in most cases are different from a circle and this leads to the wrong fit of some of the data in a class.

Table 3

RESULTS OF CLASSIFICATION WITH NB						
DRM	**PC**			**LV**		
Error	e_i	g_i	e_0	e_i	g_i	e_0
C1-C2	53%	22%	43%	7%	0%	3%
C1-C3	50%	40%	43%	3%	0%	2%
C2-C3	20%	45%	48%	3%	3%	6%

Note: DRM – data reduction method; PC – principal components; LV – Latent variables; basic (e_i), actual (g_i) and total (e_0) classification errors.

The NB classification shows that using principal components (PCs), higher classification error values were obtained compared to latent variables (LV). The reason for this is that, when calculating the PC, the restriction is assumed that the components are a linear combination of the original data, which does not apply to the drape data used. For the data used in this work, latent variables (LV) are not calculated directly in one variable but are derived from other variables in the raw data. For the following analysis, the data will be reduced by LV for the three drape classes.

The results of the k-nearest neighbour classification (kNN) are shown in table 4. LVs were used for the three classes of drape. When using this classifier, as can be seen from the results, high values are obtained at the actual error. This shows that the main reason for the classification errors is that the second-class data is incorrectly classified into the first class. The reason for the increase in classification errors is that kNN is sensitive to data with noise and with a large scatter around their average value, as well as missing values and deviations in the data. Table 5 displays the results of the DA classification. If a linear separation function is utilized, an increase in the actual error is observed. The main reason for the classification errors is that the data from the second class incorrectly fall into the first. This is because the variables cannot be related to a linear combination. Also limited in the accuracy of classification is the sensitivity to large scatters in the data. This restriction is missing in the quadratic separating function of the classifier. As can be seen from the results, the errors reach 12–17%. In classification with class C1 and other classes, there is an increase in the actual classification error rates (because the values from C2 and C3 are included in C1). In the classification between C2 and C3, higher values of the basic error are observed, because some of the data of class C2 fall into C3. The low overall classification error values (2–12%) indicate that the data between the three classes can be separated by a nonlinear separation function. Table 6 displays the outcomes of the SVM classification. Just like the previous classifiers, high error values are obtained when using the linear and quadratic separation function. In SVM, the basic classification error is shown to have high values, indicating that some of the data from the class fall into the wrong one. The lowest classification values were obtained using a radial basis (RBF) separation function.

Table 4

RESULTS OF CLASSIFICATION WITH KNN			
Error	e_i	g_i	e_0
C1-C2	0%	15%	9%
C1-C3	10%	25%	11%
C2-C3	12%	20%	7%

Note: Basic (e_i), actual (g_i) and total (e_0) classification errors.

Table 5

RESULTS OF CLASSIFICATION WITH DA						
SF	**L**			**Q**		
Error	e_i	g_i	e_0	e_i	g_i	e_0
C1-C2	8%	22%	14%	0%	4%	12%
C1-C3	0%	26%	12%	0%	1%	2%
C2-C3	0%	21%	12%	17%	4%	2%

Note: SF – separation function; L – linear; Q – quadratic; Basic (e_i), actual (g_i) and total (e_0) classification errors.

The highest values of the total classification error, when comparing the methods used, are obtained in the case of kNN and classifiers using a linear separation function. Secondly, it can be stated that the errors are lower when using a quadratic separating function. The lowest values of the total classification error were obtained when using SVM combined with

Table 6

SVM CLASSIFICATION RESULTS									
Separation function	**L**			**Q**			**RBF**		
Error	e_i	g_i	e_0	e_i	g_i	e_0	e_i	g_i	e_0
C1-C2	47%	0%	26%	12%	0%	8%	0%	0%	0%
C1-C3	67%	0%	20%	7%	0%	1%	0%	0%	1%
C2-C3	20%	0%	11%	0%	0%	0%	0%	0%	0%

Note: L – linear; Q – quadratic; RBF – radial-basis function; Basic (e_i), actual (g_i) and total (e_0) classification errors.

the RBF separation function. In summary, the classification's accuracy is dependent on the method of the amount of data reduction and the classifier's type of separation function which was used. In this case, for drape data, latent variables (LVs) and their classification with DA or SVM are appropriate methods to reduce the volume of data but use nonlinear separation functions.

The regression relationship between the drape coefficients *RD* and *DC* was estimated. The results of this analysis are shown in figure 2 and table 7. The *DC* parameter allows us to determine the drape's shape of different textile fabrics. Thus, regression graphs describing the relationship between *RD* and *DC* show differences in slope between different textile fabric classes. This shows that the degree of drape and fabric characteristics can be determined in more detail by *RD* compared to *DC*.

Table 7

CRITERIA FOR ASSESSING THE RELATIONSHIP BETWEEN RD AND DC OF DRAPE			
Class \ Criteria	**SSE**	**R^2**	**RMSE**
C1	4.34	0.68	3.94
C2	9.35	0.61	5.78
C3	1.17	0.62	2.05

Regression models have been developed using easy-to-determine drape characteristics to predict *DC* and *RD*. These characteristics are the content of cotton, polyester, elastane, and polyamide fibres in the fabric, and the number of peaks. The following feature vector was used:

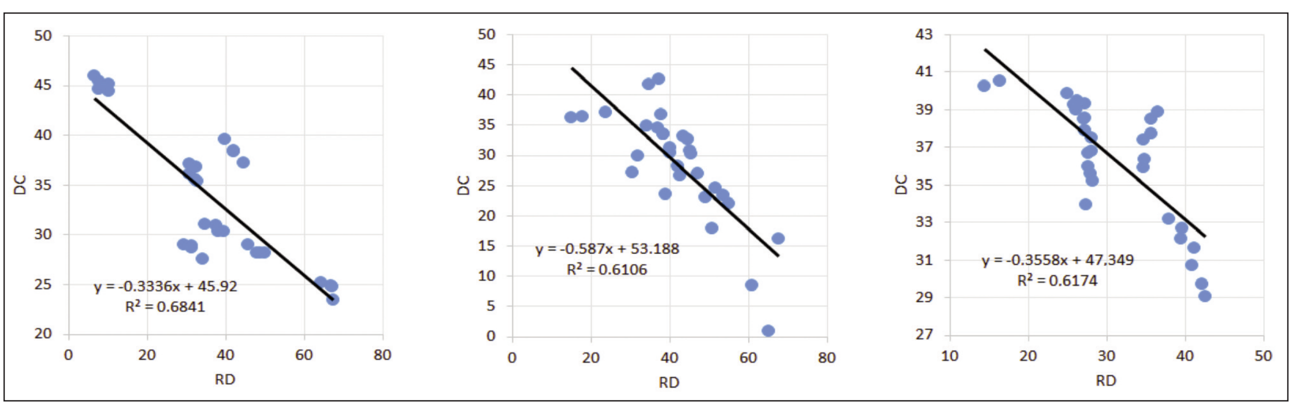
$$FV_2 = [\%Cotton, \%Polyester, \%Elastan, \%Polyamide, N] \quad (10)$$

This feature vector is reduced to two latent variables (LV). Before creating predictive models, the possibility of predicting *DC* and *RD* on the reduced data from the derived feature vector was checked. The partial least squares regression (PLSR) method was used. Figure 3 and table 8 show the results of this test.

According to the reduced data of FV2, *DC* can be predicted with an accuracy of 53% and *RD* with 79%. The average and high predictive power and the low values of the prediction errors indicate that the fibre types used in textile fabrics and the number of peaks can be used to predict *DC* and *RV*. Because the models are linear when checked, they do not accurately reflect the relationship between independent and dependent variables. When creating predictive models, it is necessary to look for a nonlinear relationship between independent and dependent variables.

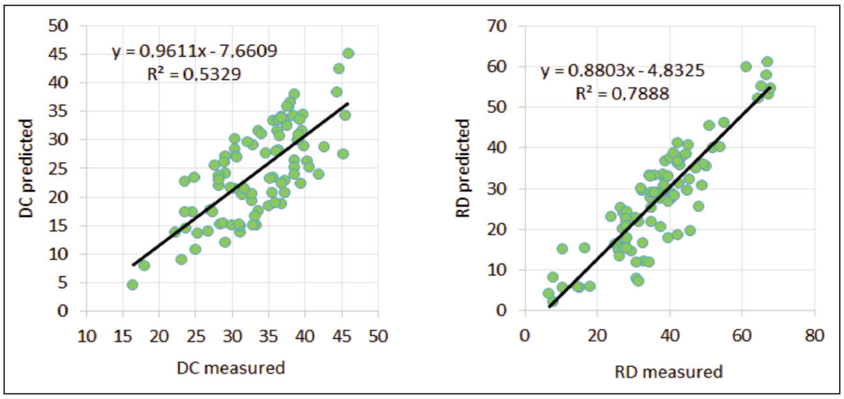
Table 8

CRITERIA FOR ASSESSING THE ABILITY TO PREDICT DC AND RD			
Coefficient \ Criteria	**SSE**	**R^2**	**RMSE**
DC	5.61	0.53	5.12
RD	2.37	0.79	3.51



a *b* *c*

Fig. 2. The connection between RD and DC: *a* – C1; *b* – C2; *c* – C3



a *b*

Fig. 3. Ability to predict DC and RD by reduced FV_2: *a* – DC; *b* – RD

Regression prediction models have been developed for the *DC* and *RD* values of the drape for two latent variables. Their main characteristics have been assessed. After eliminating the irrelevant coefficients, with $p > \alpha$, the following regression models were obtained:

$$DC = f(LV_1, LV_2)$$

$$DC = 29{,}81 + 341{,}52\,LV_1^2 - 71{,}3\,LV_2^2 \qquad (11)$$

$$RD = f(LV_1, LV_2)$$

$$RD = 36{,}15 + 31{,}55\,LV_2 - 7{,}26\,LV_1^2 + 10{,}31\,LV_2^2 \quad (12)$$

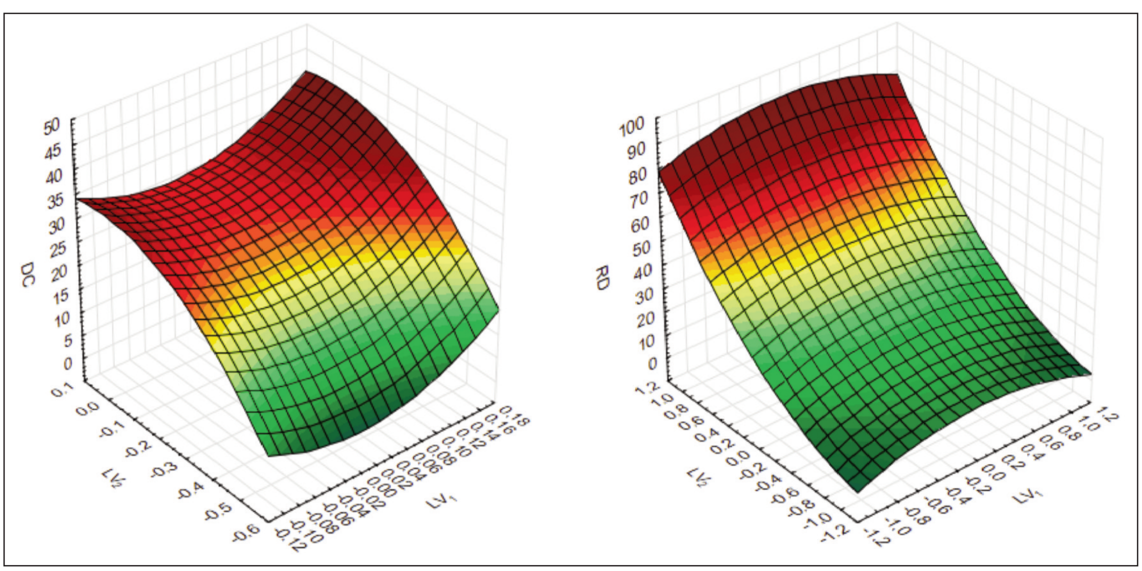
In the DC model, the first latent variable has a greater effect on accuracy. In RD – the second latent variable. This is confirmed by the calculated regression equations, which have significant coefficients. Table 9 displays the values of the parameters used to evaluate the resulting models. In the DC prediction model, the coefficient of determination is 0.68. In the RD model, this coefficient is higher (0,92). For both models F > Fcr. The p-value << α. The error values SE, SSE, and RMSE are low.

Figure 4 shows graphs of the obtained models. In both the DC and RD prediction models, it can be seen that the dependent variables can be predicted with the greatest force when they are at their upper levels. These levels correspond to the upper levels of the two independent variables. According to the investigation of model residuals, it is observed that there are no deliberate deviations of the real data from the hypothetical ones, which is an indication of their typical conveyance between the regression model obtained and real data. It follows that the precondition for normality of the distribution of the remainders of the regression models is fulfilled.

The outcomes obtained in the current work will be supplementing those reflected in the accessible literature. Results for determining the drapability of textiles from used clothing are presented. Capdevila et al. [8], indicate that the classification of drape with

Table 9

PARAMETERS FOR EVALUATION OF THE OBTAINED MODELS						
Model	**R^2**	**F**	**p-value**	**SE**	**SSE**	**RMSE**
$DC = f(LV_1, LV_2)$	0.68	$F(2.87) = 22.54$ $Fcr = 3.1$	0.00	6.16	3.31	6.16
$RD = f(LV_1, LV_2)$	0.92	$F(3.86) = 39.39$ $Fcr = 2.71$	0.00	1.09	1.08	3.55



a *b*

Fig. 4. DC and RD prediction models by LVs: *a* – $DC = f(LV_1, LV_2)$; *b* – $RD = f(LV_1, LV_2)$

discriminant analysis with a linear separation function results in classification errors of 21–26%. Due to the deterioration of the fabric after use, in the present work, the errors of classification with linear separating functions, regardless of the classifier used, exceed 35%. This problem has been partially addressed by using non-linear separation functions, which have reduced classification errors by up to 10%. The lowest values of classification errors (up to 5%) were achieved with more complex calculation procedures such as using the SVM and RBF separation functions. Also, for the used fabrics, the relationship between DC and RD is maintained in the range R2 = 0.61–0.68, as for new fabrics, but there is an increase in the error of the linear model describing their relationship by about 10–15%. It can be considered that the results obtained in this work improve those of Ragab et al. [9]. The measuring system is complemented by a light source that illuminates the drape below. This increases the degree of recognition of object areas in the image. In this study, instead of using a polar diagram, the parameters of the peaks are determined by a radius-vector function. Also, new results related to the measurement of drape from used textiles are presented. Hussain et al. [10], suggest that the prediction of the DC drape coefficient should be made according to the bending length of the fabric. An accuracy of 76–82% was achieved. In the present work, utilizing data on the fibres of the used textile fabric and the number of peaks in the drape, up to 92% accuracy is achieved in determining the main drape characteristics. Measuring instruments are more commonly used in textile recognition applications, image acquisition, processing, and analysis systems. In this way, the data extraction about draping from textile fabrics images is better performed. It is necessary to do more research on modern optical methods, such as hyperspectral analysis, stereo video cameras, and 3D scanners, to determine the drape parameters. Another important application of the methods proposed in this paper is for the study of cultural heritage collections [28]. The present paper demonstrates the possibility to analyse the drape of used textiles by their digital images. More research is needed on the appropriate use of the proposed methods and tools. As noted by Petrak et al. [14], it should include the application of standard test methods such as textile fabric thickness (ASTM D1777), and textile fabric mass (ASTM D3776).

CONCLUSION

As a result of the conducted theoretical and empirical research, analyses and summaries, the main goal and tasks in the present study have been achieved. The comparability of the methods for the analysis of the main drape characteristics of the used textile fabrics, extracted from their colour digital images, is evaluated. The results reported in the available literature have been supplemented. Methods and procedures suitable for the analysis of drape characteristics of second-hand textile fabrics were proposed.

The system for determining the main drape characteristics is complemented by a light source that illuminates the drape from below. This increases the level of recognition of object areas in the image.

Automated software tools have been adapted and researched to apply the proposed methods and procedures for digital image analysis of used textile drape, which will be used to describe the shape and predict the characteristics, as well as their classification into groups and assessment of classification accuracy in recognizing their elements. It is proposed to use a radius-vector function to determine the drape's main characteristics, such as the number of peaks, their size, and location. To predict changes in these characteristics, analytical models have been developed for the automated prediction of the drape characteristics of used textiles.

An analysis of the obtained regression models for drape parameters was made, depending on the fibres used in textile fabrics, and which models can be used in the recycling of used textiles.

Comparing the outcomes from the current work with those reflected in the accessible publications, it was found that, the deterioration of the fabric after a long run, reduces the accuracy of recognition and classification of drape, depending on the textile materials which were utilized.

For efficient classification and prediction of the drape characteristics for the used textile fabrics, it is necessary to apply more complex computational procedures, such as SVM and nonlinear separation functions of classification algorithms.

The results obtained show that textile waste can be considered a valuable resource. Textile fabrics which are no longer used can be utilized in the manufacture of new fashion products such as curtains, upholstery, tablecloths, napkins, blankets, and fashion accessories.

ACKNOWLEDGEMENTS

The research has been funded by the University of Oradea, within the Grants Competition "Scientific Research of Excellence Related to Priority Areas with Capitalization through Technology Transfer: INO-TRANSFER – UO – 2nd Edition", Projects No 232/2022 and 236/2022.

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