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Research on fabric classification based on graph neural network

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ABSTRACT – REZUMAT

Research on fabric classification based on graph neural network

Fabric classification plays a crucial role in the modern textile industry and fashion market. In the early stage, traditional neural network methods were adopted to identify fabrics with the drawback of restricted fabric type and poor accuracy. Combining multi-frame temporality and analysing fabric graph data made from fabric motion features, this paper proposes a novel hybrid model that introduces the concept of graph networks to classify 30 textile materials in a public database. We utilize the graph inductive representation learning method (GraphSAGE, Graph Sample and Aggregate) to extract node embedding features of the fabric. Moreover, bidirectional gated recurrent unit and layer attention mechanism (BiGRU-attention) are employed in the last layer of aggregation to calculate the score of previous cells. Intending to further enhance performance, we link the jump connection with adaptive selection aggregation frameworks to determine the influential region of each node. Our method breaks through the limitation that the original methods can only classify a few fabrics with great classification results.

Keywords: *fabric classification, multi-frame temporality, fabric graph data, GraphSAGE, BiGRU-attention*

Cercetări privind clasificarea materialelor textile pe baza rețelei neuronale grafice

Clasificarea materialelor textile joacă un rol crucial în industria textilă modernă și pe piața modei. În faza incipientă, metodele tradiționale ale rețelelor neuronale au fost adoptate pentru a identifica materialele textile cu dezavantajul tipurilor limitate de material textil și al preciziei scăzute. Combinând temporalitatea cu cadre multiple și analizând datele grafice ale materialului textil realizate din caracteristicile de mișcare ale acestuia, această lucrare propune un model hibrid nou care introduce conceptul de rețele grafice pentru a clasifica 30 de materiale textile într-o bază de date publică. Am utilizat metoda de învățare a reprezentării prin inducție grafică (GraphSAGE, Graph Sample și Aggregate), pentru a extrage caracteristicile nodurilor materialului textil. În plus, unitatea recurentă bidirecțională și mecanismul de atenție a stratului (BiGRU-attention) au fost utilizate în ultimul strat de agregare pentru a calcula scorul celulelor anterioare. Obiectivul nostru a fost de a îmbunătăți și mai mult performanța, de a lega conexiunea de salt cu cadrele de agregare a selecției adaptive, pentru a determina regiunea influentă a fiecărui nod. Metoda noastră depășește limitarea conform căreia metodele originale pot clasifica doar câteva materiale textile cu rezultate excelente de clasificare.

Cuvinte-cheie: *clasificarea materialelor textile, temporalitate cu cadre multiple, date grafice ale materialelor textile, GraphSAGE, BiGRU-attention*

INTRODUCTION

Fabric classification takes a wide range of applications in textile manufacturing. In the early period, investigators classified textile materials by manual operations, such as sensory, combustion, etc. which involved certain subjectivity and irreversibility. With the enrichment of variety for textiles increasingly, the current research hotspot is turned to exploring an intelligent, efficient, and exact identification strategy for textile fibres.

The study of textile material recognition has aroused broad concern in recent years [1–3]. Generally speaking, the research can be divided into two categories: static fabric recognition and dynamic fabric recognition.

Fabric recognition based on static images

Han et al. [4] segmented the colour and spatial information of fabric images and then performed wavelet transform in line with the frequency components contained in the secondary and tertiary wavelet decomposition layers to distinguish rough fabrics. Jing et al. [5] proposed extracting fabric texture features through a moving grey-level co-occurrence matrix (GLCM) and Gabor wavelet, sorting the three basic fabrics with a probabilistic neural network (PNN). The above studies mainly considered the shape and texture characteristics of textiles, which were restricted to the recognition of several fabrics in specific scenes.

Fabric recognition based on dynamic videos

Bouman et al. [6] put forward a framework for estimating material properties with fabric videos, which withdrew surface information from inputs to train the model systematically. The key element overlooked in their work was multi-frame motion information. Yang et al. [7] classified fabrics by recording the change of external features as they swing, combining the feature extraction method of the image signal (i.e. CNN, Convolutional Neural Network) with the time series learning method (i.e. LSTM, Long Short-Term Memory). The existing issue was that the potential association of fabrics was not taken into account. Bi et al. [8] proved the significance of time sequence for material property evaluation by investigating the influence of the temporal and spatial features from multiple frames of motion on fabric bending and stiffness. However, the research focused on testing the relevance of the model to human perception rather than the classification of fabrics.

To solve the problems existing in previous approaches within the study of fabric classification, a method was first proposed by Tao et al. [9] that introduced the concept of the graph to describe the information of cloth motion characteristics. The graph is a ubiquitous structure that widely occurs in many fields including biology (protein-interaction networks) [10], chemistry (molecular graphs) [11], cognition intelligence (knowledge graphs) [12], social sciences (friendship networks) [13, 14] and other areas [15–17].

Compared to general classification algorithms such as CNN [18] and LSTM [19], the definition of graph neural network was originally proposed by Gori et al. [20] and Scarselli et al. [21] yet it had attracted much attention in recent years, breaking the limitation that the traditional network model can only handle Euclidean data, treating data with generalized topology structure on the contrary. It is worth mentioning that GCN_3 [9] took a heavy computation time to handle massive fabric structure data, the above work was still in the primary stage of textile material recognition study.

Inspired by these previous works and to address the shortcomings, we put forward a customized graph neural network model based on fabric graph data for the recognition and classification of textile material. The main contributions of our work are summarized as follows:

- For motion video-based fabric classification, we apply a fabric feature acquisition method that can be independent of fabric surface texture, structure, and colour factors, and convert Euclidean fabric video data into non-Euclidean fabric graph data by incorporating spatial feature information of fabric physical attributes while considering video temporality to achieve more efficient classification and recognition of fabrics with fewer memory resources.
- We are the first attempt to introduce the graph inductive representation learning method into fabric classification. At present, the general way of aggregation resulted in the fixed radius of influence cannot realize the optimal vector representation of each node and edge of the fabric graph. Hence, we combine the jump connection and adaptive aggregation mechanism so that nodes anywhere have the same chance to obtain rich information about neighbouring nodes.
- To further raise the robustness of the entire model, we introduce the bidirectional gated recurrent unit (BiGRU), optimize it with dropout for the avoidance of the vanishing gradient problem, and distinguish the significance of neighbour nodes in each layer via the merit of layer attention mechanism.
- In addition, we evaluate different performance metrics such as accuracy, precision, recall, F1-score and loss of the model with motion videos of 30 different fabrics as the experimental datasets. We further compare the proposed model with existing methods. The result demonstrates that our method realizes classification better as compared with other approaches.

The rest of this paper is organized as follows: in the second section, we describe the framework, dataset and data pre-processing details of our proposed model; in the third section, we introduce the setup and results of our experiments; in the fourth section, we present the discussion and comparison with other works; finally, the conclusion is drawn in the fifth section.

MATERIALS AND METHODS

Fabric force model

Most of the existing fabric recognition techniques rely on appearance characterization and multi-frame motion to determine the category, neglecting the role of its internal forces in estimating its properties. We thus perform force analysis for dynamic cloths to avoid the influence of external factors such as texture, colour, and light.

The fabric force model [9] is designed based on the framework of the social force model [22] for multi-particle self-driven systems. The model treats the fabric image as a composition of interrelated and uniformly distributed particles, and the fabric forms its motion trajectory as a result of the interaction forces of wind and tissue fibres, which leads to corresponding variations in the force flow of the particles, thereby obtaining fabric force flow information and classification in terms of motion characteristics. The model arranges the particle mesh on the fabric image, which is partially described in figure 1. Estimating the combined force of the moving particles with the fabric force model, the force analysis of particle *i* is shown in equation 1:

$$m_i \frac{dv}{dt} F_a = F_w + F_{int} \quad (1)$$

where F_a represents the actual force on the particle point, F_w stands for the wind force on the particle, and F_{int} denotes the interaction force on the particle

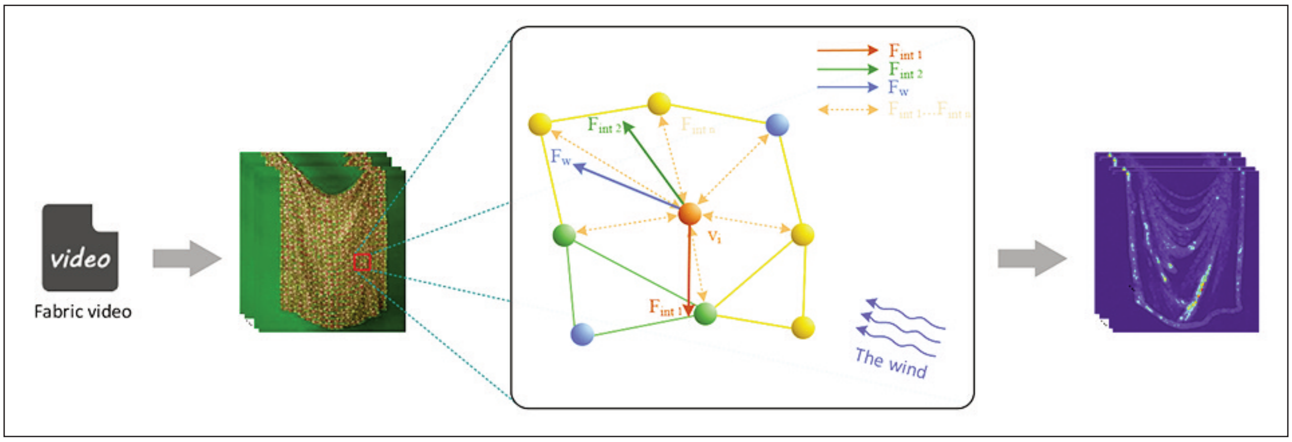

Fig. 1. Fabric stress analysis at time t

within the fabric, where F_{int} consists of the downward gravitational force on the particle point, the upward tensile force, the mutual repulsive force and tensile force between the particle points.

The actual speed of particle point i is related to the wind speed, but since i is also affected by internal tension, there is a difference between the actual speed v_i and the v_i^w generated under stable wind force, and the relaxation coefficient is defined to optimize the fabric wind force. The calculation formula of F_w is as follows:

$$F_w = \frac{1}{\tau}(v_i^w - v_i) \tag{2}$$

Each node i suffers from different wind forces, and w_i is introduced to represent the wind weight. When $w_i \to 0$, it means that the node is almost free from the wind, and $w_i \to 1$, it means that the wind force on the node is perpendicular to its gravity. Therefore, the velocity v_i^w produced under constant wind is replaced by v_i^m, and v_i^c stands for the average velocity of the adjacent nodes, which is shown in equation 3.

$$v_i^m = w_i v_i^m + (1 - w_i)(v_i^c) \tag{3}$$

In the fabric force model, the optical flow is taken to extract the interaction force F_{int} from the fabric video. The average optical flow length of each frame, O_{ave}, via the mean optical flow in a fixed space-time window and Gaussian weighted average in space. The actual speed v_i of particle i is the same as the size of the optical flow $O_{ave}(x_i, y_i)$ on the coordinate (x_i, y_i). By that, the motion speed of the particle i can be defined as equation 4.

$$v_i^m = w_i O_{ave}(x_i, y_i) + (1 - w_i) O_{ave}(x_i, y_i) \tag{4}$$

Corresponding coordinates (x_i, y_i) in the grid, where $O(x_i, y_i)$ denotes the valid temporal average of particle i, $O_{ave}(x_i, y_i)$ represents the single point optical flow value of particle i. The effective average flow field and effective optical flow between points are evaluated with the bilinear interpolation method. In the given fabric scene, the mass of particle i is set to $m_i = 1$. Thus, F_{int} is expressed as equation 5.

$$F_{int} = \frac{dv}{dt} - \frac{1}{\tau}(v_i^m - v_i) \tag{5}$$

Sample details

The dataset for the experiments is derived from the publicly available database of fabric videos with corresponding measured ground truth material properties [23, 24], which contains videos of 30 different textiles moving under three different winds. It is shown as the top two corners of the fabric fixed in the air and the same wind blowing in from the lower right position. Yet, the original fabric video as traditional Euclidean data cannot meet the requirements of the graph neural network model. We apply the fabric force model and visual word bag to convert it into non-Euclidean data, as shown in figure 2 or details.

Extract fabric movement characteristics

First, the continuous textile video was saved as a picture by frame with OpenCV, and then obtain the force flow diagram which combines the fabric force model. Next, cut the cropped image evenly into small $S \times S$ ($S \in \mathbb{R}^N$) image blocks with the slice tool, called it visual words. Last, calculate the RGB average value separately with each block as the unit in terms of the three primary colours.

Make the node feature list

Taking each frame as a graph node, filter and extract the visual words with representative fabric color features to generate a visual dictionary, which can be represented by $C = \{c_1, c_2, \dots, c_i, \dots, c_m\}$, where C stands for visual dictionary; C_i is the i-th visual word in the dictionary and a total number of visual words is m. Meanwhile, calculate and store the pixel values of RGB on each frame in force flow picture as visual words, $V = \{v_{1_1}, v_{1_2}, \dots, v_{1_T}, v_{2_t}, v_{2_{t+1}}, \dots, v_{c_1}, \dots, v_{c_T}\}$, where i is the video timing, T represents the total video duration, and c stands for the type of fabric number. According to the dictionary C, record 1 under the corresponding word c_i when it appears, and 0 otherwise. Thereby creating a node feature list by performing the above operations on all graph nodes.

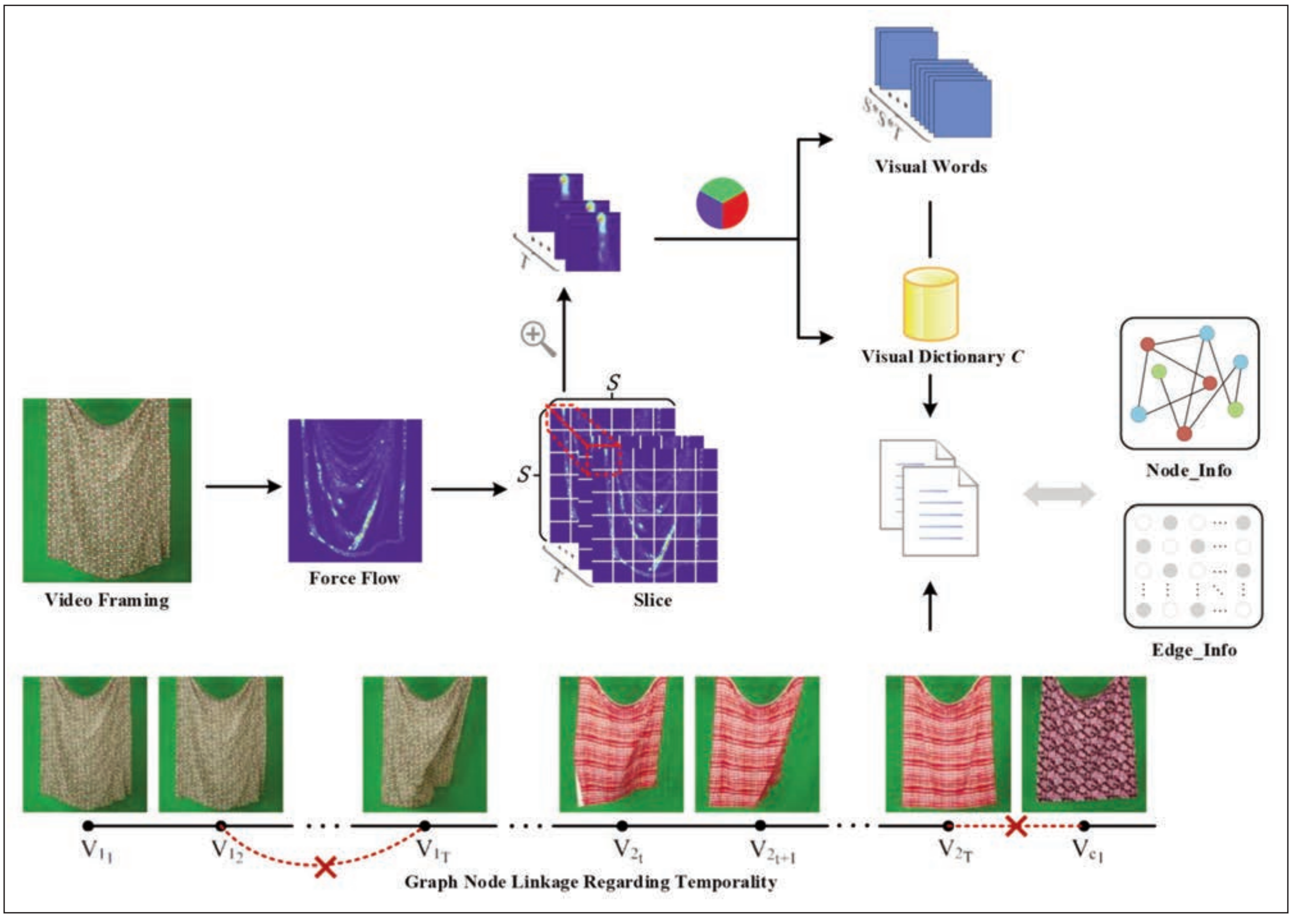

Fig. 2. Process of extracting fabric features from the video database

Construct fabric graph data

For various types of fabrics, rely on the visual word list to establish the connection between fabrics. If two nodes contain more than *Z* of the same visual word (*Z* is customized), there would be a certain similarity within them. For the same fabric judging by video temporality, like v_1 and v_2 are connected, as well as v_{2_t} and $v_{2_{t+1}}$ are connected, yet others are not connected such as v_{1_2} and v_{1_T} have no relation of time sequence.

With the above steps, each fabric video was processed into 2,700 images, and in total 81,000 fabric images are obtained. Considering each image as a graph node, when S = 6 and Z = 18, this database can generate 81,000 graph nodes and 2,916,000 visual words, and excluding duplicates, 2,230,516 words can be expanded the visual dictionary. As such, the object of our study is the fabric graph obtained from processing, i.e., node data containing force flow features and edge data representing association information. The nodes of the graph are randomly divided into a training set, a validation set and a test set in the ratio of 6:2:2, which are fed into a custom graph neural network.

Proposed model

Graph neural networks enjoy great popularity among scholars for their excellent performance in graphically structured data [25]. Graph convolutional network (GCN) [14, 26] retained the global structure of the graph as well as the attribute information of the node. Hamilton et al. [13] introduced GraphSAGE to concatenate features of the nodes and applied it to mean/max/LSTM operators for inductively learning node embeddings. Besides, Message Passing Neural Network (MPNN) by Gilmer et al. [27] further considered edge information when performing aggregation. Xu et al. [28] proposed a Jumping Knowledge Network (JK-Net) architecture in which the last layer of the model can selectively exploit information from neighbours at distinct locations, thus allowing a great capture of the node-level representation in a fixed number of graph convolution operations.

Furthermore, He et al. [29] introduced the Residual Network (ResNet) to skip layers for leveraging local information of different depths and hence can assist in model training, especially as the depth of the network increases. In summary, it can be seen that scholars have experimented with multiple parties on how to efficiently acquire graph node embedding features, which confirmed the credit of hierarchical level jump links in enhancing node learning ability.

The overall architecture of our model is shown in figure 3. We explore a hybrid architecture that efficiently generates unknown vertex embedding utilizing attribute information of vertices. Sample the neighbours of each vertex and aggregate the information contained therein to obtain the vector representation

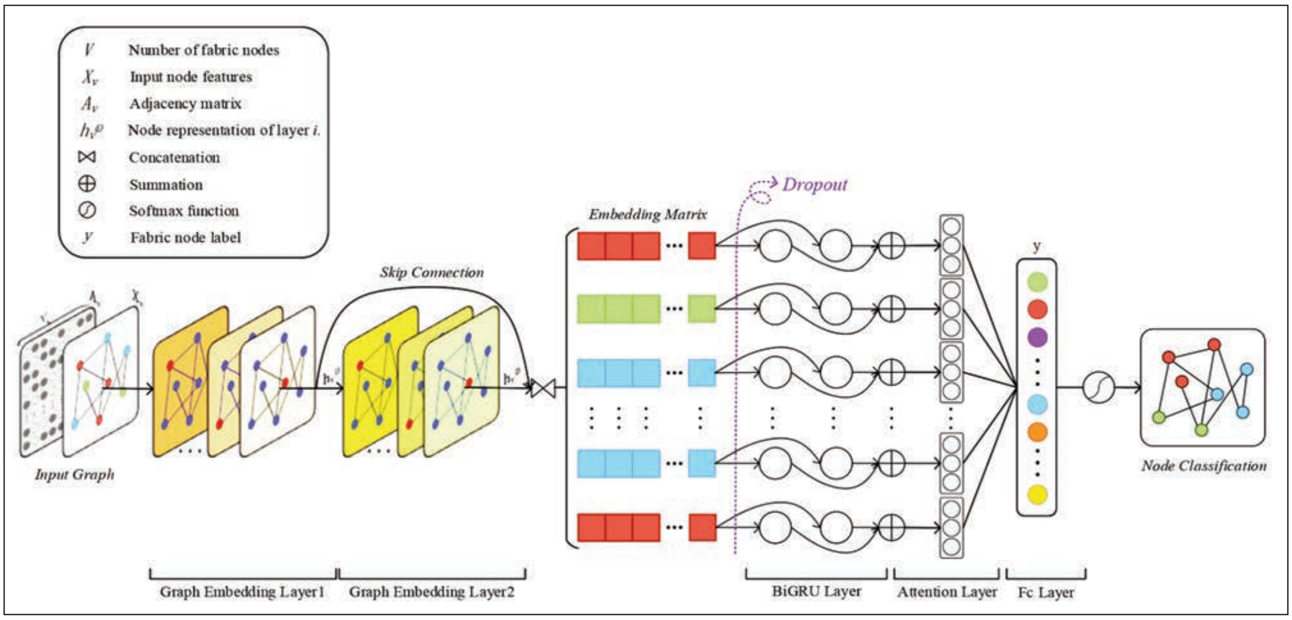

Fig. 3. The overall architecture of the proposed model

of each node in the graph. In the last layer of aggregation, each vertex filters some node feature information from embedded representations upstream and merges them selectively, i.e., the representations "jump" to the last layer. Each vertex independently performs this step to adjust its neighbourhood range, to obtain the adaptive capabilities that are required. We elaborate the details of our model by hierarchical order that illustrates the design of the bidirectional gated recurrent unit model with the attention mechanism. Applying a dropout layer after the embedding layer, the next layer is the BiGRU layer. Both GRU and LSTM are special variants of Recurrent Neural Networks (RNN) with logic gates. BiGRU-attention transmits the expression of each layer into the BiGRU so that each layer gets a forward representation and a backward representation, then sends them to the linear layer in series, and obtains the attention score of nodes in different neighbourhood ranges with softmax function, and finally receives the expression in weighting and summing.

EXPERIMENTS

Setup

The proposed model is trained and tested in NVIDIA Quadro M5000 with an 8 GB graphical processing unit (GPU), Intel(R) Xeon(R) CPU E5-2620 v3 @ 2.40 GHz, and 16 GB RAM. Our model is implemented by PyTorch and the details of the parameter required for the experiment are shown in table 1.

Results

To confirm the effectiveness of our customized method, we perform ablation comparisons in multiple experiments and choose five metrics generally applied for multi-classification tasks to measure the performance of the model including accuracy, precision, recall, F1-score, and loss (table 2).

Table 1

DETAILS OF THE EXPERIMENTAL PARAMETER

Parameter	Value	Description
Lr	0.005	Initial learning rate
Epoch	1000	Number of epochs
H_dim	64	Number of hidden units
Dropout	0.6	Dropout rate
Loss	NLLLOSS	Loss function
Optimizer	Adam	Adam Optimizer to train
Weight-decay	1e-7	L2 regulation weight

As it is known from [28] currently, the best performance of aggregation-based graph networks is two layers, and further layers would degrade the model performance. While GCN generates embedded features only for the current node during training, and cannot scale to unknown nodes, GraphSAGE provides an inductive framework by sampling and aggregating neighbouring vertices to generate embedding features for unknown nodes. According to the experimental data in table 2, regarding large-scale fabric graphs based on the same set of layer aggregation mechanisms, the accuracy, precision, and recall rate of two-layer GraphSAGE are slightly 0.5% higher than GCN, and the loss is slightly 2.4% lower. Besides, based on the same set of network embedding layers, we explore six mechanisms like concatenation, max-pooling, (Bi)LSTM-attention, and (Bi)GRU-attention. Concatenation is to connect the node representations of all layers in series and then perform a linear transformation. Yet, its transformation weights are equal for all nodes and cannot reach the adaptive effect. Max-pooling selects the most informative layer for each feature node, graph nodes

Table 2

COMPARISON OF ABLATION EXPERIMENT RESULTS

Parameter		Accuracy	Precision	Recall	F1-score	Loss
Net.Layer	**Agg.Layer**					
GCN_2	Concat	0.939	0.943	0.918	0.930	0.384
	Max-pooling	0.943	0.947	0.924	0.935	0.257
	LSTM	0.951	0.952	0.933	0.942	0.220
	BiLSTM	0.953	0.958	0.941	0.949	0.208
	GRU	0.952	0.959	0.940	0.949	0.198
	BiGRU	0.957	0.961	0.933	0.947	0.193
$SAGE_2$	Concat	0.939	0.944	0.925	0.934	0.350
	Max-pooling	0.946	0.949	0.934	0.941	0.217
	LSTM	0.949	0.952	0.943	0.947	0.228
	BiLSTM	0.957	0.960	0.938	0.949	0.207
	GRU	0.955	0.958	0.935	0.946	0.191
Ours		**0.959**	**0.962**	**0.945**	**0.953**	**0.190**

that represent more local attributes can learn embedding information from the neighbourhood, while nodes representing global states prefer features from higher levels. From the perspective of the recurrent unit structure, GRU takes fewer connections and parameters throughout the network compared to LSTM, thus the model is more efficient with training and generalizing, and the BiGRU-attention is node-adaptive since each node has different attention scores. In short, BiGRU-attention is more suitable than the above five aggregation ways for large and complex fabric graphs.

From figure 4, we can notice more intuitively the comparison of classification accuracy and training loss in multiple ablation experiments. The experimental results show that our method has the best results in terms of precision, accuracy, recall, and F1 score, respectively, as well as the lowest loss of 19.8% for the whole group.

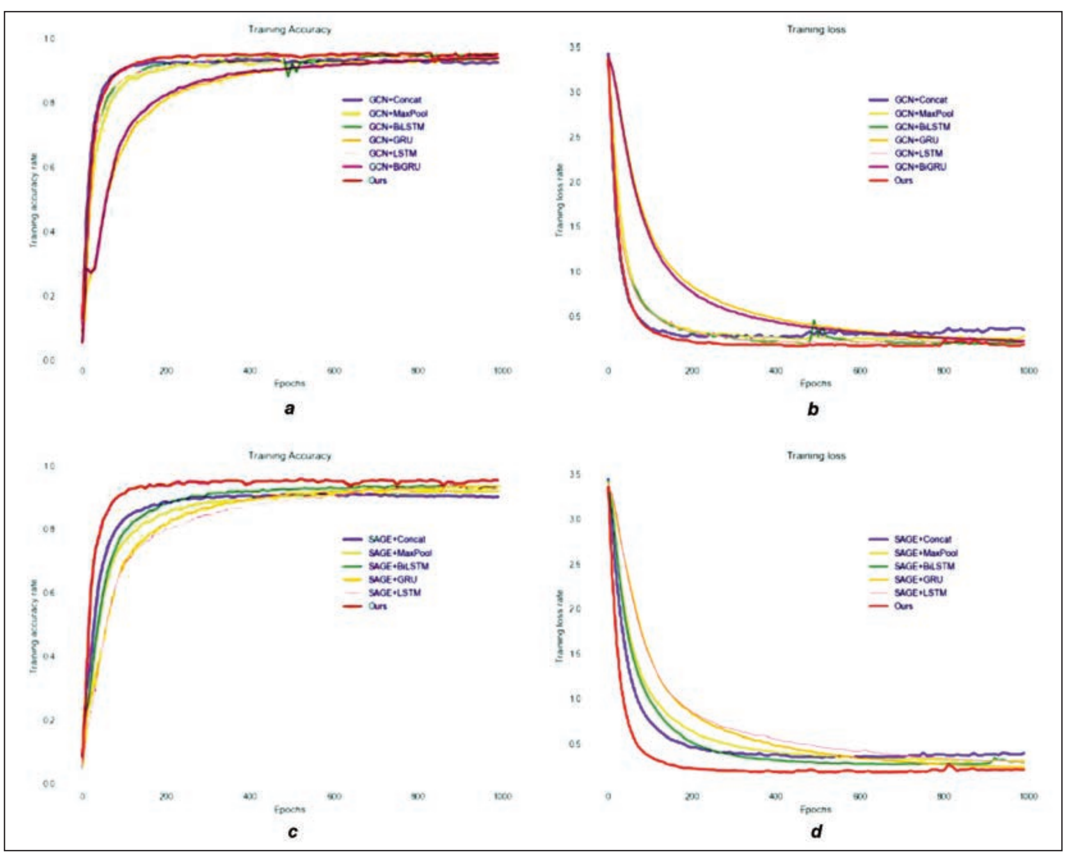

Fig. 4. Comparison of ablation experiment results: *a* – Accuracy(GCN_2+); *b* – Loss(GCN_2+); *c* – Accuracy($SAGE_2$+); *d* – Loss($SAGE_2$+)

DISCUSSION

Researchers suggested methods based on traditional machine learning techniques in previous studies. Table 3 presents a comparison of this work with other baseline approaches.

Table 3

PERFORMANCE COMPARISON AGAINST BASELINE APPROACHES			
No.	**Details**		**Accuracy (%)**
	Method	**Features**	
1	Inception V3	Based on surface features	13.1
2	SVM	Based on surface wrinkle	78.3
3	LSTM	Based on video timing	63.8
4	CNN+LSTM [7]	Based on motion video	66.7
5	Regression Model [6]	Based on stiffness and density	70.0
6	GCN_3 [9]	Based on motion video	84.5
7	Ours	Based on motion video	95.9

The above studies were tested in the same public fabric database, which can identify 30 kinds of fabrics. To reflect the advantages of our method, we apply three traditional classification algorithms in machine learning to conduct experiments and synthesize the other three existing study results for comparative analysis. As be analysed that the Inception V3 automatically classified the fabrics with the features of the fabric surface, yet the accuracy of fibre recognition was only 13.1%. The SVM only recognized the wrinkle information on the surface, and the accuracy cannot be strong due to insufficient feature extraction. The LSTM focused on the study of the motion state in datasets, and just considered the inherent timing characteristics, resulting in 63.8%. The Regression Model comprehensively analysed the feature and motion information of the surface for fabric in the video, as well as the CNN+LSTM, used the motion of appearance to infer physical characteristics for textiles, however, the results of the CNN+LSTM and regression model were not very satisfactory, 66.7% and 70.0% respectively. GCN3 and our method comprehensively considered multi-frame timing information and fabric movement characteristics. Compared with GCN_3, the accuracy of our method is about 11.4%, up to 95.9%. In summary, the customized model proposed in this paper had the best effect on the classification of fabrics.

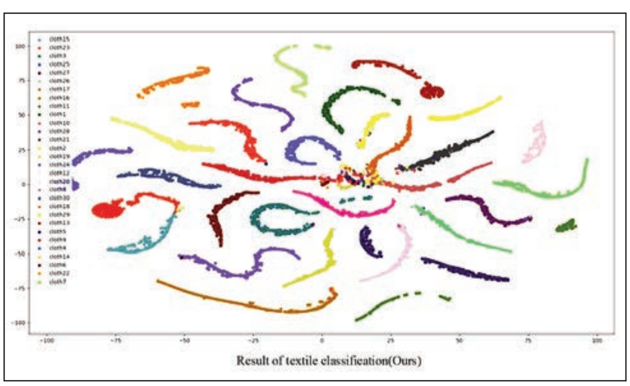

Fig. 5. Visualization of the classification result of 30 textile materials

T-SNE was presented by [31] and is mostly used to visualize high-dimensional data and project it into low-dimensional space. To get the classification recognition effect of our model visually, we visualize the experimental data with T-SNE, as shown in figure 5. It can be observed that a graph node represents a kind of fabric, we attempt to distinguish fabric categories with 30 different colours, and the more nodes of the same colour gather, the better the fabric classification. The node aggregation of the same fabric is obvious except for a very small part.

CONCLUSION

In this paper, we propose a customized graph neural network architecture for the identification and classification of textile material. Our hybrid model takes GraphSAGE to complete the graph embedding operation. and then introduce jump connection and adaptive aggregation mechanism, effectively combining the advantages of BiGRU-attention, thus further improving the model performance. Besides, the model is robust when fabric texture, colour, and other factors are disturbed. In addition, we apply a variety of classification metrics to evaluate the performance of our model. Compared with other baseline methods, the experimental results show that the performance of this method is superior to other existing research, and although there is still upward mobility in our classification effects, it is noteworthy that this work has potential in the textile and fashion industry. In the future, we will further understand the research frontiers of textiles to extract finer fabric features and more accurate motion information to achieve fabric simulation.

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The restoration of garment heritages based on digital virtual technology: A case of the Chinese pale brown lace-encrusted unlined coat

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ABSTRACT – REZUMAT

The restoration of garment heritages based on digital virtual technology: A case of the Chinese pale brown lace-encrusted unlined coat

Garment heritages are commonly missing evidence of restoration because of their age and complex preservation environment. Traditional restoration methods rely on the subjective experience of restoration personnel. Its restoration results are difficult to achieve accuracy and objectivity, exposing precious cultural relics to the risk of irreversible secondary damage. Taking the Pale Brown Lace-encrusted Unlined Coat as an example, this study puts forward a method of garment heritages restoration based on digital virtual technology. After fully researching the garment background information, we used deep learning and virtual twin technology to draw and cut the garment pieces, arrange and sew the garments, and complete the stained patterns. The results show that our method can restore the original appearance of the heritages relatively well, providing a new method reference for the inheritance and digital transmission of traditional garment heritages.

Keywords: *digitization, garment culture, deep learning, heritage restoration, pattern complement, virtual twin*

Restaurarea patrimoniului vestimentar pe baza tehnologiei virtuale digitale: Un caz de jachetă necăptușită cu dantelă de culoare maro pal confecționată în China

De obicei, patrimoniului vestimentar îi lipsesc dovezile de restaurare din cauza vechimii și a mediului de conservare complex. Metodele tradiționale de restaurare se bazează pe experiența subiectivă a personalului de restaurare. Rezultatele restaurării sale sunt dificil de atins cu acuratețe și obiectivitate, expunând relicve culturale prețioase la riscul de deteriorare secundară ireversibilă. Luând ca exemplu jacheta necăptușită cu dantelă maro pal, acest studiu propune o metodă de restaurare a patrimoniului vestimentar bazată pe tehnologia virtuală digitală. După ce am cercetat complet informațiile anterioare despre articolele de îmbrăcăminte, am utilizat învățarea profundă și tehnologia modelării virtuale pentru a desena și a croi piesele, a aranja și a asambla articolele de îmbrăcăminte, a construi tiparele. Rezultatele au evidențiat că metoda noastră poate restabili corespunzător aspectul original al patrimoniului, oferind o nouă metodă de referință pentru moștenirea și transmiterea digitală a patrimoniului vestimentar tradițional.

Cuvinte-cheie*: digitalizare, cultura vestimentară, învățare profundă, restaurarea patrimoniului, construcția tiparelor, model virtual*

INTRODUCTION

Cultural heritage is a precious carrier of historical and cultural information. The restoration and display of cultural relics are of key significance to the preservation and transmission of history and culture.

Unearthed cultural relics are often accompanied by varying degrees of deterioration. Due to the lack of accurate and reliable restoration evidence, for the same cultural relic, different periods and different restoration personnel may produce different restoration results, which is not conducive to determining its true historical appearance. To ensure the requirements of "minimum intervention" and "reversibility" in international conservation guidelines, digital virtual technology has become an important auxiliary tool in the restoration of cultural objects. In recent years, some progress has been made in the field of virtual heritage restoration. Digital photogrammetry, laser scanning, 3D modelling, and artificial intelligence have been used in the literature for heritage restoration studies. Hou et al. proposed a virtual restoration method for complex structural heritages based on multi-scale spatial geometry and applied it to the virtual restoration of the Thousand-Hand Bodhisattva in Dazu Country. The adaptive adjustment of their skeleton line extraction algorithm improves the centrality and topological relationships of the skeleton lines of the heritages, solving the problem of difficulty in discovering the logic of complex heritage geometry in the restored evidence [1]. Arbace et al. propose a recombination hypothesis of the fragments for formulating and evaluating reorganization hypotheses in digital space. This is expected to reduce the operational complexity of the restoration work and avoid the risk of further deterioration of the heritage [2]. The degree of wear and tear and restoration resistance of different categories of cultural relics vary greatly because of their different materials and organizational structures. Garment heritages are mostly composed of cellulose and protein materials. Its polymer chains are susceptible to fracture by external environmental influences. This brings great difficulty for its long-time underground preservation, physical restoration work and display transportation. Researchers mostly focus on the restoration of costume artefacts from the perspective of sewing processes and chemical treatment techniques. Ferrari Martina explored the possibility of using gellan-immobilized enzymes of bacterial origin (Bacillus alpha-amylase) to obtain a satisfactory starch removal from a damaged archaeological tunic-shroud from the Turin Egyptian Museum (Italy), without altering the original yarns or textile fibres [3]. Janpourtaher et al. analysed the materials of Songket sarong from the 19th century by using Field Emission Scanning Electron Microscopy and Energy Dispersive Spectroscopy to experimentally improve the stability of textiles and developed a method for the preservation of acid-free paper properly covered samples [4]. However, there is little literature that discusses a systematic approach to the restoration of garment heritages based on digital virtual technology in a full process. Based on this, the digital virtual restoration of garment heritages becomes more important [5]. The diversity of materials, the complexity of the organization, and the strong relevance of the aesthetic and social humanities behind the garment heritages all pose significant challenges to the virtual restoration of garment heritages [6]. We try to use digital virtual technologies such as virtual twin and deep learning to participate in the multi-step work of assisting in the restoration and display of garment heritages and provide theoretical references for the preservation and transmission of traditional costume culture.

GARMENT HERITAGES ANALYSIS

The tomb of Huang Sheng of the Southern Song Dynasty is known as “the treasure house of ancient Chinese silk” and is one of the most important physical evidence of the Chinese Maritime Silk Road [7, 8]. In October 1975, a stone tomb with a triple earthen structure was discovered in Fuzhou, China. The right side of the tomb is relatively well preserved, and its owner is named Huang Sheng. Huang Sheng's tomb yielded 480 pieces of funerary objects, including 354 pieces of costumes and silk fabrics, making it the largest known tomb of silk fabrics from the Song Dynasty. The garment heritages from Huang Sheng's tomb provide important physical information for people to understand the garment culture and textile skills of the Southern Song Dynasty. One of the most representative garment items among the excavated cultural relics is Pale Brown Lace-encrusted Luo Unlined Coat with light texture, exquisite patterns and exquisite craftsmanship [9].

Garment form

The culture and art of the Song Dynasty occupy a pivotal position in Chinese history. Influenced by Neo-Confucianism, the philosophical theories and literary thoughts of the Song Dynasty tended to be rationalized. People's aesthetic thinking also developed in the direction of pragmatic simplicity. The costumes of the Song Dynasty were fashioned with subtlety, and women's clothing emphasized the femininity of gentle, sensible and elegant [10]. The main dress forms in Song Dynasty are “robe”, “coat”, “undershirt”, “pants” and “skirt”. Among them, “coat” has an unlined coat and a thick coat. The length of the unlined coat is equal to or slightly longer than the upper body. It was worn with two lapels hanging down and was a common dress for noble women at home or when they went out.

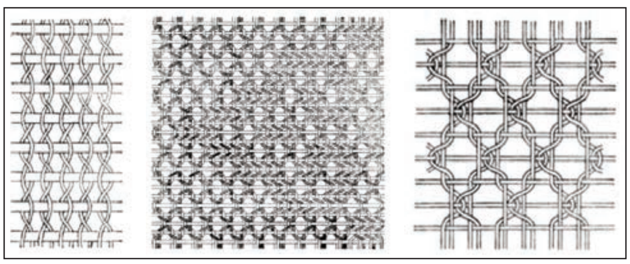
The Pale Brown Lace-encrusted Luo Unlined Coat is light brown overall. It has no buttons or ties on the collar and lapels. The length of the garment is 73 cm in both front and back, and the hemline reaches the middle of the thigh when worn on the upper body. The sleeves of the entire garment are straight, the hemline hangs down, and the collar is connected to the lapel, making it a straight one. The outer edge of the unlined coat near the neck is sewn with an additional layer of the short collar, which is overlapped and sewn on top of the original collar. Such a structure can increase the collar's fastness and also serve as a decoration. The large lapels are embroidered with peony, hibiscus, camellia and lotus patterns, and the small lapels are made with gold paint to make the patterns more gorgeous and exquisite. The overall colour of the garment is fresh and elegant, reflecting the elegant and harmonious aesthetic interest of Song Dynasty silk clothing. The Pale Brown Lace-encrusted Luo Unlined Coat is shown in figure 1.

Fig. 1. Pale Brown Lace-encrusted Luo Unlined Coat

Garment fabrics

Huang Sheng's tomb is located in Fujian Province, on the southeast coast of China. This area has a warm climate and abundant rainfall, which is suitable for growing mulberry trees and raising silkworms. It is one of the important silk-producing places in Chinese history. Pale Brown Lace-encrusted Luo Unlined Coat is a pure silk fabric. It is light in texture but strong in structure, comfortable and breathable. The extremely high level of weaving technology has allowed it to remain flat and the yarn straight for over 800 years without weft slanting.

Silk fabrics can be classified according to their tissue structure. The tissue fabric formed by twisting yarn is collectively referred to as Luo. Luo fabrics are divided into plain Luo and jacquard Luo. The plain Luo contains two warp-twisted plain Luo and four warp-twisted plain Luo. The jacquard Luo is divided into two warp-twisted jacquard Luo, three warp-twisted jacquard Luo and four warp-twisted jacquards Luo. The fabric of the composite collar of the unlined coat is two warp-twisted plain Luo, which is light in texture and moderately sparse. Its organization is shown in figure 2, *a*. The fabric of the large body piece of the unlined coat is the four warp twisted flower roving, which has different mesh sizes and resembles a fish net, as shown in figure 2, *b*. The unlined coat uses the four warp twisted leno at the big and small lapels. Four warp threads form a twisted group, and each of the four warp threads is circulated. Its left and right neighbouring groups are interwoven with large pores, which is very suitable for embroidery craft. Its organization is shown in figure 2, *c*.



a *b* *c*

Fig. 2. Unlined coat fabric organization illustrations: *a* – two warp twisted plain Luo; *b* – four warp twisted jacquard Luo; *c* – four warp twisted plain Luo

Garment patterns

The dress patterns before the Song Dynasty were relatively abstract. The popular scrolling grass patterns and composite flower patterns of the Tang Dynasty could not find direct prototypes in nature. A large number of natural images appeared in the garment patterns of the Song Dynasty. This aesthetic interest was largely due to the prevalence of literati painting in the Song Dynasty. The objects of literati painting in the Song dynasty were mainly flowers and birds in gardens and courtyards, which were lifelike and highly realistic. At the same time, people in the Song Dynasty took thinness as their aesthetic orientation. This aesthetic orientation was expressed in the dress patterns, which formed the main body of slender, dynamic plants and animals and the expression technique of mainly dots and lines. Song people loved flowers, and this is often recorded in historical materials. Song people’s love for flowers led to the prevalence of floral clothing patterns. The patterns appearing in the Pale Brown Lace-encrusted Luo Unlined Coat are all based on flowers and floral combinations, such as the use of peony, lotus, hibiscus and camellia floral combinations representing the four seasons at the lapel. Such a choice of subject matter was very popular in the paintings of the Southern Song Dynasty. The four seasonal flowers represent the rotation of the four seasons and symbolize the endless cycle of life rhythm. The flowers are in various postures, such as upward, downward, front and side, and the leaves are zigzagged and rolled. In terms of pattern organization, the four types of flowers are combined into a basic unit extending up and down in a bipartite continuous organization. The creator arranges the layout of flowers and branches and leaves according to the rectangular pattern boundary and the growth pattern of plants. The overall effect of the pattern is clear, balanced and rich in content.

Garment colour

The Confucian policy of the Song rulers had a great influence on the social characteristics of Song garment colours. Compared with the gorgeous and complicated colour characteristics of the Tang Dynasty, Song Dynasty clothing reduced the use of highly saturated colours and began to advocate light and simple colours. Men's clothing in the Song Dynasty was mainly in dark colours, and women's clothing was mainly in low-saturation plain colours. Soft colours such as violet, goose yellow and light green were commonly used in the colour scheme of garments, reflecting the aesthetic pursuit of tranquillity and simplicity [11]. After observing and comparing the unlined coat with other Song Dynasty costume items in kind, picture materials and restoration cases, we made restoration-oriented adjustments to the colours of the unlined coat. The colour recovery-oriented adjustment mainly includes the enhancement of pattern colour saturation and contrast, the normalization of main fabric colour difference, and the weakening of decay traces, as shown in figure 3.

We choose the clustering algorithm to perform colour analysis on the pre-processed garment images. The clustering algorithm can divide and merge intervals by calculating the distance between samples. We create five colour intervals based on the clustering algorithm and improve the quality of the interval partitioning by translating the different intervals through a circular positioning technique. To achieve the desired effect, the clustered colours were batch normalized and averaged based on the calculated colour distance values. The image cluster partition of

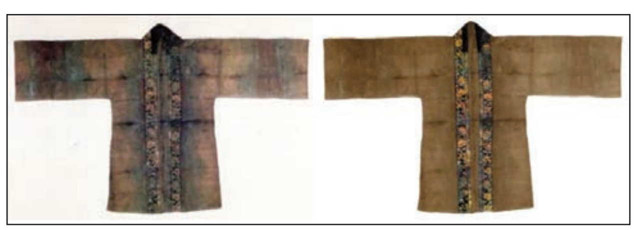


Fig. 3. Contrast of colour repair-oriented adjustment of unlined coat

Table 1

UNLINED COAT COLOR CLUSTERING ANALYSIS					
Colour	**Pale brown**	**Dark brown**	**Dark green**	**Black**	**Gold**
Impression Cluster Partitioning					
Percentage (%)	59.93	24.19	6.58	5.76	3.54
RGB	109/74/45	88/58/32	69/62/54	36/30/27	157/97/47

5 groups of images was set to consist of all colours within 10 pixels. The results of the unlined coat colour analysis were obtained by clustering as shown in table 1. The RGB (Red, Green, Blue) represent the colours of the red, green and blue channels. The RGB values of the five colours were extracted for subsequent colour recovery research.
From the analysis results, the overall colour of the unlined coat is even. The main colour of the garment is pale brown, with a light and elegant floral pattern, showing a quiet charm. A large dark colour was chosen as the base colour for the lapel pattern of the unlined coat. The light green branches and leaves and the golden flowers are set off by them to get a stately and elegant artistic expression of natural elegance.

Garment craft

The tomb owner, Huang Sheng, as a ruling class and nobleman of the Song Dynasty, spared no effort in the pursuit of perfection in her burial garments, from the choice of fabric to the design of a pattern on the cuffs. The costumes unearthed in Huang Sheng's tomb are extremely elaborate. Embroidery and golden paint were used on the unlined coat to make the pattern effect richer and more decorative.
Embroidery was used extensively on the lace of the unlined coat. Embroidery is used for the petals, stamens and leaf outline edges on the large lace pattern. The high level of embroidery makes the embroidery surface flat and precise, with a strong sense of three-dimensionality. The complex and expensive golden paint craft was used for the small lapels of the unlined coat. The garment maker dipped a patterned wooden plate into the gold paint and then printed the outline of flowers and leaves directly onto the thinly stencilled and ironed silk fabric. The width and thickness of the golden paint print depend on the strength of the wood panel used. The adhesion of the gold paint has weakened with time and some of the golden paint patterns have now fallen off [12].

RESULTS

Garment heritage restoration

With the maturity and popularity of digital technology, the virtual twin is showing an increasingly important role in garment development and display. Several companies have developed fully functional digital virtual garment development and display software platforms. These software platforms allow for varying degrees of human modelling, garment piece drawing, garment sewing, wear testing, and 3D display of finished garments. The open functionality and editable parameters of such software platforms provide effective support for the digital restoration of garment heritages. Such mainstream software platforms include CLO 3D from CVF in Korea, Optitex from EFI in the U.S. and Style 3D software from Lingdi Digital Technology in China. We chose the Style 3D software platform, version V4.8.405, which has a more complete digital repository and greater ease of use, for the restoration of the garment heritages in this study through a functional comparison.
Body model building
People in the Song dynasty admired the image of a slender and beautiful woman, and there are numerous descriptions of women's slender bodies in Chinese Song Poems. Such aesthetic standards for women of the era were widely practised among noble women who did not have to undertake heavy physical labour. The skeleton of the tomb owner, Huang Sheng, is well preserved. Based on the skeleton data, it can be deduced that Huang Sheng's height in his lifetime was about 160 cm. Based on the physical characteristics of women in the Song Dynasty, we fine-tuned the data for the Chinese GB/T1335.2-2008 clothing size women's A body type corresponding to 160 cm height, and the results are shown in table 2. The adjusted data was input into the Style 3D software platform for virtual body modelling (figure 4). The dimensions of the virtual body and the arrangement of the joints were set concerning standard specifications. We set the virtual human body in a stand-

Table 2

MODEL BODY PARAMETERS							
Item	**Height**	**Arm length**	**Neck circumference**	**Shoulder width**	**Bust**	**Waist circumference**	**Hip circumference**
Value (cm)	160.0	50.5	33.6	39.4	84.0	68.0	90.0

ing position with arms outstretched to facilitate the subsequent fitting of the garment, as shown in figure 5, a.

Garment structure restoration

According to the comparison of physical measurement and related information, we compiled various dimensional data of the unlined coat, as shown in table 3. Based on the structure of the garment and the information on each dimension, we draw up the shape diagram of the unlined coat, as shown in figure 4.

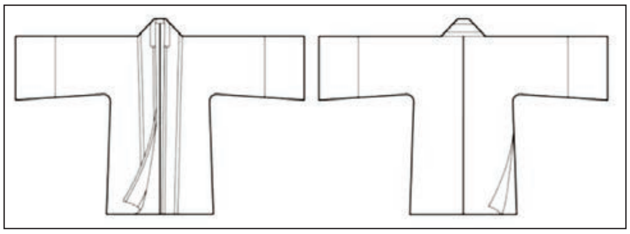


Fig. 4. Shape diagram of garment

The unlined coat cut pieces and data are stored in ".dxf" file format by Fuyi CAD software and then imported into Style 3D software for digital virtual garment placement and sewing. Correct and reasonable placement of the garment pieces and correspondence between the sewing threads are the keys to the smooth sewing of the garment. Errors such as tilting and reversing the garment pieces may lead to incorrect dressing and stitching. We finally determined the placement of the garment pieces as shown in figure 5, *b* after many times of garment piece placement, comparison debugging and simulation experiments. The part of the garment structure that is not ideal for wearing can be adjusted in time in the simulation state to ensure the integrity of the overall garment structure.

Garment pattern restoration

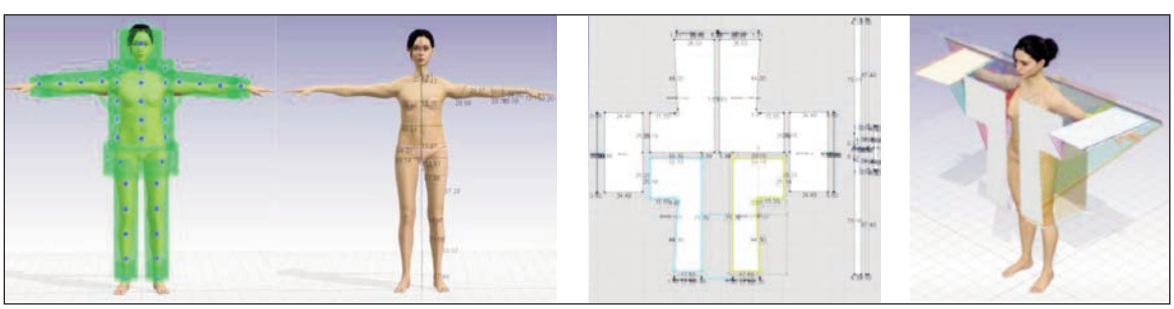
The logic of the geometric layout of the damaged part of the heritage is a key issue in the restoration of the heritage. Judgments based solely on the subjective experience of restoration workers tend to result in one-sided restoration results. The development of deep learning techniques provides effective methods for image remediation topics including heritage damage remediation. GAN works differently than most deep learning models that work serially. GAN does not require a variational lower bound but generates results directly by sampling noise. It is used by researchers for pattern complementation and creation [13]. In this study, we build a logical complementary model of garment heritages pattern defacement layout based on GAN to assist in pattern restoration.

Insufficient annotation samples, specification and style diversity of garment heritage patterns are significant challenges for training compared to most other image complementation training objects. Given such limitations, we propose a globally and locally consistent GAN for garment heritage line drawing completion, which assists in manual pattern restoration. For the machine algorithm to better understand and distinguish the structure of the pattern from the defective part, we manually outline and label the initial image. We distil the structure of the complete part of the original pattern and present it as a line drawing. We mark the defective areas of the pattern in the form of black blocks. For the problem of small samples of garment heritage patterns, we did sample augmentation on the dataset samples. We perform random flip, brightness or contrast adjustments in the present range to achieve the sample augmentation. The amplified data set samples are fed into the batch normalization algorithm for quality and specification harmonization. The trainability of the dataset is greatly improved

Table 3

DIMENSIONAL DATA OF THE UNLINED COAT

Item	Clothing length	Through-sleeve length	Waist width	Sleeve sleeve edge	Cuff width	Sleeve edge width	Front hemline width	Back hemline width	Hem edge width	Small lapels width	lapel lace width	Collar edge width
Size (cm)	73.0	133.0	47.0	25.0	25.5	0.5	48.0	52.2	1.3	1.5	4.3	2.5



a *b* *c*

Fig. 5. Virtual model and garment cutting piece position placement: *a* – virtual model joint point arrangement position and parameters; *b* – flat cutting piece of the garment; *c* – 3D placement of garment cutting piece

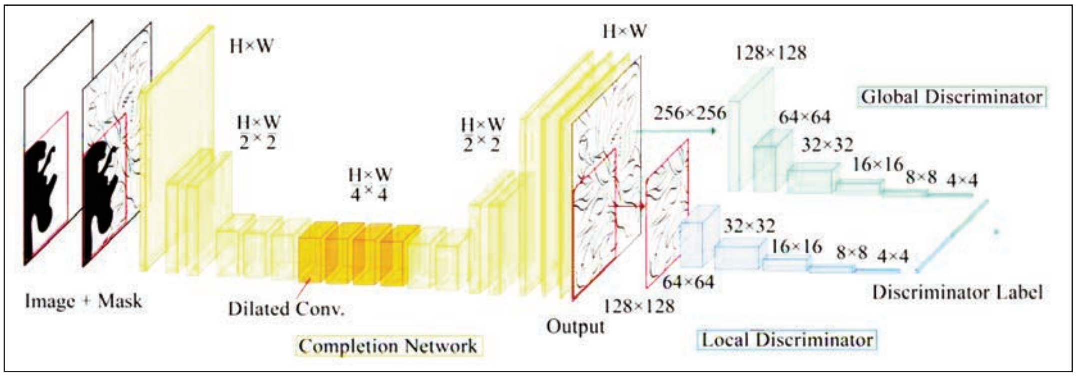


Fig. 6. The GAN architecture for line drawing completion

after image pre-processing by outlining, annotation, sample augmentation and batch normalization.

Following the manual line drawing step, we aim to complement the missing areas of the line drawing. The reason for not directly using an end-to-end pattern complementation network is that there are insufficient existing samples to fit this complex mapping. As an alternative, constructing a deep convolution network from the original defective line drawing to the complemented one is a compromise solution. We use H (height) to denote the height of the convolution layer and W (width) to denote the width of the convolution layer. Figure 6 depicts the globally and locally consistent GAN for line drawing completion [14]. The input of the GAN is the defective line drawing and its corresponding mask that is used to label the defective region and the output is a complemented line drawing. As a pre-processing, a constant colour is used to cover the completed region of the training input image, which is the average pixel value of the input image, before placing it into the network [15].

First, the completion network is a modified U-net which contains three down-sampling and up-sampling operations. Unlike the original U-net, the full convolution layers in the middle part are replaced by dilated convolution layers, which allows for increasing the area each layer can use as input. This is achieved by spreading the convolution kernels into the input map without increasing the number of learnable weights.

To discriminate the integrity of the images, global discriminators and local discriminators are used to further optimize the network parameters. The global discriminator is concerned with the harmony of the complemented image and the local discriminator is focused on the accuracy of the complemented details. The deep feature extraction encoder outputs the complemented image as a specified length label. At the end of the discriminator module, the outputs of two discriminators are fused by a concatenation layer to predict the probability of the image being real.

Let $C(x,M_c)$ denote the completion network in a functional form, with x the input image and M_c the completion region mask. For regular training, the weighted MSE (Mean Square Error) loss considering the completion region mask is used. The weighted MSE loss is shown below:

$$L(x,M_c) = \|\, M_c \odot (C(x,M_c) - x)\,\|^2 \qquad (1)$$

To estimate the complemented image, the context discriminators are treated as the GAN loss. This is the key part and involves transforming the standard optimization of the neural network into a min-max optimization problem, where the discriminator network is jointly updated with the complete network. For the network with one discriminator, the optimization equation is shown below:

$$\min(C)\max(D)\,\mathbb{E}\,[\log D(x,M_d) + \log(1 - D(C(x,M_c),M_c)] \qquad (2)$$

where M_d is a random mask and M_c – the input mask. Furthermore, the optimization equation of network with global and local discriminator is shown below:

$$\min(C)\max(D)\,\mathbb{E}\left[L(x,M_c) + \alpha \log D(x,M_d) + \alpha \log(1 - D(C(x,M_c),M_c))\right] \qquad (3)$$

In the training procedure, we first use the MSE loss function separately to train the completion network to make the network roughly converge. Then, the combined GAN loss function (L_{global} and L_{local}) is applied to fine-tune the network resulting in high accuracy. This helps stabilize the learning process. Image complementation results under the incommensurate loss function as shown in figure 7.

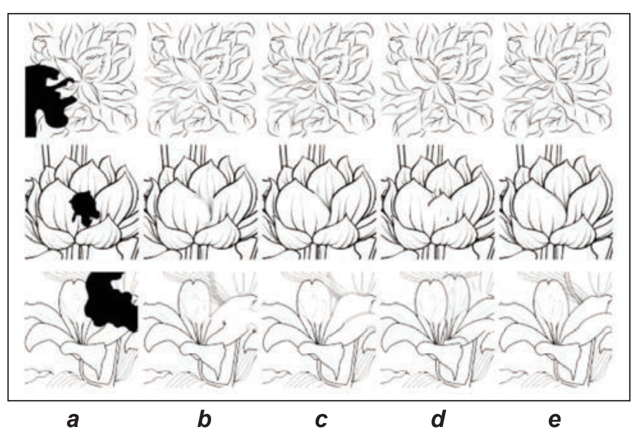


Fig. 7. Image complementation results under the incommensurate loss function: *a* – source; *b* – MSE; *c* – MSE+L_{global}; *d* – MSE+L_{local}; *e* – MSE+L_{global} + L_{local}

The line sketches patched by the machine algorithm are used as a logical reference to lay out the structure of the pattern in the defective part. By observing the logical details of the pattern around the defective part, we docked and organized the edges of the restored part. Then, we complete the restoration of the stained part and its embedding in the overall pattern by manually outlining, making the complete pattern both rational and beautiful. Based on the data results of the pattern units in the previous colour analysis section, we colour-fill the complete pattern structure. The pattern restoration result is shown in figure 8.

Fig. 8. Pattern restoration result

The craft texture of the pattern also plays a key role in the artistic expression of the garment heritage pattern. In this study, the craft texture restoration of the pattern is achieved by selectively adding mapping to the pattern and adjusting the parameters. The pattern of the large lapel is mapped with normal and displacement mapping and the pattern of the small lapel is mapped with metallic and transparency mapping in the Adobe Photoshop software. We import the craft texture effect into the style 3D software platform, overlay it in the edit bar and adjust the position of the texture so that it corresponds exactly to the original pattern. After several matching attempts, we determine the suitable intensity value for the normal map at the large lapel is 0.51, the suitable height for the replacement map at the large lapel is 0.2 mm, the suitable intensity value for the transparency map at the small lapel is 0.85, and the suitable intensity value for the smoothness map at the small lapel is 0.63. With this parameter, we obtained the pattern craft effect with the sense of light and shadow, bumpiness and texture. The pattern craft recovery method and effect are shown in figure 9.

Fabric restoration

The unlined coat is a typical Southern Song pure silk fabric with meticulous and tight organization, comfortable and breathable. The warp and weft density of the main fabric is 7214 roots/cm. The diameter of the warp thread is 0.4 mm and the diameter of the weft thread is 0.6 mm. The warp and weft density of the fabric at the lapel is 4840 roots/cm. The diameter of warp thread is 0.2 mm and the diameter of the weft thread is 0.4 mm. The warp and weft density of the fabric at the laminated collar is 3631 stitches/cm. The warp diameter is 0.15 mm and the weft diameter is 0.25 mm. Concerning the modern silk fabric properties and processing experience, we matched the three fabrics of the unlined coat with the silk fabrics in the database and fine-tuned the fabric property parameters [16]. The final fabric properties entered are shown in table 4 to facilitate the subsequent fitting of the garment.

Structural detail optimization

Based on the completion of the overall garment structure restoration, we optimize and adjust the structure details based on the feedback from the garment stress test. Traditional garment stress testing relies on the physical production of garments, and the number of stress test points is limited by the experiment. With the support of virtual twin technology, the stresses of the garment during wear can be calculated based on the garment

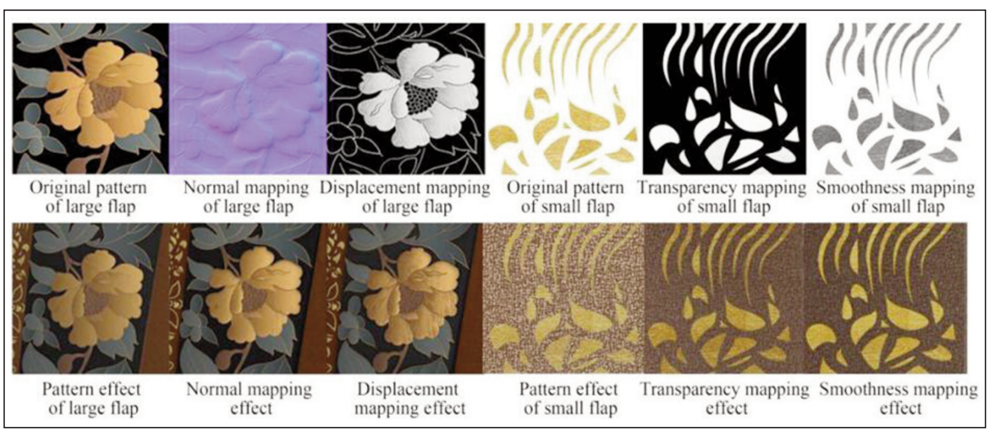


Fig. 9. Pattern craft restoration

Table 4

FABRIC PHYSICAL PROPERTIES								
Fabric	**Stretch weft**	**Stretch warp**	**Stretch bias**	**Bending weft**	**Bending warp**	**Bending bias**	**Weight (GSM)**	**Thickness (mm)**
Main fabric	0.00	12.48	7.92	7.00	8.10	7.70	160.10	0.10
Counterpane fabric	17.88	12.89	0.44	10.72	14.38	12.14	27.78	0.10
Conforming collar fabric	31.01	21.39	1.83	11.64	13.36	12.32	69.70	0.10

Table 5

STRESS VALUES AT CRITICAL POINTS									
Item	**Back cervical point**	**Lateral neck point**		**Arms**		**Frontal bust line point**		**Lateral hip line point**	
Number	1	2	3	4	5	6	7	8	9
Position	Medium	Left	Right	Left	Right	Left	Right	Left	Right
Stress value (kPa)	6.41	30.63	23.94	5.40	4.32	9.65	7.46	3.13	3.53

a *b*

Fig. 10. Three-dimensional display effect: *a* – stress distribution of unlined coat; *b* – garment restoration effect

structure, the model's body shape and the fabric properties. After entering these data in the Style 3D software platform, we can dynamically observe the stress distribution of the garment while it is being worn in a real-time visualization window. The unlined coat that completed the structure and fabric restoration in the previous paper was worn on the body of a simulated model of Huang Sheng's body type, and its stress test results are shown in figure 10, *a*. The overall stress distribution of the unlined coat is relatively uniform and all of them are in a non-stressed state below 40 kpa. The stress test data of nine representative structural points are shown in table 5. In summary, the recovered unlined coat structure does not require further detailed optimization adjustments in this session.to facilitate the subsequent fitting of the garment, as shown in figure 10, *b*.

The Pale Brown Lace-encrusted Luo Unlined Coat that has completed the restoration of structure, fabric, pattern, colour and technology is worn on the virtual model, and the restoration effect was completed as shown in figure 9, *b*.

CONCLUSIONS

This research proposes a garment heritage restoration method based on deep learning, virtual twin and other digital virtual technologies. We elaborate and analyse how digital virtual technology can intervene in the restoration of the structure, pattern, colour, and fabric of garment heritages, and practice restoration with the example of the Pale Brown Lace-encrusted Luo Unlined Coat from Huang Sheng's tomb in the Southern Song Dynasty in Fuzhou, China. As shown by the results, our proposed method can relatively well restore the original appearance of the garment heritages and meet the display needs of the public. However, there are some limitations in this study. The method proposed in this study has a relatively high requirement for the proportion of missing and damaged information on garment heritages, which will be focused on in our future work. We hope that this study will provide a theoretical reference for the restoration of garment heritages and help the inheritance of traditional costume culture.

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Shaping the textile women's digital work sustainability by legislative and taxation adjustments

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ABSTRACT – REZUMAT

Shaping the textile women's digital work sustainability by legislative and taxation adjustments

The objective of this study is to examine the relationships between factors connected to the capability aspects of the female working on the digital platform and the performance-sustainability of that employment. There are selected 3 groups of factors: first, professional learning and digital skills and capabilities of digital female workers; second, entrepreneurial learning and orientation as a personal and corporate precondition for successful work online on a platform, and third group of factors connected to the legal ecosystem issues, tax, social protection, and labour relations as important frameworks to digital work sustainability. The dependent variable is defined as females from textile and fashion design sub-sectors working online on the platform's sustainability, treated as performance. Empirical research with 396 female participants working online on platforms connected to the jobs, tasks, and freelancing from textile, fashion design, and other textile sub-sectors was provided in Serbia in 2022. They have by a five-level Likert scale evaluated the level of the factors and their 16 statements' impact on the dependent variable. All three independent variables do exhibit a positive relationship with the dependent one. The most significant influence has the professional and digital skills and capabilities of female workers or their corporations. The paper's findings can serve to remind female digital workers that they cannot neglect the element of entrepreneurial capabilities and digital and professional skills in their digital activities. The results can be useful for the government to enforce consistent, dynamic, and adjusted taxation, social protection, incentives, and employment regulations for textile female digital workers and all others in boosting employment within new flexible patterns and technologies. The research is further shown relative to the SDGs on gender equality, digital divide issues, and pillars of social, economic, and environmental sustainability. The research model for this study was drawn from the literature on digitalization, work flexibility, institutional, financial and social theory and contributes to the current literature.

***Keywords**: female digital work, gender equality, gender digital divide, techno-entrepreneurship, textile and fashion*

Adaptarea sustenabilității activității digitale a femeiilor din industria textilă prin măsuri legislative și fiscale

Obiectivul acestui studiu este de a examina relațiile dintre factorii legați de aspectele de capacitate ale femeii care lucrează pe platforma digitală și sustenabilitatea bazată pe performanță a respectivei angajate. Sunt selectate 3 grupuri de factori: în primul rând, formarea în context profesional și abilitățile și capacitățile digitale ale lucrătoarelor pe platforma digitală; în al doilea rând, formarea și orientarea antreprenorială, ca o condiție prealabilă personală și corporativă pentru munca de succes online pe o platformă, iar al treilea grup de factori este legat de problemele ecosistemului juridic, impozitele, protecția socială și relațiile de muncă în calitate de cadre importante pentru sustenabilitatea activității digitale. Variabila dependentă este definită ca fiind reprezentată de persoanele de sex feminin din sub-sectoarele textile și design vestimentar, care lucrează online la sustenabilitatea platformei, tratată ca performanță. Cercetarea empirică cu 396 de femei participante care lucrează online pe platforme conectate la locuri de muncă, sarcini și freelancing din domeniile textil, design vestimentar și alte sub-sectoare textile a fost realizată în Serbia în 2022. A fost evaluat nivelul pe o scară Likert pe cinci niveluri al factorilor și impactul celor 16 afirmații ale acestora asupra variabilei dependente. Toate cele trei variabile independente prezintă o relație pozitivă cu cea dependentă. Cea mai semnificativă influență o au abilitățile și capacitățile profesionale și digitale ale lucrătoarelor de sex feminin sau ale corporațiilor acestora. Concluziile lucrării pot servi pentru a le reaminti lucrătoarelor de pe platforma digitală că nu pot neglija elementul capacităților antreprenoriale și al competențelor digitale și profesionale în activitățile lor digitale. Rezultatele pot fi utile pentru guvern pentru a aplica impozitarea, protecția socială, stimulentele și reglementările de angajare consecvente, dinamice și adaptate pentru lucrătoarele de sex feminin pe platforma digitală din industria textilă și pentru toate celelalte, pentru a stimula angajarea în noile modele și tehnologii flexibile. Cercetarea este prezentată în continuare în legătură cu Obiectivele pentru Dezvoltare Durabilă privind egalitatea de gen, problemele decalajului digital și pilonii durabilității sociale, economice și de mediu. Modelul de cercetare pentru acest studiu a fost extras din literatura de specialitate privind digitalizarea, flexibilitatea muncii, teoria instituțională, financiară și socială și contribuie la literatura actuală.

***Cuvinte-cheie**: activitatea digitală feminină, egalitatea de gen, decalajul digital de gen, tehno-antreprenoriat, textile și modă*

INTRODUCTION

Concerning the problems of high unemployment rates among women during the Covid 19, particularly relevant to this research are the digital labour or market opportunities that arise for gender working online on platforms as enforcement mechanisms for the demand for digital labour. The pandemic led to a widespread shift of workers to work from home, which changed the nature of employment in the EU and Serbia in the long run. Many workers, including a high proportion of women, now work flexibly in some form and many desire patterns for their next job. 11% of workers in the EU reportedly are active in platform work [1]. Many people (an estimated 4.2 million in 2013) around the world worked as virtual freelancers [2–7]. More than half of the GDP in many EU countries is expected to be digital by 2022 (the European Commission's 2022 Work Program supports digital transformation). Employees operating as freelancers in Serbia have more than doubled in number in the last five years, with a large share of women employed by gig economy businesses. Although this type of work offers more flexibility, workers, especially women, are affected by wage disparities and worse working conditions. Although the EU has included specific provisions for platform workers in its action plan, legal structures in Serbia are not adapted to digital work patterns, and workers have called for stronger labour and social protection. It is therefore critical that policymakers in Serbia address these concerns and effectively shape the transformation by seeking to create new employment opportunities for women and help them acquire the digital skills they need to benefit from expanded opportunities.

The authors focus their research on the relationships between the sustainability of women's digital employment on a platform and the educational, digital skills, entrepreneurial learning, and orientation and factors of institutional regulatory structure's adaptation to digital transformation and flexible work. By choosing women's digital work opportunities the authors paid attention to SDGs pillars of sustainability and gender equality (the EU Treaty on Functioning mandates to eliminate inequalities and promote equality by 2030, so why is important that the employment rate of women would o increase faster than that of men by the end of the decade) [8].

Serbia is taken as a case country for the research, as it is in terms of population, in the world among the ten economies by the number of freelancers, is one of the dominant online digital jobs for women, especially young ones [9]. The poor quality of jobs offered to women in Serbia, the short-term jobs that women find, the insecure and volatile forms of temporary work with many inconveniences that force them to other forms of employment, and the insecurity in regular jobs could be considered as reasons for freelancing of women, as most often their online work the on platform in Serbia. The country is very attractive for this type of work, especially for women, which reflects in the flourishing of digital platform work in Serbia [10], approximately 100,000 freelancers in 2021 were employed in equal numbers (49.2%) by women and (50.8%) by men. The online platform workforce (both gender) in Serbia is generally highly skilled, with most having a post-secondary education or higher. The gender gap in online platform professions is striking: the IT sector is heavily dominated by men paid much better than women predominate in writing, translation, language courses, textile design, fashion, and other sub-sectors. 36% of employers on the platform are legal entities, 20% are natural persons, and 30% are mixed enterprises. 94% of freelancers reported that they do not conclude a contract or that the contract has no meaning in the Serbian legal system. About two-thirds of Serbian platform freelancers work for foreign clients. The number of female platform workers is rising, the most work through digital labour platforms as their primary source of income. Thirty of them intend to continue working this way in the future, as the average gross salary of online workers is almost double the average gross salary in the country, which was the further reason for the authors to focus on the regulatory structures ecosystem to support these trends development. As far as the legal framework for platform work in Serbia is concerned, there are theoretical and practical gaps in the legal system, policy, and practice.

Females from the textile and fashion sector work in various patterns of digital activities online on platforms such as salary work arrangements, freelancers, entrepreneurs, small businesses, and undeclared workers. For most of these legal forms having an entrepreneurial education, learning and orientation are essential for success [11–13] in all dimensions, autonomy, proactiveness, innovativeness, risk-taking, and achievement [14–16]. That was the reason for the authors to consider entrepreneurial learning and orientation a relevant variable for the research of the possible interdependence between women from the textile and fashion sector working online on platform sustainability [17, 18].

Although platform work is a diverse phenomenon, the platform or gig economy is commonly understood to encompass crowd labour and work-on-demand via applications. Non-standard employment, according to the International Labour Organization includes part-time and temporary work/agency work, various multi-party employment connections, dependent self-employment, and concealed employment ties. Many studies on platform work see non-standard work patterns with casual, daily, or seasonal contracts as not covered by standard employment protection, or are only covered to a limited extent in expansion. Although many platform workers' legal status is unclear, they are mainly classified as self-employed. Work can also be done under civil law in many countries, with contracts used for work done by self-employed people and to control short-term employment arrangements. Not all non-standard workers are precarious, as some non-standard work contracts, such as fixed-term or part-time contracts, may provide sufficient job and income security. Some civil law traditions refer to contracts that are not officially regulated, which does not apply to a large number of non-standard transactions.

The employment situation of female workers on the platform in Serbia is a pressing labour market and fiscal regulatory issue in the country. These employees are at high risk of being placed in the wrong category, not being registered, not disclosing, or, in small amounts, engaging in self-employment, although a field relationship takes the form of an employment relationship (even if the terms and conditions of the forum say otherwise). The platform workforce in Serbia, for example, is dominated by young people, more than 40% of whom are young women aged 20–35, who can be integrated into the amended labour law to create flexible work patterns. It is similar to the offline world situation, where most of their working peers also lack job security. Many EU nations provided labour law modernization and labour market flexibility through modifications, according to which common law systems are more adaptable to changing economic situations than civil law systems, and through the political channel. In Serbia, for example, those who have organized themselves have predominantly opted to be entrepreneurs (18% are women), and just a few have launched a firm. Because no other solutions may be authorized as self-employed environments, following the model of existing liberal solutions, many female digital workers on the platform live in secret jobs, in the informal sector. The platform is not recognized in Serbia as an employer, and by its very nature, digital work belongs to flexible forms of work assignment. As a result, the disparity between legal remedies and new job kinds adds to the expansion of informal employment. Thus, many freelancers do not have a contract according to the Serbian legal system and do not provide guarantees that the employer will abide by what is agreed in the contract.

The term sustainability used in this research refers to initiatives, programs, and policies that aim to preserve a unique resource. It links to the sustainability pillars [19, 20], and each of the 17 SDGs that include gender equality through sustainable female employment as integrated goals. That content is mostly connected to the aims of SDG 5 (Employment and economic benefits of women, their equality), SDG 8 (Average salaries and unemployment rates), and SDG 12–15 with its aims on the pillar of environmental sustainability, gender-sensitive, where women's voices and perspectives are critical in addressing climate and environmental sustainability challenges; and SDG 17 [21]. The following four pillars of sustainability illustrate the complexity of what is required to ensure the sustainability of textile women's platform work and jobs:

- *Human sustainability* is related to human capital in society, where women are factors in human development and human resource building [22, 23].
- *Social sustainability which is* a time of pan-democracy, social accountability could support social and economic resilience, and ethical issues related to technological development are now more addressed through national laws and regulatory structures.
- *Economic sustainability* which focuses on capital preservation aiming to enhance the quality of life by involving women in economic development through their equal participation is of special importance for the research. It is supported by ecological arrangement and social capital relations among people, in which women must be at the centre [24, 25].
- *Environmental sustainability* aims to contribute to the improvement of human welfare through initiatives to protect natural capital and applications [26].

In terms of the SDGs' postulates and the four pillars of sustainability, there are many barriers to women's platform work sustainable development. In addition, gender gaps in age, income, and urban/rural areas reinforce the gender digital divide, lower-income levels than men due to social conventions (lack of conventional security, land, or property generally under a man's name) [27]. Among the financial obstacles is the financial institution's inability to develop appropriate financial products for women, as well as unequal educational chances for women which lead to low numeracy and computer literacy [1, 28, 29].

Women also face individual constraints on the labour market's demand side, a lack of work experience, academic disparities, lack of design and professional capabilities for the textile work on the internet, limited mobility, as well as limited asset ownership and control, non-innovative tax policies, incentive systems, social protection, and security concerns, that prevent them from finding and maintaining work opportunities on the platform [30]. On the demand side of the labour market, challenges can be seen in the drivers for digital jobs, skills, and work arrangements needed for the platform work, which are the main motives for the research, and should also be supportive of the national authorities' activities on the innovation of their financial and labour regulatory structures in the creation of an ecosystem for such work of women, and human, social and economic sustainability aims fulfilment [31]. Other general drivers of demand for digital jobs for female workers from the textile and fashion industry on the platform can be identified in the relation to working opportunities for women from the textile and fashion sector: Online Outsourcing, the Private textile sector, businesses in the ICT sector, Digital entrepreneurship, Virtual freelancing, Microwork, Digital online, Platforms for job matching via the internet.

The context of the research is presented through the introduction, literature review, materials, and methods with the key results, conclusion, and references used.

MATERIALS AND METHODS

For the research, there was provided with an empirical online questionnaire in Serbia in 2022. The sample of the research was 396 female respondents, aged 20–46, working online on various platforms. Five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) was mentioned in the questionnaire. All respondents were needed to agree or disagree with the 16 statements related to further four variables with the rank that best describes their reaction.

A variable – Professional and digital skills and capabilities (abbr. PDS), with its claims:

- *Skilling for a digital job should be the guiding principle in textile women's well-being, empowerment, and anti-poverty promotion policies*.
- Investing in the professional skills of textile women, and improving access to programs under the umbrella of human sustainability in the long term. (Human Sustainability).
- Support women from all walks of life to new job opportunities and help companies provide higher quality digital jobs to qualified women, with better access to digital technologies, digital literacy, skills gaps, and shortages, help SDGs goals fulfilment.

B variable – Entrepreneurial learning and orientation (ELO), with its claims:

- Entrepreneurial orientation of the female digital worker or entrepreneur from the textile, and fashion sector with autonomy in decision-making and risk-taking, achievement-guided, proactiveness, innovativeness, and readiness to assume responsibility for failure could benefit from capitalizing on new digital working opportunities.
- The entrepreneurship competence of female textile workers through measures supporting lifelong learning could lead to better learning outcomes in competencies: problem-solving, digital competence, tolerance, entrepreneurial competence, and a responsible attitude towards the environment.
- Entrepreneurial learning, Planning, design, Implementation, Monitoring, and evaluation including the provision of practical entrepreneurial experience to help establish a functional education and develop entrepreneurial competencies.

C variable – Legal structures, Tax, labour law, and social protection regulation and policy (abbr.TP), with its claims:

- The financial, taxation legal void, ad Serbian labour market policies are unsuited to the flexibility of work in the digital age and are more vulnerable to social exclusion, poverty, and child and health care of female digital workers from the textile and fashion sectors.
- Social protection for female workers from the textile and fashion sectors working on digital platforms in the digital era of pandemics is not offered in a way that encourages formal labour on platforms, but undeclared work.
- Improving online platform labour laws is important for the long-term viability of women's digital employment and platform employers' legal treatment.

The dependent variable with its statements is defined as follows*:*

D variable – *Textile women's platform work sustainability* (abbr. TWPWS):

- Full digital labour market involvement with gender equality of women working in textile and fashion sectors promotes long-term economic growth and sustainable development (*Economic and Environmental sustainability*).
- With responsibility for securing food, water, fuel, and shelter for their households, women are dependent on natural resources and could be agents of change in their responsible digital work in the textile and fashion sectors (*Environmental sustainability*).
- New digital technologies, and family-friendly policies, would help to narrow the gender gap and digital divide *(Social Sustainability).*

The research's hypothesis is defined as follows, *H0 = PDS, ELO, and TP levels significantly impact the level of TWPWS.*

Descriptive statistics for the statements made are given in table 1. The highest mean value has statement a11 and amounts to 4.4570707 (*Skilling for a digital job should be the guiding principle in textile women's well-being, empowerment, and anti-poverty*

Table 1

STATEMENTS VALUATION						
Statement	a_{11}	a_{12}	a_{13}	b_{11}	b_{12}	b_{13}
Mean	4.4570707	4.3636364	4.3409091	4.3560606	3.8712121	4.3030303
Std Dev	0.6043517	0.6195882	0.5488245	0.7200483	0.5567351	0.6154886
Std Err Mean	0.0303698	0.0311355	0.0275795	0.0361838	0.027977	0.0309295
Upper 95% Mean	4.5167774	4.4248483	4.39513	4.4271975	3.9262145	4.3638373
Lower 95% Mean	4.397364	4.3024244	4.2866882	4.2849237	3.8162097	4.2422233
N	396	396	396	396	396	396
Statement	c_{11}	c_{12}	c_{13}	d_{11}	d_{12}	d_{13}
Mean	4.5075758	4.1060606	4.3863636	3.9545455	4.1515152	4.3409091
Std Dev	0.5579739	0.5814549	0.6596631	0.5061191	0.5440334	0.5488245
Std Err Mean	0.0280392	0.0292192	0.0331493	0.0254334	0.0273387	0.0275795
Upper 95% Mean	4.5627006	4.1635052	4.4515348	4.0045473	4.2052627	4.39513
Lower 95% Mean	4.4524509	4.048616	4.3211925	3.9045436	4.0977676	4.2866882
N	396	396	396	396	396	396

Table 2

MODEL EVALUATION	
Parameter	**Value**
RSquare	0.751689
RSquare Adj	0.749788
Root Mean Square Error	0.208877
Mean of Response	4.14899
Observations (or Sum Wgts)	396

Table 3

ANOVA				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	3	51.773505	17.2578	395.5544
Error	392	17.102758	0.0436	Prob > F
C. Total	395	68.876263	-	<0.0001

promotion policies). The lowest mean value has statement b12 and amounts to 3.8712121.

Multiple correlations and regression analysis show that the coefficient of multiple determination is 0.751689, which means that with 75.46% variability, the dependent variable D can be explained by the independent variables: A, B, and C (table 2). The correlation of the variables is strong.

The assessment of statistical significance amounts to [F(3,392) = 395.5544, p<0.0001]. It is given in table 3.

Table 4 determines the magnitude of the contribution of independent variables to the dependent variable D. The highest contribution has the independent variable A and it is 0.571978, then the variable C and it is 0.289564, and the lowest contribution has the independent variable B and it is 0.207854. Based on these data, the set hypothesis H0 can be accepted: Levels A, B, and C in groups affect level D.

Based on the data from the previous table, a multiple regression equation (equations 1 and 2) can be formed, which reads:

$$y = -0.048048 + 0,5250467 \cdot x_1 + 0,1722494 \cdot x_2 + 0,2709472 \cdot x_3 \quad (1)$$

or

$$D = -0.048048 + 0.5250467 \cdot A + 0.1722494 \cdot B + 0.2709472 \cdot C \quad (2)$$

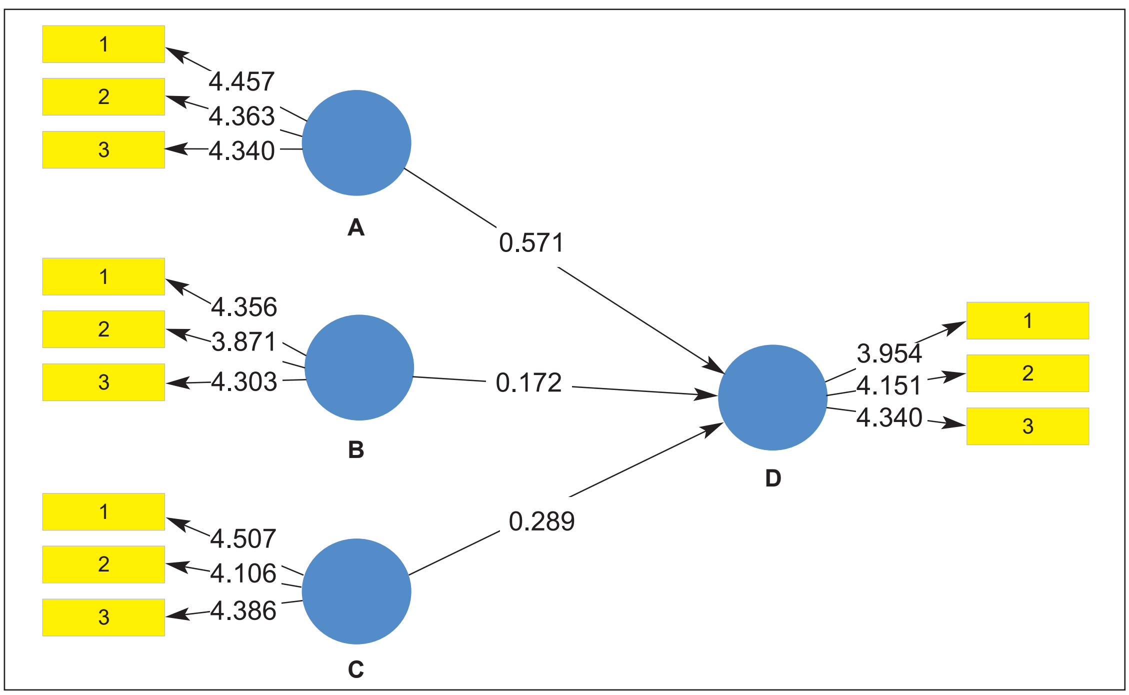

Fig. 1. Path coefficients results

Table 4

CONTRIBUTION COEFFICIENTS						
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**	**Std Beta**	**VIF**
Intercept	–0.048048	0.124458	–0.39	0.6997	0	-
A	0.5250467	0.027414	19.15	<0.0001	0.571978	1.4080296
B	0.1722494	0.023299	7.39	<0.0001	0.207854	1.2478428
C	0.2709472	0.029922	9.06	<0.0001	0.289564	1.6142929

Key findings of the research confirmed the main hypothesis resulting in the positive relationship of all defined factors and statements with the digital work sustainability of textile and fashion design women on the platform. The most important role has educational factors, professional and digital skills, and capabilities, which are the precondition for the job itself, and long-lasting factors that have to be permanently improved as the digital labour market requirements developed. Positive relationships are found with entrepreneurial learning and orientation and also legal, and financial structures as part of the institutional ecosystem which with its level of adjustments and innovation in favour of flexible patterns of work and digitalization supports the sustainability of such employment of women. Sustainable digital employment of women is the aimed performance of the research.

CONCLUSION

The research on the digital platform work of women's development and factors of impact on its sustainability realized in this paper has shown that the sustainability of that work depends on the professional and digital skills and capabilities of textile and fashion women in Serbia and could be seen as a driver for their digital employment as a performance. Also has been shown that inclusive macroeconomic policies are important for the SDGs (Goal 5), defined as regulatory structures and policy factors of importance for the supportive ecosystem development.

The government, through its regulatory structures and policy-level adjustments or omissions, affects WPWS's economic and social SDGs goals. As far as the legal framework for women's platform work in Serbia is concerned, there are theoretical and practical gaps in the financial legal system, fiscal policy, and practice.

The authors consider further exploring the conditions necessary to strengthen the fiscal ecosystem for sustainable women's platform work in Serbia very important. Modernization of the labour legislation for platform work of female textile and fashion design workers and practices tailored to them and their businesses could be supported by the findings of this research.

Entrepreneurial learning and orientation as a less important factor in the relationship with digital employment of textile women mean that female entrepreneurship in the sector and entrepreneurial orientation need to be permanent subjects in the learning programs and culture to strengthen the innovativeness and achievement approach of female technopreneurs in the textile and fashion industry sectors.

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Digital methods in the development of adaptive clothing for people with disabilities

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ABSTRACT – REZUMAT

Digital methods in the development of adaptive clothing for people with disabilities

Social integration of people with disabilities is a significant issue, therefore effective interventions to provide improvement of quality of life for people who have some kinds of disabilities are crucial. Specialists from various fields, including those in the field of clothing design, are working on creating products that meet people with disabilities' needs. These products must be ergonomic, comfortable and provide the necessary psychological comfort. The whole process of designing functional products is very complex, it requires continuous research, using knowledge from various fields for better development of products.

This paper addresses the topic of developing adaptive clothing for people with multiple sclerosis in the context of social inclusion and adaptation to new ways of life. All the proposals and ideas are analysed accordingly and different constructive and technological solutions are proposed to customize and adapt the basic clothing.

Keywords: *adaptive clothes, multiple sclerosis, 3D design, CLO 3D software, simulation*

Metode digitale în dezvoltarea articolelor de îmbrăcăminte adaptate pentru persoanele cu dizabilități

Integrarea socială a persoanelor cu dizabilități este o problemă importantă, prin urmare intervențiile eficiente pentru a asigura îmbunătățirea calității vieții persoanelor, care au anumite tipuri de dizabilități, sunt cruciale. Specialiști din diverse domenii, inclusiv cei din domeniul designului vestimentar, lucrează la realizarea de produse care să răspundă nevoilor persoanelor cu dizabilități. Aceste produse trebuie să fie ergonomice, comode și să ofere confortul psihologic necesar. Întregul proces de proiectare a produselor funcționale este foarte complex, necesită cercetare continuă, folosind cunoștințe din diverse domenii, pentru o mai bună dezvoltare a produselor.

Această lucrare abordează tema dezvoltării articolelor de îmbrăcăminte adaptative pentru persoanele cu scleroză multiplă în contextul incluziunii sociale și al deprinderii cu un nou mod de viață. Toate propunerile și ideile sunt analizate în consecință și sunt recomandate diferite soluții constructive și tehnologice pentru personalizarea și adaptarea îmbrăcămintei de bază.

Cuvinte-cheie: *articole de îmbrăcăminte adaptive, scleroză multiplă, proiectare 3D, softul CLO 3D, simulare*

INTRODUCTION

Multiple sclerosis is an autoimmune disease that affects the central nervous system, causing demyelination, axonal degeneration, and gliosis. This impairment of the immune system leads to lesions that produce motor, sensory, cognitive, visual or even sphincter dysfunctions (most often urinary and intestinal). In the more or less long term, these disorders can progress to an irreversible handicap. Even if current treatments can reduce relapses and improve the quality of life of patients, they are most often insufficiently effective in preventing the progression of the disability in the medium-term [1, 2].

Between episodes, the symptoms may disappear completely; however, it often results in permanent neurological problems, especially in more advanced stages of the disease.

For most people with multiple sclerosis, the severity of the symptoms depends on the temperature. Therefore, choosing the right clothes is very important. At the beginning of the disease, weakness is often the problem and the best clothing choices would be zippered clothing or Velcro. As the disease progresses, partial paralysis may occur, which requires the choice of traction items or side zipper pants. Of course, the level of the person's ability to dress himself and the choice of what would be most useful to him must be assessed. If a person has complete paralysis, the best items would be the products with the back open, as the person will be locked in a wheelchair or a bed. If the person uses a wheelchair the accessories that make life easier with assistive devices, such as wheelchair bags, cup holders and more are recommended.

Adaptive clothing should be designed to meet the needs of the people that wear this type of clothes [3–6].

It is recommended that the following factors be taken into account when designing or choosing clothes for people suffering from multiple sclerosis:

- To opt for light, breathable fabrics: they can have a cooling effect because they "breathe". In other words, we need to make sure that the heat can escape and, if necessary, work with different layers of breathable fabric.
- Choose light colours because they reflect sunlight, while dark colours absorb heat.
- Put comfort first and choose clothes tailored to the needs.

For the analysis, 2 cases found in people suffering from this problem were selected. The first case is going to be about people who have difficulty walking and moving with the help of a cane. And the second case will be about people who cannot move alone and are in a wheelchair.

THE ANALYSIS OF EXISTING PRODUCTS

Market analysis for adaptive products

Making clothes for people with disability is a little more complicated because these people need clothes adapted to their measures and movements. To ease their life as much as possible, the clothes also have to provide thermal comfort, protect them regarding climatic variation, to be easy to dress [7–11].

Sometimes fashionable clothes available in stores do not meet the demands of people with Multiple Sclerosis because they don't offer thermal comfort and security and do not provide autonomy [12].

To have a better idea of the needs of the market and this niche, it is a good idea to perform the marketing analysis and what it proposes. For this analysis, we stopped on the first 4 webpages that came up when searching for clothes for this specific group of people (figure 1).

According to figure 1 and the analysis carried out by browsing the existing online stores, it was noticed that most of the adaptive products for people with multiple sclerosis were simple, for older people and many of them were meant to be worn at home. Taking into consideration that MS often debuts at the age of 20–40, it can be concluded that most of the clothing articles available on the market were not fit for the MS people age group.

To correct and provide comfort while wearing clothes, it was proposed to develop products adapted to the needs of these people and with a pleasant aesthetic appearance and adapted to today's trends.

Although further research is needed in this area, the findings have a favourable impact on how this issue is explored [17].

Ordinary clothing for people with disabilities

To understand where to start with adaptive clothing, an analysis of existing ordinary products was needed. For people with multiple sclerosis, even the slight tremble of the hands can cause a big discomfort in dressing. That's why to better understand what was needed to adapt and to change to ease the life of a person with MS it was decided to try on different types of clothing that people were normally wearing and to see the places that may cause discomfort (figures 2 and 3). This was done by simulating an avatar

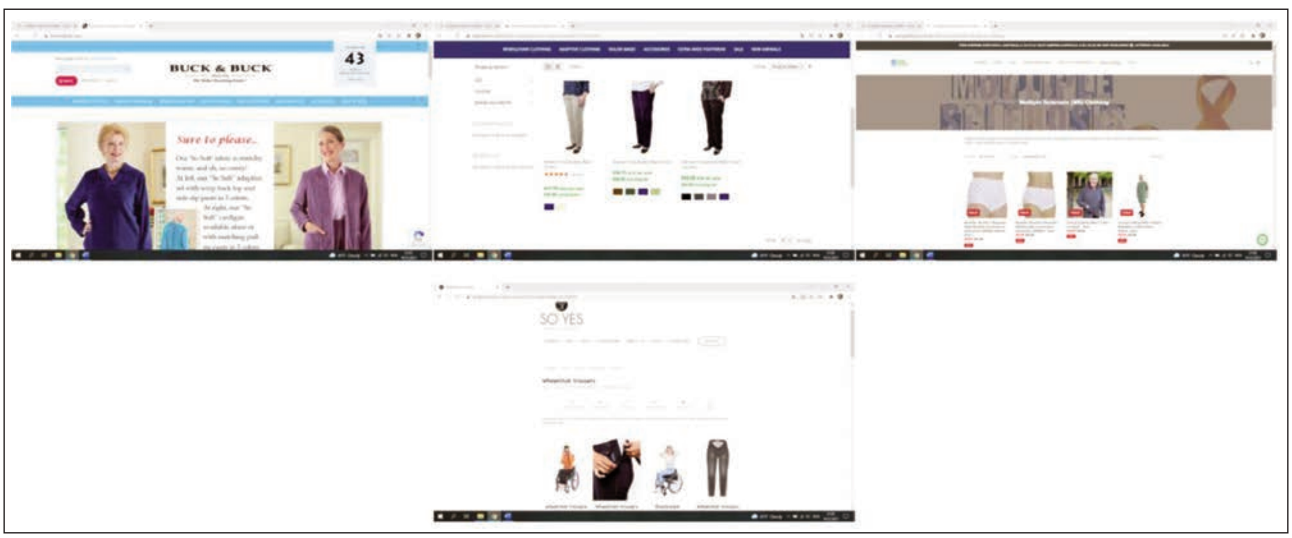

Fig. 1. Market analysis for adaptive products [13–16]

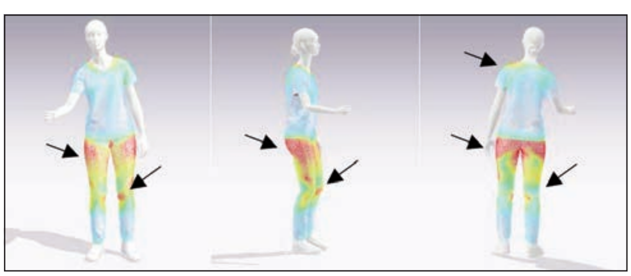

Fig. 2. Topographic diagram for the person moving with the help of the cane

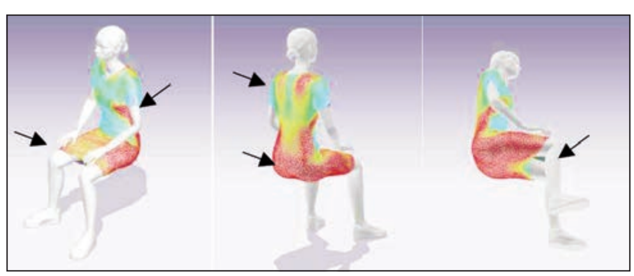

Fig. 3. Topographic diagram of a person in a wheelchair

in CLO3D software which is a 3D fashion design software program creating virtual, true-to-life garment visualization with cutting-edge simulation technologies for the fashion industry [18].

By using the virtual prototypes [19–21] the user can see and explore the final product on a virtual mannequin (avatar) before the manufacturing and if the chosen design solution is the right one.

By applying this software, as can be seen in figure 2, when the avatar was moving with the help of a cane, the most uncomfortable part of the pants was around the hip area, more specifically from the hip to the knees. We can also see that near the shoulder area, some tension might appear because of the movement of the body.

Following the analysis of the topographic scheme for figure 3 it can be noticed that the dress was very uncomfortable for a person in a wheelchair. The most affected zones were the leg, hip, upper back part and bust area. These areas were the ones that hindered the movement of the hands and also created great discomfort for the person who wore clothes not adapted to their needs.

ELABORATION OF PRODUCTS ADAPTED FOR PEOPLE WITH DISABILITIES

Following the analysis from above, it was proposed to try to adapt different types of clothing and to see how the adaptive clothing fit and what kind of comfort they offered using the CLO3D software for simulation and fitting the virtual garments. The topographic diagrams were used as a way to analyse the obtained results of this research paper.

Elaboration of products adapted for people who travel with the help of a cane

In figure 4 the first presented set was adapted for people who moved with a cane. This was done by adapting the pants and the t-shirt. For the upper part, the t-shirt was adapted by making the silhouette larger, and more flexible. Additionally, the form of the neck part was changed to make it free and comfortable. The most important part was the back. It was made from two parts that overlapped and were fixed on the shoulder with clasps. This allowed the wearer to be more flexible and was very easy to pun on.

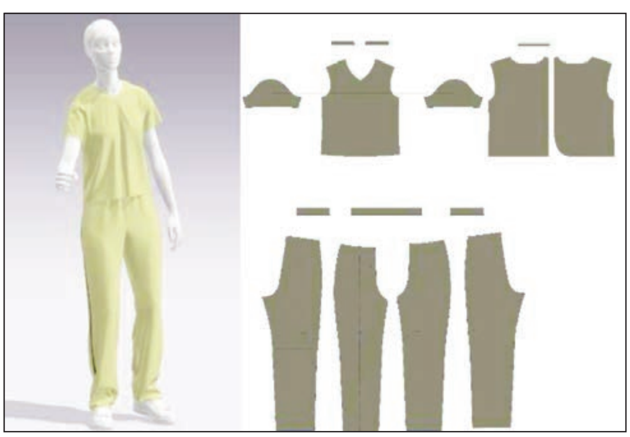

Fig. 4. Model A: Development of products adapted for people who travel with the help of a cane

The pants were adapted by adding the elastic band and by adding clasps and zippers on both sides of the pants. This was done to make the process of dressing easier and the clasps and zippers were easy to use even when the wearer had trembling hands.

The same proposal was applied to figure 5, where the t-shirt was unchanged but the emphasis was put on the textile. The material used was stretch cotton. For the shorts, the same technique was applied as in the first case. Part of the belt was made elastic to ensure comfort and on the sides of the pants, clasps were applied to ensure an easy putting on of the clothes. Further, the silhouettes were kept free to ensure the movement of the body.

Fig. 5. Model B: Development of products adapted for people who travel with the help of a cane

In the last case (figure 6), elastic was used on the back of the dress to ensure comfort, the sleeves were made with ruffles at the top to ensure the movement of the hands and the placket in front was with Velcro band to create easy putting on of the clothes. In the example the dress was done long because some of the people with MS can be insecure with their legs and the way they walked to ensure psychological comfort; it was decided to try this type of length on the dress.

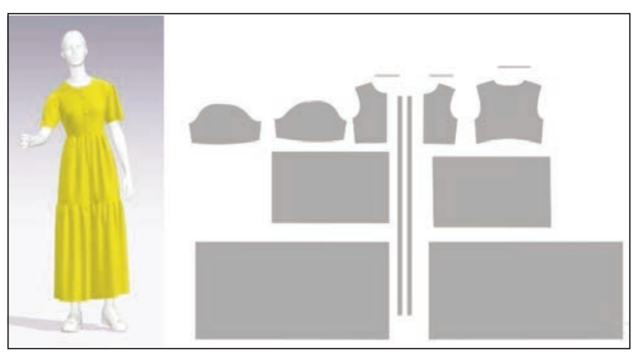

Fig. 6. Model C: Development of products adapted for people who travel with the help of a cane

The next step consisted of analysing the topographic schemes of the adapted clothes above to see how

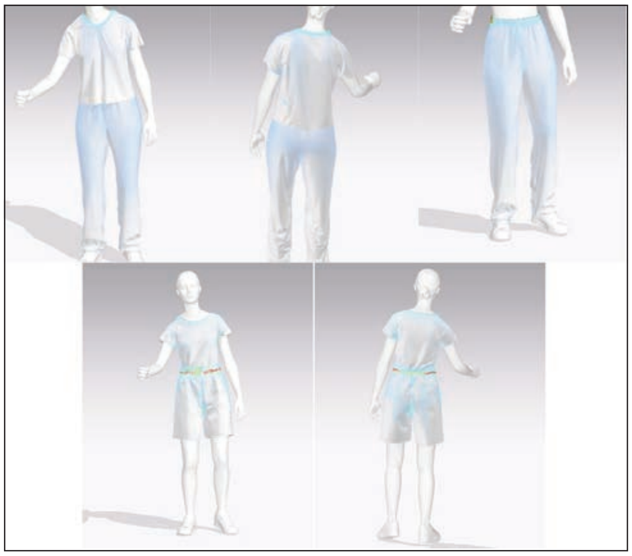

Fig. 7. Topographic scheme of adaptive products for people travelling with a cane

Fig. 8. Topographic scheme of adaptive products for people travelling with a cane

successful the adaptation process was (figures 7 and 8).
Figures 7 and 8 show us the topographic schemes of the adapted clothes and how successful were the ideas and the methods selected. The fit seemed good without any major discomfort that could irritate the wearer. The places that were mentioned above that created discomfort have been adjusted to fit normally.
Following the analysis of the constructive and topographic schemes of the adaptive products for the people who moved with the help of the cane it can be seen that the red areas have disappeared, they are freer, more flexible and more comfortable to wear. In figure 7 some yellow/orange areas around the waist can be seen which showed the tension of the elastic introduced at the base for a more comfortable fit. For the rest of the clothes, it can be noticed that the fit did not create any tension or discomfort in any parts of the clothes or body.

Development of products adapted for people using a wheelchair

Compared to the first case, where the cane was used to walk, in this one, the wheelchair was used as a means of transport. This made the adjusting process more complex and complicated because the person was most of the time in a sitting position.
So, for the second example, a deeper study was done and different ideas and methodologies were applied to obtain adapted clothing for people in a wheelchair.
Different cuts to a mix of textiles and adjustments were applied to try to obtain a variety of ensembles. The following results are presented in figures 9–11.

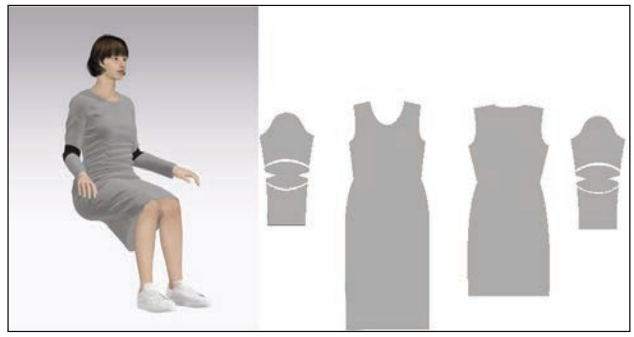

Fig. 9. Development of products adapted for people using a wheelchair

For the first model (figure 9), the adaptation was done by creating the pleats in the front with the help of an elastic. This was done both for comfort and an aesthetic look. For the sleeve, it was decided to adjust the length and add another soft textile so that in the elbow region there would not be any injuries or discomfort. The neck area was lowered in an oval shape to ensure easy putting on.
As for the textile it was decided to choose an elastic one made of cotton to guarantee the circulation of the air and the heat of the body.
As the last adjustment, a slit was added on both sides for comfort and not to cause any discomfort while sitting.
Continuing this idea, more complex models were adapted. For the next two figures from below the pants were selected as the main item to adjust and conform to the necessity of the people who were going to wear these clothes (figures 10 and 11).
This ensemble was full of different items and construction details. The first item was a type of sleeveless

Fig. 10. Development of products adapted for people using a wheelchair

bomber jacket. It was done by adding a zipper in the front and the straps were regulated with the help of a Velcro band. At the neck part, a collar was added. The back part was shorter than the front, so when seated, the back would not have any discomfort in the wheelchair.
The shirt had a raglan type of sleeve to ensure easier movement and to minimize the discomfort that might have appeared. The dressing was done from the front part with the help of the clasps. The hem of the shirt was shorter in the front and longer in the back. This was done so there won't be any discomfort and excess textiles in the front. The same idea was applied in the back. Because the person is in a sitting position the shirt will ride up and the lower back part will be exposed. To prevent this a longer back part was added.
And the last part of this ensemble was the pants. This pair presented a lot of cuts and extra textile material. This was done to ensure comfortable wear for the person.
The back of the pants has darts around the hip and back of the knee area. This was done because these parts gather a lot of material, especially around the knee. So, to ensure a comfortable bent of the knees, some darts were introduced in these specific areas.
The front part of the pants was very sectioned. This was done to ensure comfort in the bent parts of the legs where a lot of textiles gathered. At the knee section, an extra soft and elastic textile was added because this part stretches out. For the bottom part of the legs, an extra textile was added to adjust to different sizes of the calf because the legs can swell, especially in the lower part. Moreover, this makes the dressing process a lot easier. The upper and lower bent is both with an elastic band.

Fig. 11. Development of products adapted for people using a wheelchairapted for people using a wheelchair

The locking system was combined. The first part was made from claps that stopped at the mid-upper leg part and the rest with a zipper. This was done on both sides of the pants.
The most important piece was the back. It was made from two parts that overlapped and fixed at the shoulder with clasps. This gave more flexibility and was very easy to pun on, the sleeves being kept short.

The pants were adjusted by adding the elastic band, clasps and zipper on both sides of the pants. The zipper was placed in the front part of the pants to make wearing it easier. All the adjustments were selected to ease the use even when the wearer had trembling hands (figure 11).
Further the topographic schemes of the adapted clothes were analysed to see how successful the adaptation process was (figures 12 and 13).
The models below showed us the topographic schemes of the adapted clothes and how successful were the ideas and the methods selected. The fit seemed good without any major discomfort that could irritate the wearer. The places that were mentioned above that caused discomfort have been adjusted to fit normally.

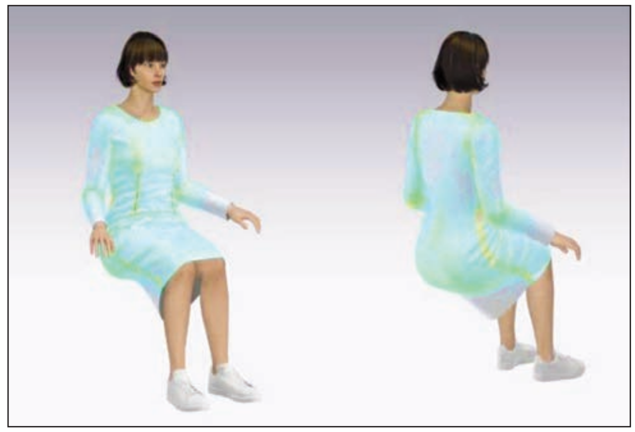

Fig. 12. Topographic diagram of adaptive products for wheelchair users

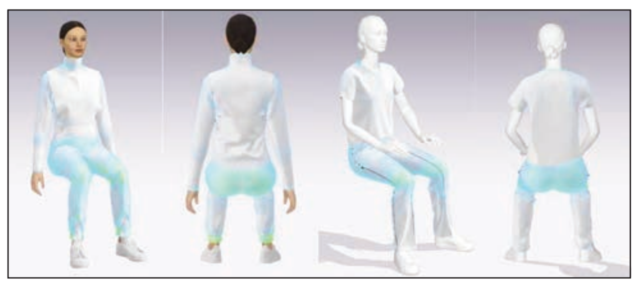

Fig. 13. Topographic diagram of adaptive products for wheelchair users

Analysing figure 13, it can be seen that the products were adapted to the needs. For some parts of the items, a change of colour can be seen because in those regions an elastic was added to offer comfort and to adapt to the necessities.
This cannot be avoided, but every effort has been made to minimize any inconvenience this may cause. Otherwise, the garments were free and convenient.

Details of adaptive products for cane and wheelchair users

To make the clothes more comfortable different and unusual types of closures were added. Because people with MS often have trembling hands and sometimes have no strength to dress, or can get tired very quickly a lot of adjustments were added. As we know

Fig. 14. Details of elaborated adaptive clothing

MS attacks people from the age group 20–40. A lot of research was done to find the right way to modify the outfits. At the same time the items needed to be fashionable and fit the taste of young people. To facilitate this process, it was proposed to use zippers, clasps, Velcro bands, and elastic in different parts of the clothes to insure ease in the process of dressing. The photos from figure 14 demonstrate the methods used for adapting the elaborated garments.

CONCLUSION

This paper aims to study the existing adaptive clothing for people with multiple sclerosis and to try to develop products taking into account certain needs and requirements of these people.

As a first step, a mini study of the online market offering adaptive products was carried out and it was found that most of the products were for older people and the clothes were meant to be worn at home. For young people the range found is more limited. And considering that this disease begins in young people between the ages of 20–40, the given products do not fit into the segment given by consumers.

The next step was to study the topographic pattern of ordinary clothing used by most people and note some inconveniences and problems that may arise in the case of people with more special needs. In the next phase, an attempt was made to develop patterns and templates for tailored products so that they would be stylish and provide the necessary comfort to the wearer.

In addition, the topographic pattern of these garments was checked and it was observed that the products were more comfortable, in both cases. This area still needs further research, but the results obtained have a positive influence on exploring this theme.

Therefore, this study comes with the idea of elaborating and performing the adapted process in 3D, to see the applicability of these systems and help integrate 3D with adapting clothing. This represents a significant step towards a better understanding of the processes, errors and new possibilities that may arise. Further research can be oriented towards the customization of adaptive clothing products according to the specific destination and the categories of the wearer studied.

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An undamaged pattern generation method from 3D scanned garment sample based on finite element approach

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ABSTRACT – REZUMAT

An undamaged pattern generation method from 3D scanned garment sample based on finite element approach

The purpose of this study is to propose a new method to achieve pattern generation from garment sample without damage. The non-contact three-dimensional (3D) scanner was employed to get the point cloud data of garment samples. The Bowyer-Watson algorithm was used to implement Delaunay triangulation for surface reconstruction. The finite element (FE) approach was employed to achieve the consideration of the fabric properties in surface development. The proposed method was demonstrated to effectively realize the pattern generation of 3D sample clothes with fabric properties without damaging the garment samples, and to be suitable for different clothing styles and fabrics. Compared with traditional methods, the proposed method has higher accuracy (2.21% higher on average) and better stability.

Keywords: *3D scanned garment, fabric properties, finite element, pattern generation*

O metodă de generare a tiparelor fără deteriorare dintr-un articol de îmbrăcăminte scanat 3D, bazată pe abordarea cu elemente finite

Scopul acestui studiu este de a propune o nouă metodă pentru a genera tipare din articolul de îmbrăcăminte fără deteriorare. Scanerul tridimensional (3D) fără contact a fost folosit pentru a obține conturul punctat al articolelor de îmbrăcăminte. A fost utilizat algoritmul Bowyer-Watson pentru a implementa triangularea Delaunay, pentru reconstrucția suprafeței. Abordarea cu elemente finite (FE) a fost utilizată pentru a lua în considerare proprietățile materialului textil, în dezvoltarea suprafeței. S-a demonstrat că metoda propusă realizează în mod eficient generarea tiparelor pentru articolele de îmbrăcăminte 3D, ținând cont de proprietățile materialului textil, fără deteriorarea acestora și că este potrivită pentru diferite stiluri de îmbrăcăminte și materiale textile. În comparație cu metodele tradiționale, metoda propusă are o precizie mai mare (în medie cu 2,21% mai mare) și o stabilitate corespunzătoare.

Cuvinte-cheie*: îmbrăcăminte scanată 3D, proprietăți ale materialului textil, element finit, generare de tipare*

INTRODUCTION

Nowadays, clothing sample processing (processing according to the garment samples given by customers) is one of the important sources of customer orders in the garment industry. What pattern making technology has become the most important method adopted by garment manufacturing enterprises is obtaining patterns from garment samples. To obtain patterns from garment samples, professional pattern makers, with years of experience, are required to manually measure garment pieces after splitting garments into pieces or directly measure the garments. The measurement is to analyse its garment structure and obtain the data of the size, radian, and angle. According to the obtained data, clothing patterns are made by experience. After repeated trial and error, the new garment made with this pattern is similar in shape to the target sample. On the one hand, this process is highly dependent on professional pattern makers, and the experience of technicians will also affect the obtained garment patterns [1]. It seems a nicer choice to use digital means to replace traditional processes. On the other hand, for high-end clothing, precious clothing collections, or protective cultural relics, if they need to be reproduced or recreated, the traditional method of samples to patterns will cause irreversible damage [2] and inaccurate measurement. The non-contact 3D scanning technology can obtain the depth information of garment 3D modelling more accurately without damaging the sample [3, 4]. The digital means of obtaining patterns from garment samples include scanning, surface reconstruction, and surface development. Depth information needs surface reconstruction to get a 3D garment model. The Bowyer-Watson triangulation algorithm [5] for surface reconstruction is not restricted by spatial dimension, and its implementation is simpler. 3D scanning only obtained 3D modelling information of garments, but different fabrics would have an impact on the production of the garment pattern [6]. In the surface development process, accurate patterns may not be obtained if only depth information is considered without fabric parameters [7].

The finite element method has been employed to study the fabric compressibility [8] and impact properties of fabrics [9]. The finite element (FE) algorithm can help to couple the properties of the material to the entity for bra design [10]. Any three-dimensional surface can be flattened into a two-dimensional plane by increasing the force [11]. Therefore, the combination of three-dimensional scanning technology and finite element approach can realize the non-destructive pattern generation of sample garments with fabric parameters.

In this work, the depth information (the point cloud data) was accurately obtained by 3D scanned samples to avoid damage to garment samples. Then, the surface was reconstructed by Delaunay triangulation based on the Bowyer-Watson algorithm. Also, as different fabrics were supposed to be considered, the surface expansion was conducted by the finite element approach. Finally, this novel method was compared with the traditional methods to demonstrate its superiority and was also carried out in different styles to prove its applicability.

MATERIALS AND METHODS

Materials

In this study, firstly, a cheongsam style [12] containing a dart, dividing line, sleeve, collar, and asymmetrical pieces was selected for the experiment. A plain-woven 100% Cotton fabric was utilized. The fabric parameters of the garment sample are shown in table 1.

Data acquisition of the garment

To obtain the 3D depth information of clothing, the garment was worn on the 160/84A female mannequin. Since the garment was made of soft material, the contactless high-precision hand-held 3D scanner [13] (Einscan-Pro2X, XianLin, China) with a precision of 0.1 mm, a scanning speed of 550,000 points/s, and a spatial point distance of 0.2 mm – 3 mm was employed. The scanning process is shown in figure 1.

The scanner needed to be rotated around the garment and keep a distance to scan the garment until the point clouds were obtained entirely. The Geomagic Design X 64 software was carried out to

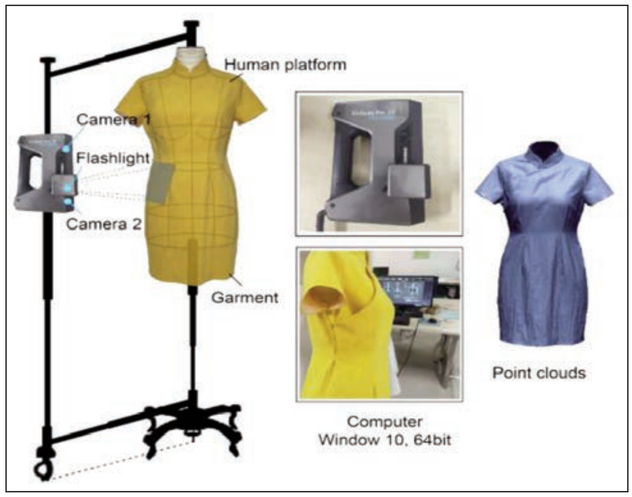


Fig. 1. Data acquisition

pre-process point cloud data, including coordinate system reconstruction, denoising, 50% sampling, and smoothing. The data was exported as a file in ASC format for subsequent processing.

Surface reconstruction and style segmentation

The point cloud data obtained by scanning was disorganized, and need to be triangulated by the Bowyer-Watson algorithm [14]. In figure 2, *a*, the spatial scattered point data and the adjacent points obeying the topology were connected to form a mesh structure so that the garment model was reconstructed. For the parts segmentation of style, as shown in figure 2, *b*, the 3D model was divided into *n* sub-facets by over-segmentation [15]. Then the region fusion processing was carried out. Where the features were not significant, such as waist dart, underarm dart, and so on, the boundary needed to be adjusted manually. The garment parts were obtained. By parameterizing the surface of each garment component, the NURBS surface model was obtained by fitting NURBS surface pieces [16]. The data of the garment part was exported as a file in STP format.

Surface flattening to generate patterns

In this approach, surface development was implemented in NX Open C++ Software. As shown in figure 3, the finite element method was used to expand the surface.

Table 1

FABRICS PROPERTY OF A GARMENT SAMPLE					
Fabrics property	**No.**	**Value**	**Fabrics property**	**No.**	**Value**
Fabric content	P_1	100% Cotton	Weft bending rigidity (N/m)	B_2	5.0
Weave structure	P_2	1/1 Plain	Static drape coefficient (%)	F	41.08
Weight (g/m²)	m	138.6	Warp elastic modulus (MPa)	E_1	128.71
Thickness (mm)	h	0.443	Weft elastic modulus (MPa)	E_2	113.95
Warp density (threads/cm)	D_1	23	Warp Poisson's ratio	v_1	0.1532
Weft density (threads/cm)	D_2	24	Weft Poisson's ratio	v_2	0.1262
Warp bending rigidity (N/m)	B_1	6.0	Shear stiffness	G	2.24

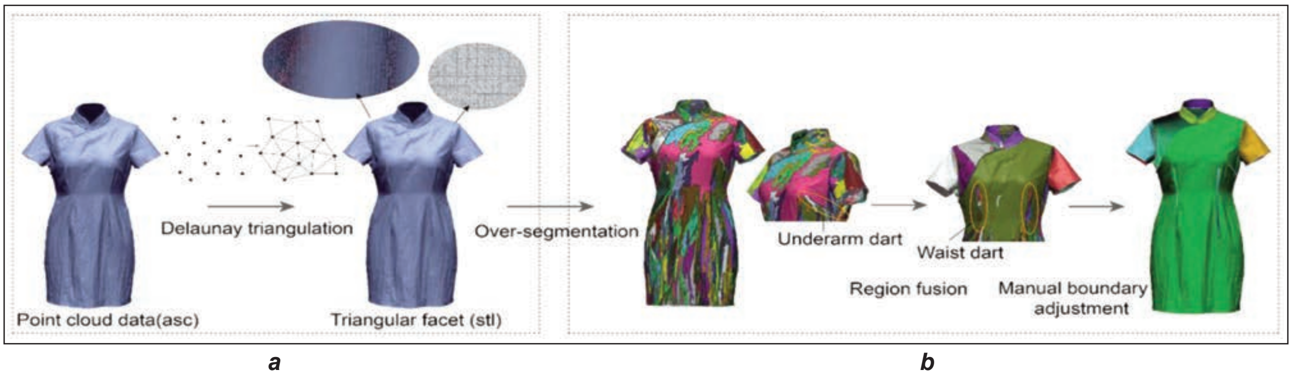


Fig. 2. Surface reconstruction and style segmentation: *a* – garment model reconstruction; *b* – segmentation of style

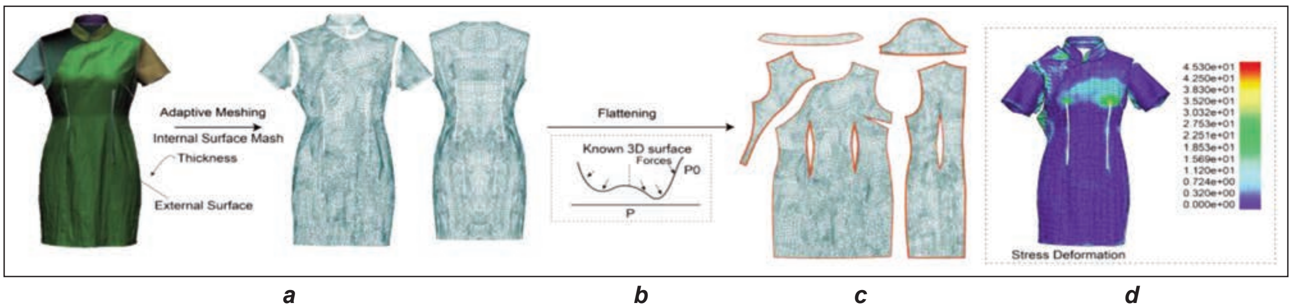


Fig. 3. Surface flattening based on finite element method: *a* – adaptive meshing; *b* – flattering; *c* – pattern generation; *d* – stress deformation

It was assumed that the soft fabric was a continuous homogeneous medium flexible sheet [17]. Thus, the parameters of fabric structure, such as weave structure P_2, warp and weft density D_1, D_2, could be ignored. The thickness h and the weight m were used to define the physical properties of surfaces. In figure 3, *a*, the internal surface was selected for adaptive meshing. As the garment fabric was regarded as an orthotropic elastic material, the surface was discretized based on the constitutive equation of the orthotropic elastic model [17–19]. The stress-strain relationship is the following:

$$\begin{pmatrix} N^{11} \\ N^{22} \\ N^{12} \end{pmatrix} = \begin{pmatrix} \frac{E_1}{1-v_1v_2} & \frac{E_1v_1}{1-v_1v_2} & 0 \\ \frac{E_2v_1}{1-v_1v_2} & \frac{E_2}{1-v_1v_2} & 0 \\ 0 & 0 & G \end{pmatrix} \times \begin{pmatrix} e_{11} \\ e_{22} \\ 2e_{12} \end{pmatrix} \quad (1)$$

where N and e are the stress and the membrane strain, respectively. The main parameters of the formula are explained in table 1. The relationship between bending moment and bending strain is the following:

$$\begin{pmatrix} M^{11} \\ M^{22} \\ M^{12} \end{pmatrix} = \begin{pmatrix} B_1 & \sigma_2 B_1 & 0 \\ \sigma_1 B_2 & B_2 & 0 \\ 0 & 0 & \tau \end{pmatrix} \times \begin{pmatrix} \chi_{11} \\ \chi_{22} \\ 2\chi_{12} \end{pmatrix} \quad (2)$$

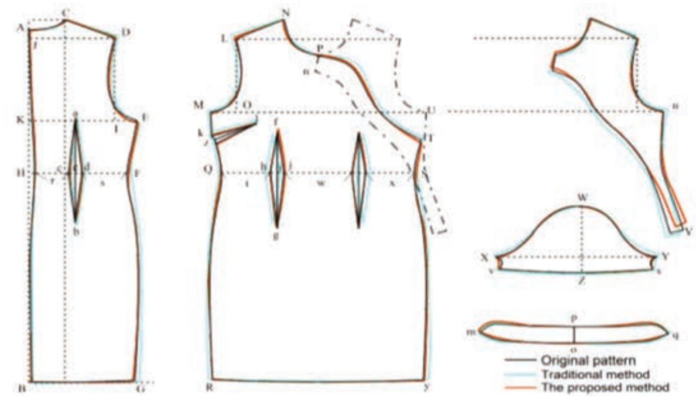
where M and χ are bending moment and bending strain, respectively, τ – the torsional rigidity, which could be calculated; α_1 and α_2 were parallel with Poisson's ratios, which were related to the anticlastic curvature. Because the anticlastic curvature of the thin woven fabric was minimal, α_1 and α_2 were assumed to be 0.

The known values were thickness h, weight m, elastic modulus E_1, E_2, Poisson's ratio v_1, v_2, bending rigidity B_1, B_2, and the initial stress and strain were 0. Besides, static drape coefficient F was also the one of fabric mechanical properties expression form, and could also be characterized by fundamental mechanical parameters, so F was not considered. It was assumed that the forming process was proportional loading. The finite element equation was established based on the deformation theory of elasticity and the principle of virtual work. Then the Newton-Raphson iterative algorithm was utilized to solve the problem. The position on the initial surface body P_0 and the final shape nodes P were obtained under certain boundary conditions. Finally, as shown in figures 3, *c* and *d*, the shape and size, stress, and strain of the flattening plane were obtained. Then smooth the curve appropriately and adjust the length of the piece to be consistent [19]. The area change ratio of patterns before and after adjustment was controlled within 0.1%. Finally, the pattern was imported into CAD software in DXF format. Employing the seam allowance given, lengthwise grain line and cut-outs marked, garment industrial patterns were generated.

RESULTS AND DISCUSSION

Comparison with traditional methods

To prove the superiority of the proposed method, this method was compared with traditional manual



PARAMENTERS OF PATTERN					
NO.	Pattern dimensions (cm)		NO.	Pattern dimensions (cm)	
1	Center back seam	$\overset{\frown}{AHB}$	17	Back armhole line	$\overset{\frown}{DE}$
2	Neck waist length	$\overset{\frown}{AH}$	18	Sleeve length	WZ
3	Shoulder width/2	JD	19	Sleeve width	XY
4	Front shoulder line	LN	20	Sleeve opening	vs
5	Back shoulder line	CD	21	Side seam opening position	$\overset{\frown}{uV}$
6	Bust line	MU+2KE	22	Front waist dart position	t
7	Waist line	t+w+x+2 (r + s)	23	Up front waist dart length	fi
8	Hem line	$\overset{\frown}{Ry}+2\overset{\frown}{BG}$	24	Under front waist dart length	ig
9	Side seam	$\overset{\frown}{EFG}$	25	Back waist dart position	s
10	Front neck hole	$\overset{\frown}{NP}$	26	Up back waist dart length	ae
11	Back neck hole	$\overset{\frown}{AC}$	27	Under back waist dart length	eb
12	Necklace line	$\overset{\frown}{mq}$	28	Waist dart width	Cd
13	Top collar width	po	29	Underarm dart position	Mk
14	Front armhole depth	LO	30	Underarm dart length	kl
15	Back armhole depth	DI	31	Underarm dart width	kz
16	Front armhole line	$\overset{\frown}{ML}$	32	Front edge	$\overset{\frown}{pT}$

Fig. 4. Patterns and the parameters of the pattern

methods. The traditional manual method was to require professional pattern makers to measure the dressed sample garments manually, and then made patterns according to their own experience and understanding of the style. Three professional pattern makers, who basically have the same experience, skills, and knowledge, were invited to complete the experiment together. Figure 4 shows the original pattern of the sample garment (the black line), the obtained patterns by means of traditional method (the blue line) and the proposed method (the orange line). 1–32 parameters of the pattern are also shown in figure 4. Among these parameters, parameters 1–8, 12–13, 18–20 are the main control dimensions of the body, collar, and sleeves, respectively, which determines the accuracy of the main size. Parameters 28, 31, 32 are related to modelling design, which determines the design of some details of clothing.

The dimension of the obtained patterns and the original pattern were compared and analysed. To scientifically compare the accuracy of different pattern dimensions, in equation 3, the dimension change was expressed by the pattern dimension change ratio *Y*, which could be defined as:

$$Y = \frac{y_2 - y_1}{y_1} \tag{3}$$

where y_1 and y_2 are defined as the original pattern dimension and the obtained pattern dimension, respectively. The pattern dimension change ratio *Y* of 32 parameters of the pattern is shown in figure 5. The smaller the change ratio of the pattern dimension, the higher the accuracy of the pattern.

In figure 5, the pattern dimension change ratio *Y* of the traditional method is obviously higher than this of the proposed method. For the pattern parameters of Back armhole depth(15) and line(17), Sleeve length(18), width(19), and opening(20), Under front waist dart length (24), Up back waist dart length(26), Underarm dart length(30) and width(31), and Front edge(32), the traditional method has a higher ratio of change, that is, a lower accuracy. Because when dressing, these length dimensions measured manually need to contact the measuring point, resulting in fabric deformation and not enough accurate measurement. Manual measurements would cause dimensional errors due to factors such as human gestures and habits, so the non-contact measurement method could be more accurate. Figure 6 shows the average change ratio and variance of pattern dimensions of several methods. Compared with the traditional method, the average change ratio of pattern dimension generated by the proposed method (the FE approach based on 3D scanning) is

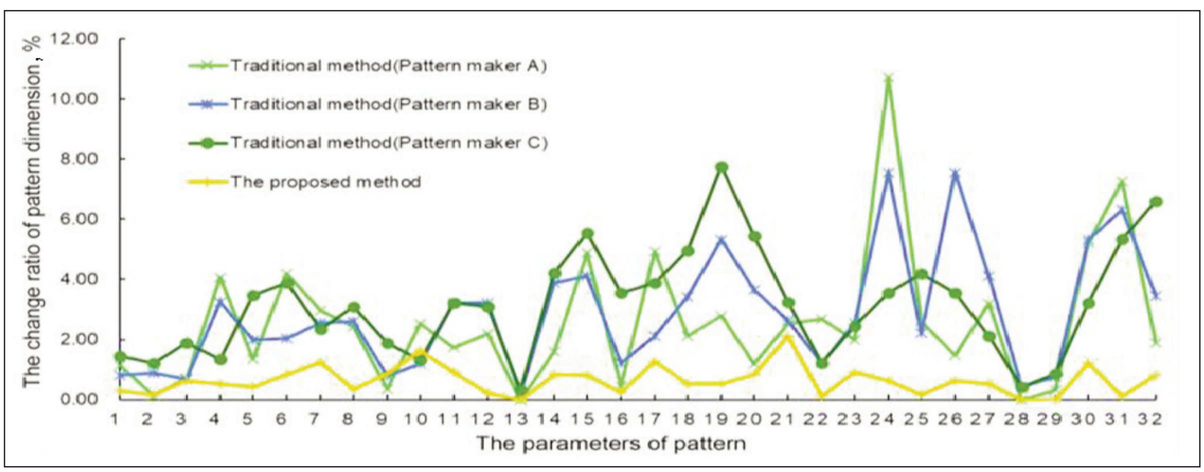


Fig. 5. The pattern dimension change ratio *Y* of 32 parameters of the pattern

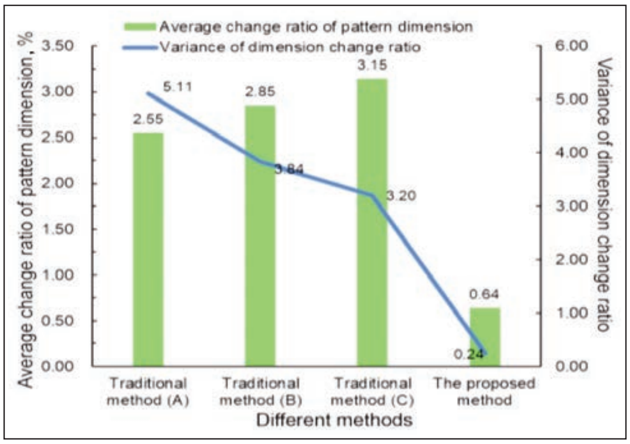


Fig. 6. The average and variance of pattern dimension change ratio

the lowest, which is 0.64%. According to the data in figure 6, the accuracy of the proposed method is 1.91%, 2.21% and 2.51% higher than that of the three traditional groups, respectively, with an average increase of 2.21%. So the proposed method has higher accuracy and better stability. This is because, in the process of data acquisition, a three-dimensional clothing shape can reflect the real shape of clothing better than a two-dimensional shape, while non-contact data acquisition can eliminate human errors to obtain the most objective three-dimensional data. As shown in figure 6, though these technicians have the same experience, skills and knowledge, the errors of different pattern makers are still different. This leads to larger errors and instability in pattern dimensions. The proposed digital method can obtain the garment pattern based on the FE method without damaging the sample garments and considering the properties of the fabric. So, accuracy and stability are the best.

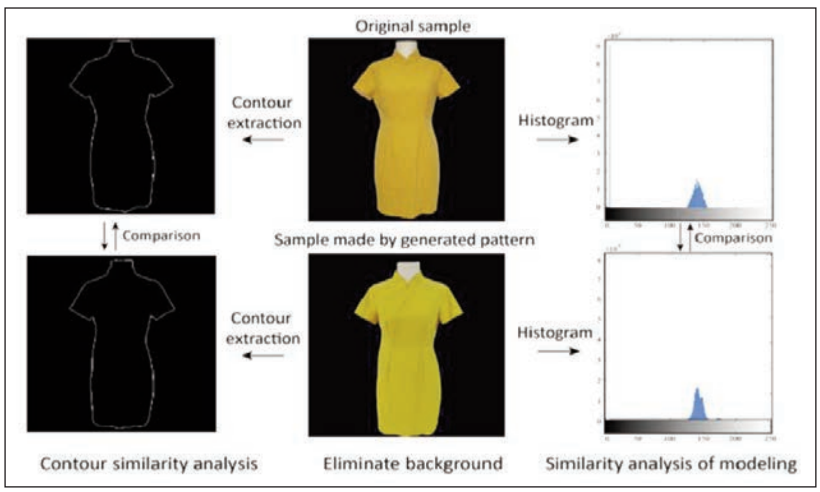
The verification of garment similarity

Generated patterns were then recreated into garments. The similarity of the generated pattern shape was supposed to be verified by the shape similarity analysis between the original garment and the reproduced garment. Under the same shooting conditions, the sample clothes were worn on the female mannequin. After that, their front, side, and back photos with the size of 3456×3456 pixels were obtained. The similarity of modelling was analysed by MATLAB programming [21]. Figure 7 shows the procedure of the similarity analysis of shape.

Firstly, in figure 7, *a*, the background of the photo needed to be removed. The contour information was extracted by Fourier descriptor in figure 7, *b*. In figure 7, *c*, the similarity of modelling were compared employing Cosine similarity and histogram method. When the closer data of these two methods are to 1, the similarity is higher. *S* represents the mean values of these three views. The mean similarity *S* of the contour is 0.9801. The mean modelling similarity *S* of the Cosine distance and Histogram method is 0.9762 and 0.8714, respectively. Therefore, the high similarity indicates the rationality of the method.

Applicability to different styles of clothing

For different garment styles, the suitability of this pattern generation method needs to be demonstrated. As shown in table 2, the first style is wide-leg pants,



a *b* *c*

Fig. 7. Shape similarity analysis process: *a* – eliminate background; *b* – contour similarity analysis; *c* – similarity analysis of modelling

Table 2

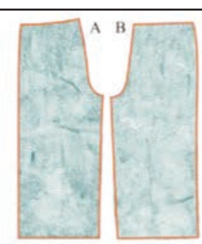
THE GENERATED PATTERNS OF DIFFERENT CLOTHING STYLES				
Materials	**Sample garments**	**3D models**	**Generated patterns**	**Average change ratio of the pattern (%)**
P_1 100%C B_2 15.33 P_2 Plain F 0.652 m 184.66 E_1 219.95 h 0.516 E_2 110.12 D_1 18 v_1 0.185 D_2 13 v_2 0.162 B_1 18.33 G 1.45				0.59

Table 2 (*continuation*)

Materials	Sample garments	3D models	Generated patterns	Average change ratio of the pattern (%)
P1 100%C B_2 45.3 P2 Twill F 0.487 m 510.66 E_1 383.09 h 1.89 E_2 179.16 D_1 51 v_1 0.152 D_2 37 v_2 0.127 B_1 62 G 0.82				0.73
P1 100%C B_2 2 P2 Satin F 0.178 m 128.3 E_1 221.8 h 0.269 E_2 140.5 D_1 44 v_1 0.312 D_2 92 v_2 0.207 B_1 3 G 0.21				1.54
P1 100%C B_2 2 P2 Satin F 0.178 m 128.3 E_1 221.8 h 0.269 E_2 140.5 D_1 44 v_1 0.312 D_2 92 v_2 0.207 B_1 3 G 0.21				2.23

the second style is a denim vest, and the third style is a one-piece dress. The green grid is the originally generated pattern, and the red edge is the shape after proper trimming.

The average change ratio of each pattern in table 2 is not more than 1.54 % (due to the limited space, the detail dimension is not shown here). The results show that this method applies to general skirts, trousers, and jackets. The 4th group was tested on a real human body with style 3, and the average change ratio of the generated pattern was 2.23%. Compared with the experiment of wearing the female mannequin, the change ratio of the generated pattern is increased. Because the circumference of the body (chest, hips) and posture will cause greater distortion of the fabric, and the breathing of the human body will cause errors in data acquisition.

CONCLUSIONS

In this study, under the condition of not damaging the garment samples, a new method to achieve pattern generation from garment sample with fabric properties based on a finite element approach was proposed. This proposed approach employed a non-contact 3D scanner for depth information acquisition of garment samples, Delaunay triangulation based on the Bowyer-Watson algorithm for surface reconstruction, and FE algorithm considering fabric performance for surface development. By comparing with the traditional methods, the proposed method proved to be more accurate and stable. Furthermore, this method applies to different clothing styles and fabrics, whether the garment for scanning is worn on the female mannequin or the real person.

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3D interactive design of wedding dress

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ABSTRACT – REZUMAT

3D interactive design of wedding dress

Based on the human torso point cloud, this paper proposes a method from the 3D design of the corset to the 2D pattern expansion. The point cloud of the human body is obtained through 3D scanning. The human body model for research is constructed, and the 3D basic style design of the corset is carried out, based on the same style and different structural line design, and through the curved surface flattening platform to convert 3D into 2D patterns. The verification was made through a virtual simulation platform and physical production methods. This study enriches the application prospect of digital technology in clothing design. Our proposed solution provides a more intuitive wedding dress design method and improves fit and comfort. It can significantly reduce the difficulty of wedding pattern-making and improve the efficiency of wedding design. In addition, our proposed method is not only suitable for wedding dress design, but also other styles of clothing design.

Keywords: *interactive design, wedding dress, pattern-making, try-on, fashion design*

Design 3D interactiv al rochiei de mireasă

Pe baza conturului punctat al trunchiului uman, această lucrare propune o metodă de la proiectarea 3D a corsetului până la generarea tiparelor 2D. Conturul punctat al corpului uman este obținut prin scanare 3D. Se construiește modelul corpului uman și se realizează designul de bază 3D al corsetului, bazat pe același stil, dar design diferit de linii structurale și utilizând platforma de aplatizare a curbei suprafeței pentru a converti modelele 3D în tipare 2D. Verificarea s-a realizat cu ajutorul platformei de simulare virtuală și metodelor de producție fizică. Acest studiu îmbogățește perspectiva de aplicare a tehnologiei digitale în designul vestimentar. Soluția noastră propusă oferă o metodă mai intuitivă de proiectare a rochiei de mireasă și îmbunătățește gradul de potrivire și confortul. Poate reduce semnificativ dificultatea modelării rochiei de mireasă și poate îmbunătăți eficiența designului acesteia. În plus, metoda noastră propusă nu este potrivită numai pentru designul rochiei de mireasă, ci și pentru alte stiluri de design vestimentar.

Cuvinte-cheie*: design interactiv, rochie de mireasă, construcție de tipare, probare, design vestimentar*

INTRODUCTION

The wedding dress industry is constantly changing along with people's lifestyles. In recent years, its sales model has developed from a traditional rental type to individual customization. The dressing occasions have gradually moved from being worn on the wedding day to a dinner party and daily routine. At present, a few South Korean and Italian scholars have conducted research on wedding gowns, but they usually focus on certain aspects such as materials, pattern innovation, marketing and detailed design [1, 2]. Funduk and Pavko-Čuden explored the structure, performance and social characteristics of contemporary Slovenian wedding dresses [3]; Kwon designed a new wedding dress pattern through the study of the structure and details of the wedding dress and the analysis of existing basic patterns [4]; Tu and Hu researched the construction of wedding photography and clothing product system indicators, and provided a substantial reference and basis for the business strategy of wedding photography companies [5].

3D body scanning technology is widely used in various fields of the textile and apparel industry to obtain accurate body size data for design customization and virtual prototyping [6, 7]. Daanen and Hong proposed a customization model based on 3D human body scanning, linking 3D scanning technology with manufacturing technology to achieve mass customization of clothing [8]. For clothing with special functions such as protective clothing, body posture is more important for computers for computer simulation and prediction of clothing drape [9]. Jolly et al. developed jacket and trouser patterns based on the four postures of motorcycle riding, flattened the 3D clothing model to obtain a 2D pattern, and then performed a virtual fit analysis of the clothing [10]; Liu et al. developed garment pattern by using surface unfolding technology and evaluated the comfort based on clothing pressure [11–16]. Wu and Kuzmichev simulated classic swimming postures and dynamic underwater postures and optimized the design of diving suits based on 3D body scanning technology and virtual fitting technology [17]. For tight-fitting clothing, more significant material properties and pressure comfort should also be considered [18], Cheng et al. proposed a new method to evaluate and test the pressure and comfort of male underwear [19].

The production of wedding dress with traditional manual plate making method can no longer meet today's personalized consumer needs. Tao and Bruniaux directly conceived virtual clothing on the human body model adjusted the clothing shape, and tried on the 3D virtual software to save the process of two-dimensional plate design [20]; Yao et al. through three-dimensional scanning technology and curved surface modelling technology, a personalized female girdle model is generated, and the dividing line can be flexibly designed according to needs [21]. In the same way, this method can also be used for prototyping other tight-fitting garments, such as personalized custom-made cheongsams and wedding dresses. Digital-based clothing production models are urgently required. Combining customization with digital technology is the future development trend of the clothing industry.

In this experiment, digital clothing technology is used to 3D scan the body size of the experimenter, and the body point cloud is used to construct the surface of the wedding corset. Based on the constructed surface, the plane pattern of the wedding corset is obtained, and the change design is carried out based on the basic shape. It is a precise plate-making concept and the development trend of the times. It can reduce the gap between the body shape and the national standard, which is gradually becoming obese with the development of The Times but also meet modern people's pursuit of personalized customization.

METHOD

Technical roadmap

The technical roadmap of this study is shown in figure 1. Step 1, collect the point cloud data. Step 2, build the human model according to the point cloud. Step 3, build the clothing model on the human model. Step 4, design the clothing structure line on the clothing model. Step 5, expand the surface surrounded by the clothing structure line, and obtain the clothing pattern. Step 6, virtual fitting with the pattern. Step 7, virtual wedding dress design.

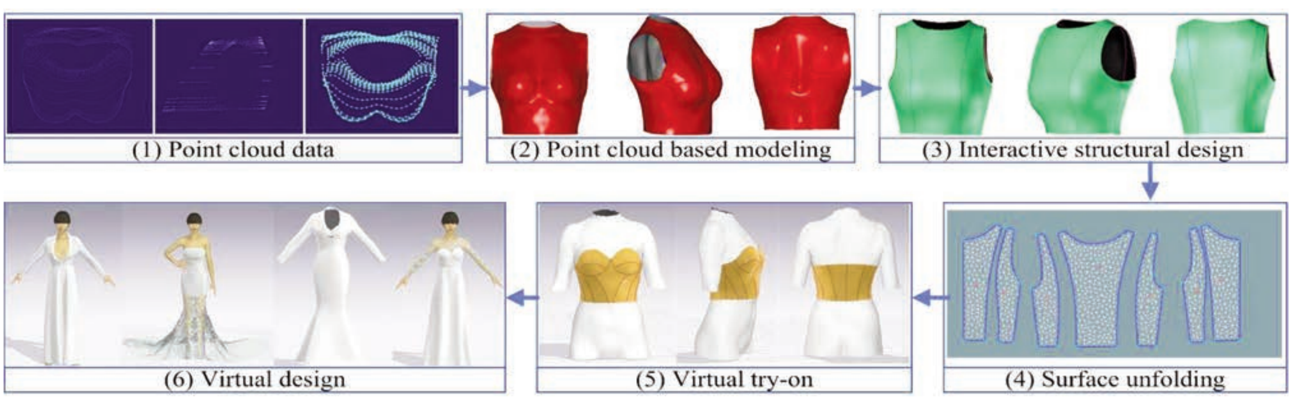

Fig. 1. The technical roadmap of this study

Point cloud data processing

The surface of the human body is an irregularly changing curved surface, and the curved transition parts such as armpits, inner thighs, and pleural sulcus will not be scanned. The human body point cloud obtained by scanning is purified in ANTHROSCAN human body data analysis software to automatically repair the holes in the transition part. The generation of noise is an inevitable objective factor. After the scanning experiment, the human point cloud is denoised, which lays a more accurate experimental data foundation for point cloud extraction, curve fitting, surface reconstruction and other experiments. Figure 2 is the completed picture of denoising.

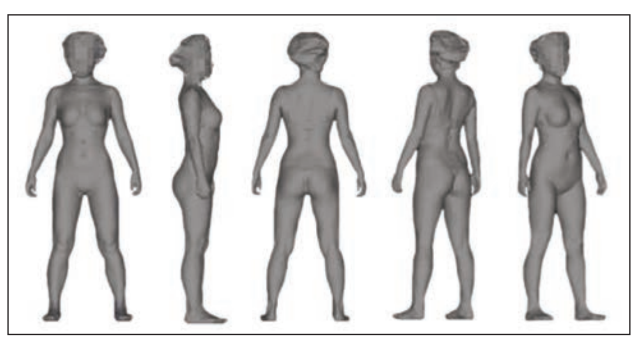
Fig. 2. Denoising complete picture

Construction of a basic model 1 of corset

The basic model 1 construction is the three-dimensional surface construction of the vest. When constructing a basic surface, it is necessary to intercept the point cloud of the required part. The upper boundary of the basic model 1 is the upper boundary taken through the cross-section parallel to the shape of the human neck through the seventh cervical vertebrae point, with a slight inclination; the left and the right boundary are taken longitudinally with the cross-section passing through the end of the shoulder and the axillary point as the cross-section; the lower boundary is a horizontal cross-section cut based on the thinnest part of the waist of the human body, that is, the navel.

After observation, the basic model 1 can be divided into three parts: the neckline to the shoulder endpoint, the shoulder endpoint to the bottom of the sleeve, and the bottom of the sleeve to the waistline for the extraction of key point clouds. According to the change of the human body surface from the neckline to the shoulder endpoint, this part uses the parallel intercept point cloud method to intercept the point cloud. From the neckline to the shoulder endpoint, the point cloud is extracted with equal gradients (viewing the human body from the side the back neck is higher than the front clavicle, gradually transitioning to the level of the shoulder point). The area from the end of the shoulder to the bottom point of the sleeve cage can be divided into two parts: the front chest area and the back area for surface construction, and the front chest key point cloud and the back key point cloud are respectively intercepted horizontally. The point cloud distribution from the bottom point to the waistline of the sleeve cage is approximately columnar, so the key point cloud is intercepted horizontally to obtain a uniform key point cloud that is approximately elliptical.

Complete the interception of different key point clouds in the three regions, perform curve fitting, and adjust the number of nodes and order of the fitted curve to make the starting point of each fitted curve consistent, and generate the lofted surface according to the fitted curve. The surface construction of the basic model 1 of the corsets is completed, as shown in figure 3.

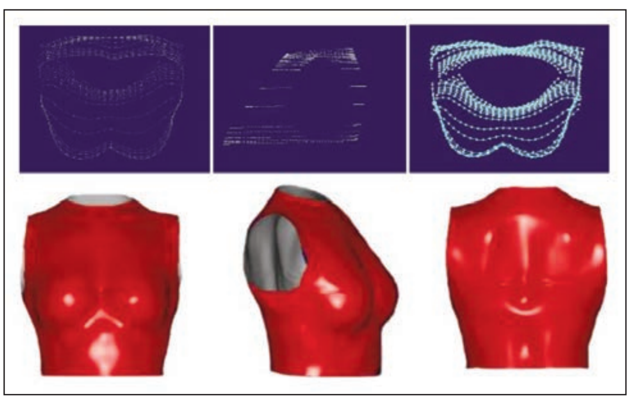

Fig. 3. The basic model 1

Construction of the basic model 2 corset

The basic model 2 corset is the cup type. When determining the basic position and shape of the upper boundary line, it is necessary to ensure its beauty and smoothness of the upper boundary line. Because the front middle and upper boundary of the cup-shaped corset is heart-shaped, the upper boundary of the front chest and back are not on the same horizontal plane, and the scanned human body is in a three-dimensional state, the basic position and shape of the upper boundary of the cup-shaped corset can be determined by rotating the purified human body point cloud in different angles and dimensions according to the needs of the style. Further precise the upper boundary, the shape of the location to meet the requirements, as shown in figure 4, the basic model of 2.

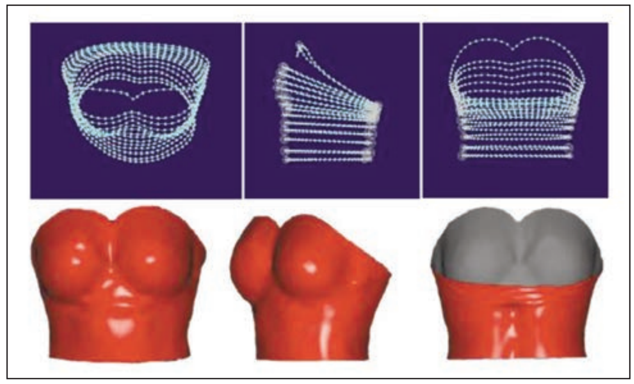

Fig. 4. The basic model 2

Construction of the basic model 3 corset

The basic model 3 corset is the wipe chest. To construct the curved surface model, the upper boundary is first determined. According to the scanned human body, first, determine the upper bound of the wipe chest style, and then determine the position and shape of the upper boundary (front chest, back) and lower boundary of the basic three bra style on the processed human body point cloud, and adjust to the required style.

Because the upper boundary line of the wipe chest style is slightly higher than the back, the point cloud extraction in the upper and lower boundary area needs to be intercepted from the point cloud with a certain angle in the front and back of the upper boundary line, and gradually transition to parallel. The point cloud is intercepted at the level of the waistline.

Select the upper boundary or lower boundary as a reference, fit each key curve and adjust its order, starting point position and several nodes to make the surface construction smooth and accurate, as shown in figure 5 for the basic model 3 corset.

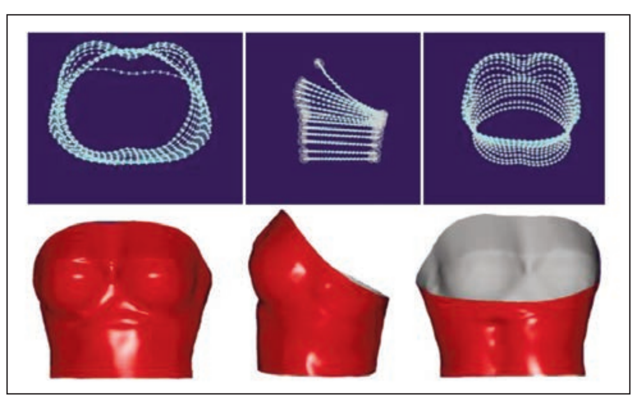

Fig. 5. The basic model 3

Style expansion and curved surface expansion

After the three basic types of corsets are constructed, save them in obj. format and import them into the Design Concept Auto platform for segmentation design. Basic section 1 has a variety of division methods. The general division method is adopted for structural line positioning, and the principle of beautiful and reasonable structure is followed. The basic common structure lines are divided by the back seam at the front and rear sleeves, the front and back shoulder seams are divided by the back seams, and the back of the front sleeve (front shoulder seam) is combined with the back of the back-shoulder seam (rear sleeve), V sub-neckline, as shown in the three divisions of basic model one in figure 6.

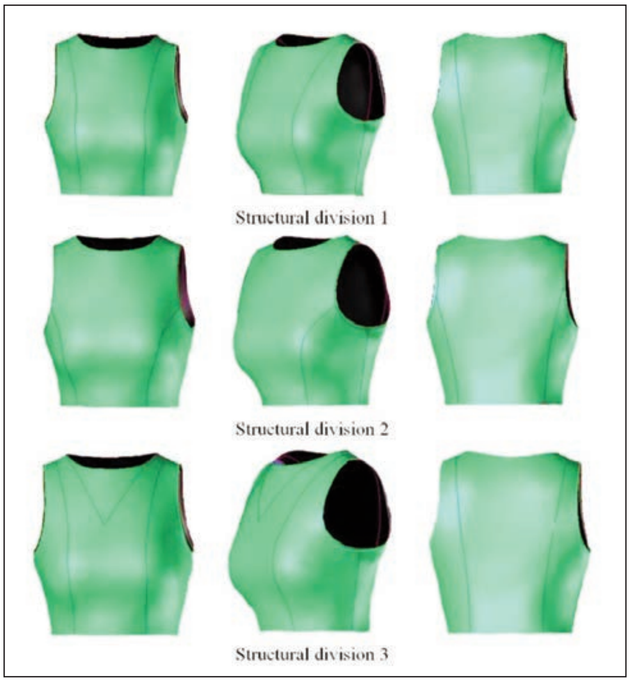

Fig. 6. Division of basic model 1

Basic model 2 is closely related to basic model 1. At this stage, certain segmentation changes will be carried out, and the changes will focus on factors such as conforming to the female body shape and highlighting the curvilinear beauty of the female chest and waist. Including the horizontal and vertical division of the cup, the horizontal division with a certain oblique angle from the bottom of the bust to the waist, and the horizontal division with a certain oblique angle from the shape of the human ribs, reflecting the beauty of women's torso; the vertical division of the cup, from the bottom of the bust to the waist for a certain angle of longitudinal division, the objective female chest and waist difference is divided into an equal longitudinal diagonal line, which is in line with human aesthetics and human body structure; the whole body of the body is divided into equal parts longitudinally with a certain angle, which is simple and generous, similar to a person holding a love heart in both hands, as shown in figure 7, the basic model 2 can be divided into three parts.

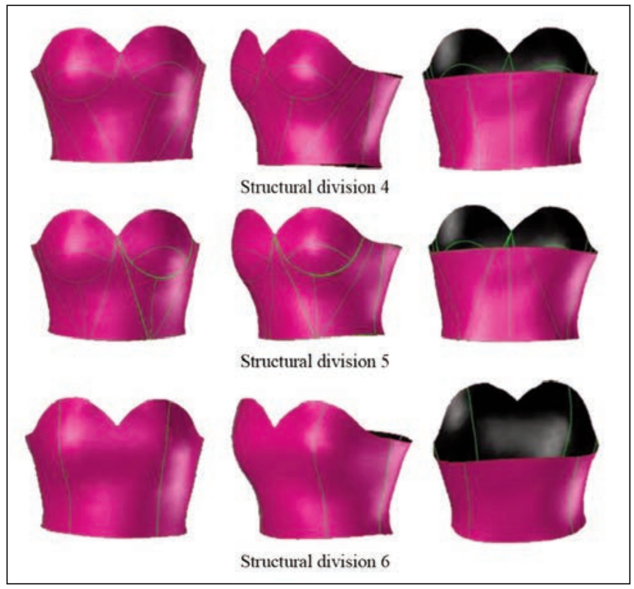

Fig. 7. Division of basic model 2

Basic model 3 is closely related to basic model 2. Basic model 2 has already been explained, then model 3 will be explained by ordinary division. When performing the common three kinds of segmentation, it is necessary to pay attention to the setting of the structural segmentation line to conform to the law of curvature of the human body surface. As shown in figure 8, the two divisions of the basic model 3.

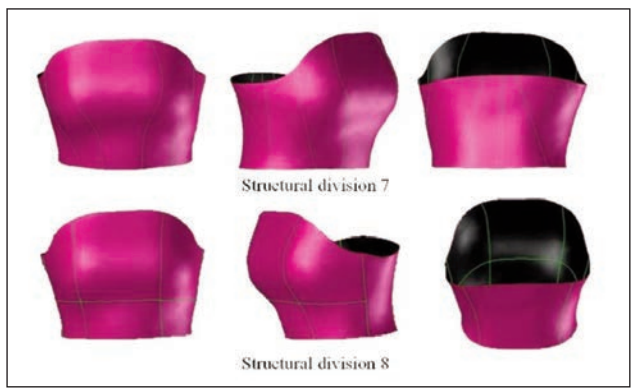

Fig. 8. Division of basic model 3

Curved surface development

After accurately positioning the basic structure dividing line in the Design Concept Auto platform, it enters the stage of unfolding the corset surface. After the three basic types of corsets are set, there are a total of 8 divisions. According to the 9 segmentation methods, select six of them for surface expansion. Two points should be made before expansion: First, the curved surface of each expansion area must be a closed contour curve; second, the lines cannot overlap each other. Figure 9 is a split and expanded view.

RESULT

Import the previously built human body model into the virtual fitting platform in the obj. format, and

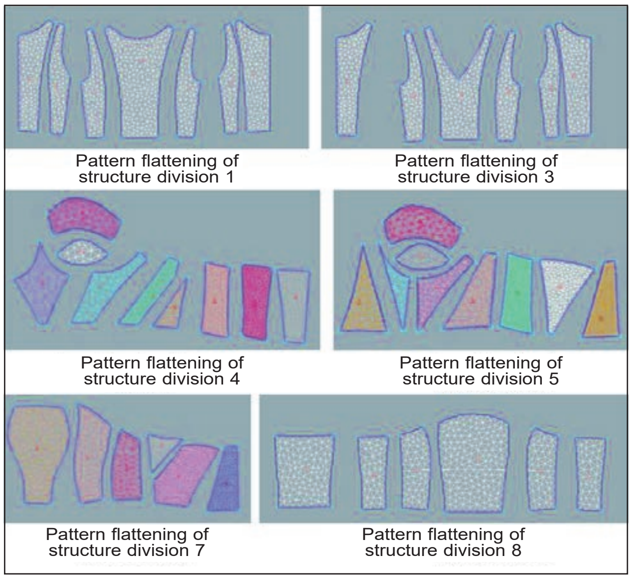

Fig. 9. Split expansion

import the two-dimensional pattern of the unfolded surface into the virtual fitting platform in the DXF. format, adjust the position of the human body model, and perform a virtual fitting. First, the two-dimensional pattern is positioned around the human body according to the stitching position in three dimensions; second, the stitched part is stitched with a sewing thread tool; finally, the stitched pattern is hardened to check whether the stitching position of each side is correct to simulate, the virtual effect after completion is shown in figure 10.

Fig. 10. Virtual rendering

The virtual fitting platform equipment includes the distribution of body surface pressure after the human body is dressed. In the pressure mode, it can be observed that the pressure between the garment and the human body is greater. That means the bust is closer to the garment and the pressure on other parts such as the shoulders and waist gradually decreases. From the pressure effect analysis diagram in figure 11, the green area indicates that the clothing fits the human body, and the yellow area indicates that the clothing fits the human body.

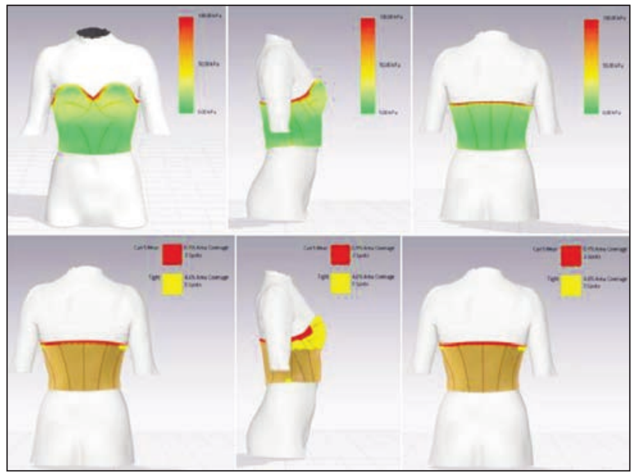

Fig. 11. Pressure effect analysis diagram

Import the two-dimensional pattern of the unfolded surface into the PGM clothing CAD system in DXF. format to complete the pattern, and then import it into CLO3D for virtual simulation design. By adjusting the parameters of each part of the female human body in the platform to the scanned human body value, that is, the bust circumference is 88 cm, the waist width is 68 cm, the hip width is 90 cm, and the height is 162 cm. The shape and design method of the wedding dress is divided into three parts: corset, skirt, and decoration. The paper pattern is adjusted according to the three-dimensional display effect until it meets the requirements. Figure 12 is a simulation effect diagram.

Fig. 12. Wedding dress virtual effect

The final paper pattern can be directly drawn after the details are perfected, and the model for physical production. Figure 13 is the style drawing of the wedding gown. According to the style drawing, physical production and try-on are carried out. The subject of the three-dimensional scan and the test-wearer of the finished product should be the same person to ensure the rigour and scientific nature of the research. When trying on, the invisible zipper or strap should be opened first, and the waist of the wedding dress should be supported by the hand. The staff should assist the subject to try on (because the garment is more complicated and has many layers) from bottom to top. Figure 14 shows the actual picture of the wedding dress.

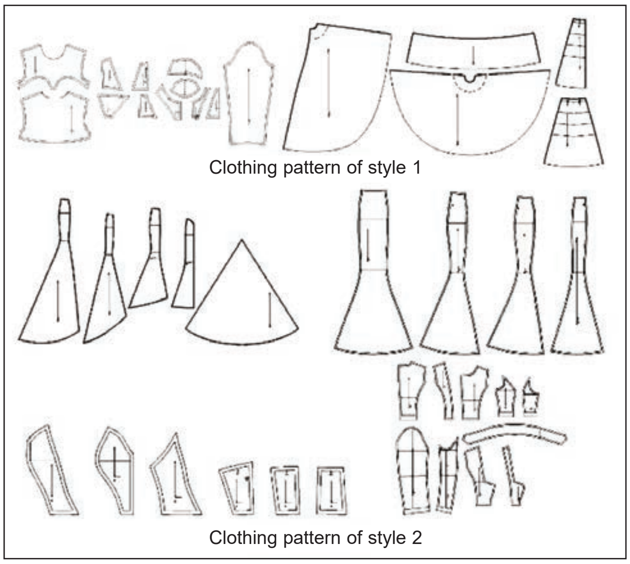

Fig. 13. Style drawing


Fig. 14. Wedding dress physical map

DISCUSSION

The method is feasible and reasonable according to the comprehensive evaluation of 5 technicians engaged in the wedding dress industry, combining static pressure, dynamic pressure and practical standards of wedding dress design. Subjective evaluations of the wearers showed that the chest and waist of the garment fit better with themselves, without discomfort, chest compression, or dyspnea. When the subjective performed the horizontal arm forward movement (bouquet), there was no looseness or falling of the top; when the arms are bent at 45° and the palms are moved inward (arms in arms), there is no huge deformation or slippage of the top.

Compared with traditional wedding dress production, the clothing adopts 3D visualization technology, obtains the human body point cloud through 3D scanning, constructs the human body model and 3D clothing style model, transforms the 3D style into a 2D pattern, and adjusts the virtual simulation version. All these operations are carried out on the computer, which greatly saves the time of traditional wedding dressmaking, and reduces manpower and cost. It is a new practical fashion design method with strong operability and realizes real accurate plate making.

CONCLUSION

This research focuses on "the structural design of female western-style wedding dress based on the point cloud of the human torso", and designs the basic corset. The research of wedding dress design methods through a virtual simulation platform verifies a new three-dimensional visual clothing design method, which meets the expectations of pre-study.

1. Achieved a two-dimensional pattern acquisition method based on the torso point cloud. The human body point cloud is obtained through 3D scanning, and the 3D surface model of the human body with arms is constructed according to the surface characteristics of the female human body, which prepares for the verification of the 3D style design method of the corset.

2. Completed the curved surface construction of the basic three-dimensional style of the corset in the reverse platform, and obtained the style expansion of the same style with different structures.

3. The three parts of the corset, skirt, and decoration are designed in the computer for a virtual simulation of the wedding dress, and the layout is adjusted according to the design requirements. The final design and the two-dimensional pattern can be completed at the same time, which can directly reflect the lack of design, improve the design, and improve work efficiency, shorten the cycle of clothing from design to shipment.

This method is valuable for enterprises from the acquisition of human body point cloud data to the surface construction and expansion of basic corset model, to the 3D virtual fitting and the final sample fitting. Compared with traditional wedding design, the method can improve work efficiency, shorten the work cycle, and customers can interact in time, so it is more scientific and operable.

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Research on garment flat multi-component recognition based on Mask R-CNN

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ABSTRACT – REZUMAT

Research on garment flat multi-component recognition based on Mask R-CNN

The automatic recognition of garment flat information has been widely researched through computer vision. However, the unapparent visual feature and low recognition accuracy pose serious challenges to the application. Herein, inspired by multi-object instance segmentation, the method of mask region convolutional neural network (Mask R-CNN) for garment flat multi-component is proposed in this paper. The steps include feature enhancement, attribute annotation, feature extraction, and bounding box regression and recognition. First, the Laplacian was employed to enhance the image feature, and the Polygon annotated component attributes to reduce the interaction interference. Next, the ResNet was applied to realize identity mapping to characterize redundant information of components. Finally, the feature map was entered into two branches to achieve bounding box regression and recognition. The results demonstrated that the proposed method could realize multi-component recognition effectively. Compared with the unenhanced feature, the mAP increased by 2.27%, reaching 97.87%, and the average F_1 was 0.958. Compared to VGGNet and MobileNet, the ResNet backbone used for Mask R-CNN could improve the mAP by 11.55%. Mask R-CNN was more robust than the state-of-the-art methods and more suitable for garment flat multi-component recognition.

Keywords: *Mask R-CNN, garment flat, feature enhancement, multi-component network, component localization and recognition*

Cercetări privind recunoașterea multi-componentelor liniare ale articolelor de îmbrăcăminte bazate pe metoda Mask R-CNN

Recunoașterea automată a informațiilor despre îmbrăcăminte a fost cercetată pe scară largă prin tehnologia computerizată. Cu toate acestea, caracteristica vizuală neaparentă și acuratețea scăzută a recunoașterii reprezintă provocări serioase pentru aplicație. Aici, în această lucrare, inspirată de segmentarea instanțelor multi-obiect, este propusă metoda rețelei neuronale convoluționale regionale (Mask R-CNN) pentru multi-componentele liniare ale articolelor de îmbrăcăminte. Pașii includ îmbunătățirea caracteristicilor, adnotarea atributelor, extragerea caracteristicilor și regresia și recunoașterea spațiului de delimitare. În primul rând, operatorul Laplacian a fost utilizat pentru a îmbunătăți caracteristica imaginii, iar atributele componentelor adnotate Polygon au fost utilizate pentru a reduce interferența interacțiunii. Apoi, rețeaua ResNet a fost aplicată pentru a realiza maparea identității și pentru a caracteriza informații redundante ale componentelor. În cele din urmă, harta caracteristicilor a fost introdusă în două ramuri, pentru a obține regresia și recunoașterea spațiului de delimitare. Rezultatele au demonstrat că metoda propusă ar putea realiza în mod eficient recunoașterea multicomponentelor. Față de caracteristica neîmbunătățită, mAP a crescut cu 2,27%, ajungând la 97,87%, iar media F_1 a fost de 0,958. În comparație cu VGGNet și MobileNet, rețeaua backbone ResNet a fost utilizată pentru Mask R-CNN, care ar putea îmbunătăți mAP cu 11,55%. Mask R-CNN a fost mai robustă decât metodele de ultimă generație și mai potrivită pentru recunoașterea multicomponentelor liniare pentru articolele de îmbrăcăminte.

Cuvinte-cheie*: Mask R-CNN, îmbunătățirea caracteristicilor liniare ale articolelor de îmbrăcăminte, rețea multicomponentă, localizarea și recunoașterea componentelor*

INTRODUCTION

In the textile and garment industry, garment CAD technology intends to become increasingly versatile in garment flat, pattern making, grading, and layout modules [1]. However, the obtained garment flat information and pattern-related dimension acquisition still rely on visual inspection of trained patternmakers' experience [2]. It is highly subjective, inefficient and prone to misjudgment [3]. Currently, image recognition technology based on computer vision has sprung up to meet the needs of information exchange between garment flat and pattern-related dimensions [4].

Nowadays, the garment flat recognition framework is driven by two scenarios based on the attribute difference: single or multiple object recognition. Compared to single recognition, multiple object recognition could assign multiple attributes for each instance simultaneously [5]. Moreover, the multi-component learning framework is more effective by jointly inter-class and intra-class recognition tasks. They could boost each other to prevent overfitting and the mutual promotion to ensure the feature representations robust and discriminative [6]. Thus, a multi-component learning network was established to automatically recognize garment flat.

Nowadays, garment flat recognition methods mainly are divided into two types: mathematical model and machine learning approach [7]. Compared with other methods, deep learning could extract high-level semantic features, without requiring artificially designed features, and has advantages in image recognition, classification, and detection [8]. In terms of deep learning in multi-object recognition, the recognition methods could be divided into attribute combination [9], classifier combination [10], and deep learning architecture modification [11]. In related research, Guan et al. established a series of databases for different recognition attributes, and different learning models were selected [9]. However, this method requires prior knowledge and many different models are prone to random errors. Later, Donati et al. converted multi-object into multiple single-object combinations by combining deep learning, template matching, and other classifiers. Nonetheless, the recognition accuracy was only 73.8% [10]. The main reason is that the garment flat is and composed of curves without texture and colour features, resulting in inconspicuous features [12]. Compared to the classifier combination, the modified deep learning Hypotheses-CNN-Pooling was proposed. However, this method was based on the entire image, which leads to redundant calculations [11]. Since then, the recognition framework based on the garment component was proposed [13]. The component-based recognition studies will more conform to patternmakers' minds which can select pattern prototypes according to the component category. More importantly, the component has more discriminating features because of removing too many irrelevant factors in contrast to the integral garment. Zhou et al. applied a part-based deep neural network cascade mode to integrate different component-recognition sub-network into a cascade for human parsing. The parsing results verify the superiority of this framework [14]. Furthermore, Zhou et al. applied VGG16-CAM to component-based garment recognition. The components could be effectively recognized, but the recognition accuracy only reached 82.23% [15]. This is because simultaneous multi-component recognition is prone to interfere with each other, resulting in low recognition accuracy. Therefore, it is necessary to find a method to address the problem of the unapparent visual feature and low recognition accuracy in the multi-component recognition of garment flat.

In this work, inspired by multi-object instance segmentation, the method of Mask R-CNN was proposed. First, the Laplacian was used to enhance the image feature. The Polygon annotated component attributes reduce interaction interference. Second, the ResNet backbone was applied to extract the feature. Finally, it combined the region proposal network (RPN) and full connection layer (FCL) for joint multi-component detection and recognition. We demonstrated that the proposed method has better performance than an unenhanced feature, other backbone architectures, and recognition methods. It is of great practical significance to automatically obtain garment flat information and reduce the subjectivity of patternmakers.

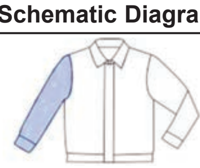
EXPERIMENTAL SECTION

Multi-attribute dataset annotation

Garment flats with collar, sleeve, and body components were selected for multi-component recognition. The dataset was established according to pattern prototype and component category, as shown in table 1.

Table 1

COMPONENT CATEGORY AND SCHEMATIC DIAGRAM

Component	Category	Schematic Diagram	Component	Category	Schematic Diagram
Sleeve	Long sleeve		Collar	Stand Collar	
	Short sleeve			Lapel	
Body	Shirt			Peak Lapel	
	Jacket		-	-	-

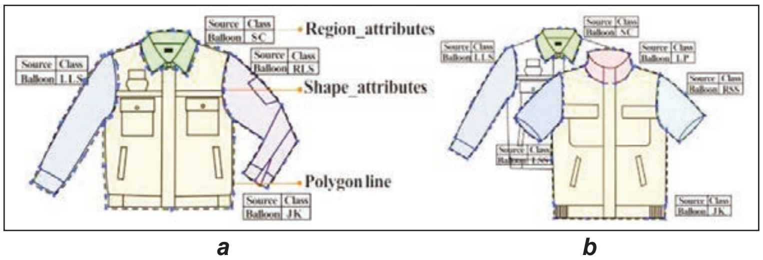


Fig. 1. Garment flat annotation: *a* – single annotation; *b* – multiple annotation

The 360 garment flats were kindly gifted from Zhejiang Lanting Garment Co., Ltd., China. The image resolution was 120 dpi, without other pre-processing. To meet the requirements of network training, VGG Image Annotation was applied to mask selection and attribute annotation. The attributes were annotated respectively (if the occlusion area exceeds 60%, it will not be annotated). Then the Polygon, instead of the Rectangle, annotated component attributes to reduce interaction interference (figure 1).

Multi-component recognition network establishment

Mask R-CNN, which integrates a full convolution network (FCN) and feature pyramid network (FPN) based on the Faster R-CNN was proposed [16]. It has low requirements on image quality and is more suitable for garment flat multi-component recognition. The results of feature extraction directly affect the recognition accuracy. Nowadays, the feature extraction networks, such as VGGNet, MobileNet, AlexNet, ResNet, etc. all have good recognition effects. Considering the particularity of the garment flat with less feature information, the ResNet-50 was applied as the backbone architecture to extract the feature. Compared to others, the problems of gradient explosion or dispersion caused by a deep network could be avoided by performing identity mapping on the redundant information of the garment flat. The residual block of ResNet is illustrated in figure 2 [17]. It transforms the fitting objective function into a residual function, which is more sensitive to small fluctuations. After feature extraction by ResNet, five feature layers (C2-C5) with different sizes and dimensions were fused in combination with FPN to generate the feature maps. Then the original garment flat had already obtained the highly abstract feature. Among them, C2 and C3 layers were used to extract shallow features to recognize the shape feature with obvious structures such as sleeves, collar, and body components. C4 and C5 layers were employed to recognize component subdivisions by extracting high-level semantic features.

Later, several regions of interest (RoIs) for each pixel position on the feature maps were set. The RoIs were sent into RPN for binary classification (foreground/ background) and bounding box regression to generate the refined RoIs. Then the refined RoIs were pooled into a fixed-size feature map through RoI Align to solve the misalignment problem caused by twice quantization processes. The goal is to ensure the pixels in the original image are completely aligned with the pixels in the feature maps. The backpropagation formula of RoI Align is illustrated in equation 1. The main purpose is to calculate the gradient between the output and the target value, and backpropagation to update the weight:

$$the\ \frac{\partial L}{\partial x_i} = \\ = \sum_r \sum_j \left[d(i, i(r,j)) < 1\right](1-\Delta h)(1-\Delta w)\frac{\partial L}{\partial y_{rj}} \quad (1)$$

where: L represents the function of RoI Align, x_i – the point on the feature map before pooling, y_{rj} – the j-th point in the r-th bin after pooling, r – the number of bins, j – the number of points in r-th bin, i – the point coordinate on the feature map, $i(r,j)$ – the floating-point coordinate after pooling, $d(.)$ – the distance between pixel points, Δh, Δw – the horizontal and the vertical coordinate difference between i and $i(r,j)$.

Then the RoIs after RoI Align processed entered into two branches to achieve multi-component recognition. Among them, one branch realized component subdivision through RoI classification and bounding box regression. The other was the mask generation network composed of FCN, which generated masks consistent with the size and shape of garment components. Then the category classification, bounding box regression, and mask generation were realized (figure 3) [18].

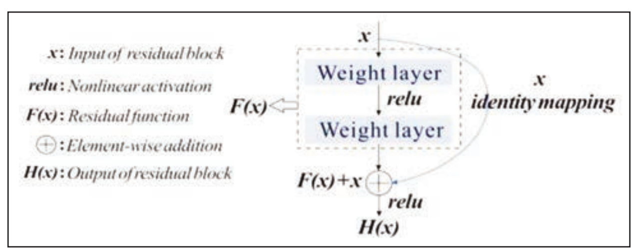


Fig. 2. Residual block of ResNet

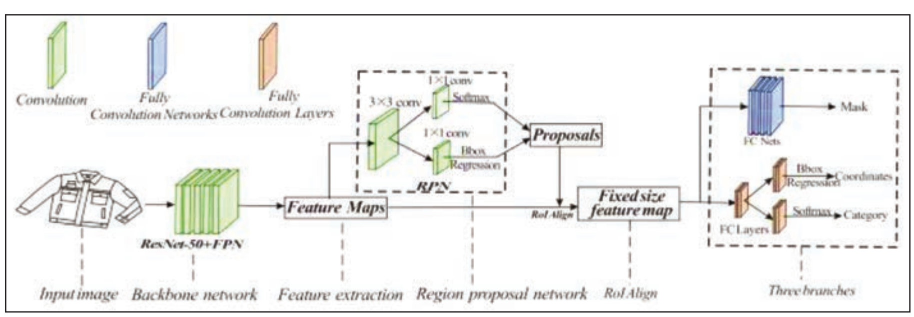


Fig. 3. Multi-component recognition framework

The network losses mainly contain class, bbox, and mask loss. The formula of the loss function is shown in equation 2. The classification and bounding box losses are identical to those defined in the work of Dai et al. [19]. The mask loss as the average binary cross-entropy loss is defined in the work of He et al. [16]. And the multi-target loss function was employed.

$$L = L_{cls} + L_{bbox} + L_{mask} \quad (2)$$

where: L_{cls} represents the class loss, L_{bbox} – the bbox loss and L_{mask} – the mask loss.

Multi-component recognition experiments

The experiments were implemented on a PC with AMD Ryzen 9 3900X CPU and AMD Radeon RX 6700XT GPU. The operation system was on Windows 10 with Tensorflow. The proposed method was performed on Python software.

According to the optimal standard of machine learning, the dataset was divided into training and testing set according to 8:2. Due to the small magnitude of the self-dataset, the experiments were pre-trained on the MS COCO 2014 to improve the generalization ability. The weights were transferred to the pre-training model by model similarity and transfer learning. The ResNet-50 was applied as the feature extraction backbone. The experiments were performed with a gradient of 25 epochs to determine the approximate training epochs. The trend was shown in figure 4. It was observed that mean average precision (mAP) tended to be stable after 100 epochs. In addition, the correlation between training time and epoch was analyzed. It could be observed that the epoch was significantly and positively correlated with the training time ($R^2 = 0.97$). Thus, considering the mAP and training time, the epoch was determined to be 100 and the number of images per iteration was 50. Since the garment components were relatively small relative to the entire garment and their size is uncertain, the scale of the RPN anchor was adjusted to better detect small targets. The main parameters of Mask R-CNN were shown in table 2.

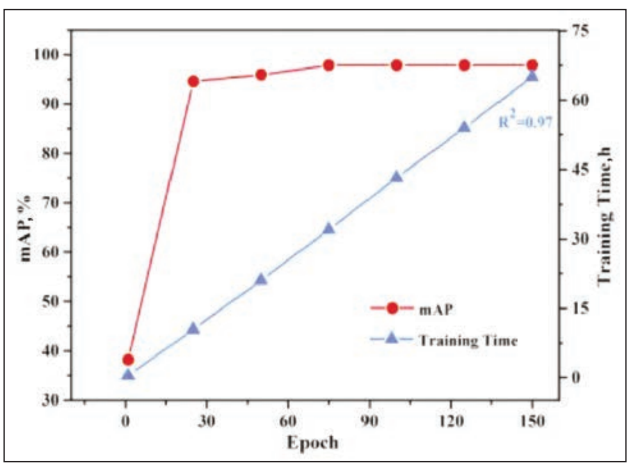


Fig. 4. mAP trend with epoch

RESULTS AND DISCUSSION

Evaluation metric selection

In target detection and recognition, average precision (AP) and mAP are often selected as evaluation metrics of the recognition network. Generally, the higher the value is, the better the network will be. According to the COCO dataset, the evaluation metrics are AP@50:5:95, $AP^{IoU=0.5}$, and $AP^{IoU=0.75}$. The IoU is the intersection over the union, as illustrated in equation 3:

$$IoU(i) = \frac{n_{ii}}{\sum_j (n_{ij} + n_{ji}) - n_{ii}} \quad (3)$$

where: n_{ii} represents the pixel numbers of the category i, which is predicted to be i, n_{ij} – the category j, which is predicted to be i. Otherwise, n_{ji} stands for the opposite.

For the evaluation of component recognition, accuracy and precision are used. Among them, the accuracy represents an evaluation of the overall correct recognition. And precision is the evaluation of a certain category. F_1 score is taken as the harmonic average, which takes into account the precision and recall, as shown in equation 4:

$$Accuracy = TP + TN / TP + FP + TN + FN$$
$$Precision = TP / (TP + FP),\ Recall = TP / (TP + FN)$$
$$F_1 = 2Precision * Recall / (Precision + Recall) \quad (4)$$

where: TP is the correct recognition, FP – the false, FN – the number of components.

Multi-component recognition results

The multi-component recognition network was trained on the self-constructed dataset. Figure 5,*a* is the network loss of the training set. All losses decreased rapidly in the iteration [0, 10] stage and tended to converge stably in the later stage. The total loss steadily converged to 0.25 after 100 iterations and the class, bbox, and mask losses all converged to 0.1. Figure 5,*b* is the losses of the testing set, which is similar to the training set. Although there had

Table 2

MAIN PARAMETERS OF MASK R-CNN

Configuration	Parameter	Configuration	Parameter
Backbone	ResNet-50	Detection_Min_Confidence	0.7
Backbone_Strides	[4, 8, 16, 32, 64]	Learning_Rate	0.001
RPN_Anchor_Scales	(32, 64, 128, 256, 512)	Learning_Momentum	0.9
RPN_NMS_Threshold	0.7	Weight_Decay	0.0001

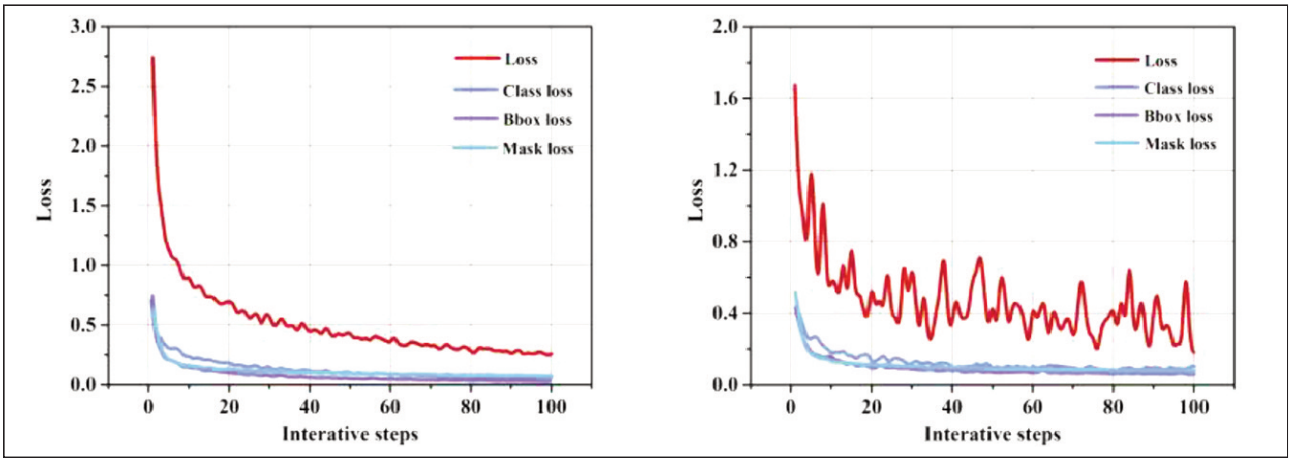


Fig. 5. Loss curve: *a* – training set; *b* – testing set

been a certain degree of small-range fluctuations in a total loss, the overall trend tended to converge. Thus, the network constructed in this paper was well-trained and had no over-fitting problem.

The trained multi-component recognition network was tested when the IoU = 0.5. The results demonstrated that the garment components could be recognized and localized. Among them, the rectangle represented the component position and the data was the mask quality. Different colour masks could accurately cover the component areas, and the bounding boxes could be positioned. It is applied to a garment flat containing one or more styles. The average mask quality score reached 99.2 % in garment flat containing one style, and in two or more styles was 98.1 % (figure 6). However, due to the insufficient features caused by mutual occlusion, some components appeared recognition omissions.

To further characterize the recognition effect, evaluation metrics were used. The mAP reached 97.87 %, and the average F_1 was 0.958 (table 3). The results showed that the Mask R-CNN based on ResNet-50 is effective. The garment components could be recognized at high precision. Among them, the F_1 of the sleeve and collar was higher than that of the body component. The reason was the shape of the sleeve and collar was more obvious than that of the body, and ResNet-50 could fully learn the component subdivision difference. The AP of the stand collar and

Table 3

EVALUATION METRICS OF MULTI-COMPONENT GARMENT FLAT

Category		Precision	Recall	F_1	Average F_1	AP/ %	mAP (%)
Sleeve	Long sleeve	0.944	1.000	0.971	0.964	98.4	97.87
	Short sleeve	0.957	0.957	0.957		98.83	
Body	Shirt	0.889	0.800	0.842	0.91	95.83	
	Jacket	0.955	1.000	0.977		98.14	
Collar	Stand collar	1.000	0.917	0.956	0.986	96.43	
	Lapel	1.000	1.000	1.000		98.74	
	Peak collar	1.000	1.000	1.000		98.73	

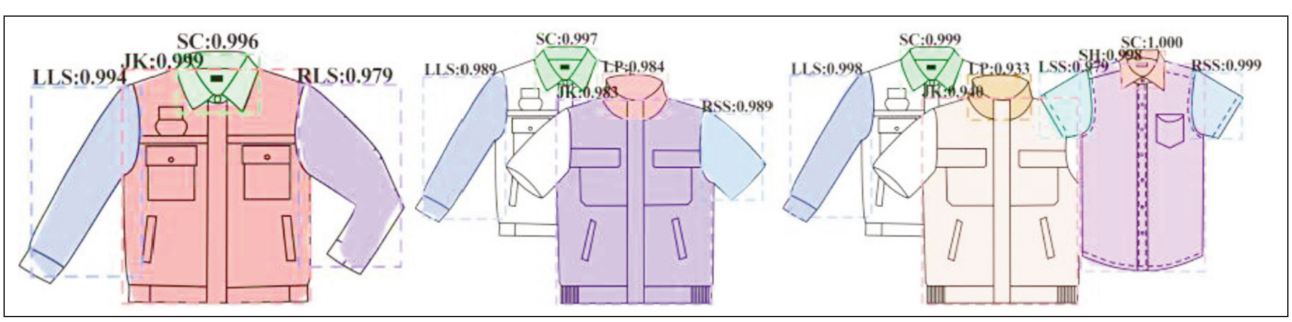


Fig. 6. Garment flat recognition results: *a* – single; *b* – double; *c* – multiple

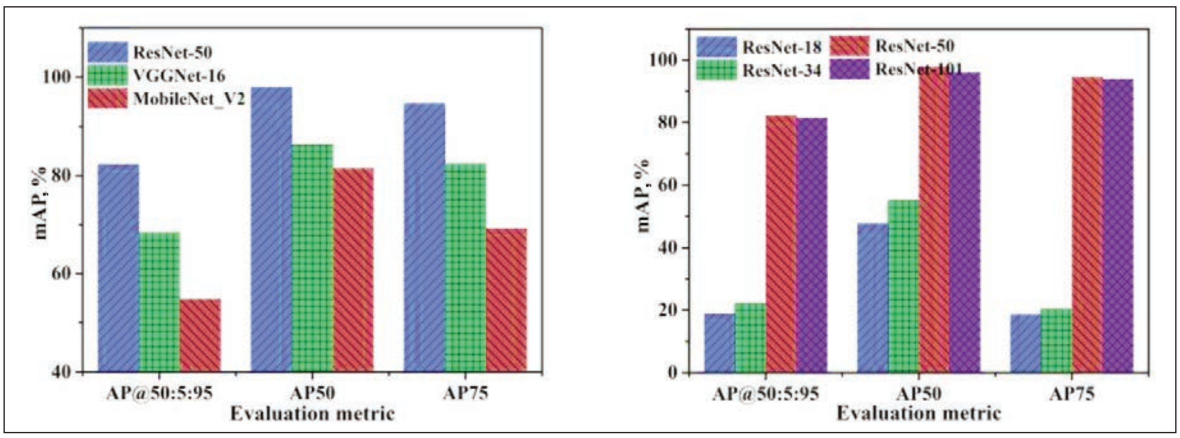
shirt was relatively small because the box localization and mask annotation could not completely coincide with the test set, resulting in a decrease.

Experimental comparative analysis

The specifications and proportions of the garment flat were not uniform. It was easily blurred, which directly affected the clarity of visual features. Edge sharpening was applied to enhance the shape feature to solve this problem. Currently, the main sharpening methods are first-order-based Sobel, Prewitt, and second-order-based Laplacian operators. Table 4 is the sharpening results.

It could be seen that Sobel and Prewitt operators formed pseudo edges. Among them, Prewitt expanded the edge silhouette and was almost distorted. And the internal details were still not obvious after Sobel sharpened. Compared with the aforementioned, the Laplacian operator not only enhanced the internal details but also heightened the edge feature. Therefore, the shape edge of the garment flat was enhanced by the Laplacian operator, and the definition of Laplacian is defined in [18]. Moreover, the multi-component experiments were carried out with enhanced features under the same network parameters. As we can see that the enhanced feature has a more distinguishable shape feature. It could effectively recognize the components, and the mAP improved by 2.27 % after feature enhancement (table 5).

To verify the ResNet-50 is more suitable in garment flat multi-component recognition, the ResNet-18, ResNet-34, ResNet-101 and other backbones such as VGGNet-16 and MobileNet_V2 were selected (figure 7). It could be seen that the mAP of ResNet-50



a *b*

Fig. 7. Comparison of backbones: *a* – other backbones; *b* – ResNet backbones

Table 4

RESULTS OF FEATURE ENHANCEMENT				
Sharpen operator	**Origin**	**Sobel**	**Prewitt**	**Laplacian**
Garment flat 1				
Garment flat 2				
Garment flat 3				

Table 5

COMPARATIVE EXPERIMENTS		
Recognition network	**Mask R-CNN**	**Mask R-CNN with enhanced feature**
mAP (%)	95.6	97.87

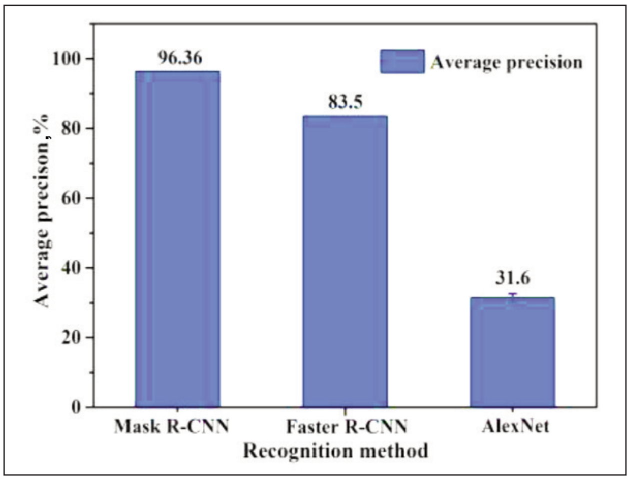


Fig. 8. Comparison of recognition methods

was improved by more than 11.55 % than other backbones. It is because the ResNet replaces the original target by fitting residual mapping, which makes the network more sensitive to small fluctuations [17]. On the other hand, ResNet-50 has a deeper network layer than others. The high-level convolutional kernel could cover larger-scale features and combine more low-level features. Compared to ResNet-101, the mAP of ResNet-50 only increased by 1.97%, but training time was reduced by more than double. The main reason is that the ResNet-50 already has a good feature extraction ability to extract the local gradient and edge shape features. However, ResNet-101 weakens the low-level feature while extracting more high-semantic information due to the depth network. And the weight needs to be updated layer by layer, resulting in a significant increase in training time. The core convolution layers 3 × 3 were adopted in ResNet-18 and ResNet-34 as a basic block, and network depth is relatively shallow that some components such as body components in garment flat could not be recognized effectively. Therefore, the ResNet-50 is more suitable as a feature extractor.

To verify the advantages of Mask R-CNN in garment flat recognition, the Faster R-CNN and AlexNet were selected (figure 8). The recognition precision of Mask R-CNN was significantly the highest. This is because of the pixel deviation of Faster R-CNN during the pooling process. The RoI Align is used in Mask R-CNN which is combined with the FCN's accurate pixel Mask to achieve higher precision. Moreover, the lowest precision of AlexNet is mainly due to feature interference. Other components weakened the feature, resulting in the precision being only 31.6%.

CONCLUSIONS

In this paper, the garment flat multi-component recognition method based on Mask R-CNN was proposed. The main conclusions were drawn as follows:

1. The proposed method could realize the recognition and localization of garment flat components effectively. The network was robust and had low requirements for image quality.
2. The feature enhanced by Laplacian could effectively improve the mAP by 2.27%, reaching 97.87%, and the average F_1 was 0.958.
3. According to the experimental comparison, Mask R-CNN based on ResNet-50 had higher recognition accuracy than that of other backbones and recognition methods.

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Determination of used textiles drape characteristics for circular economy

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ABSTRACT – REZUMAT

Determination of used textiles drape characteristics for circular economy

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.

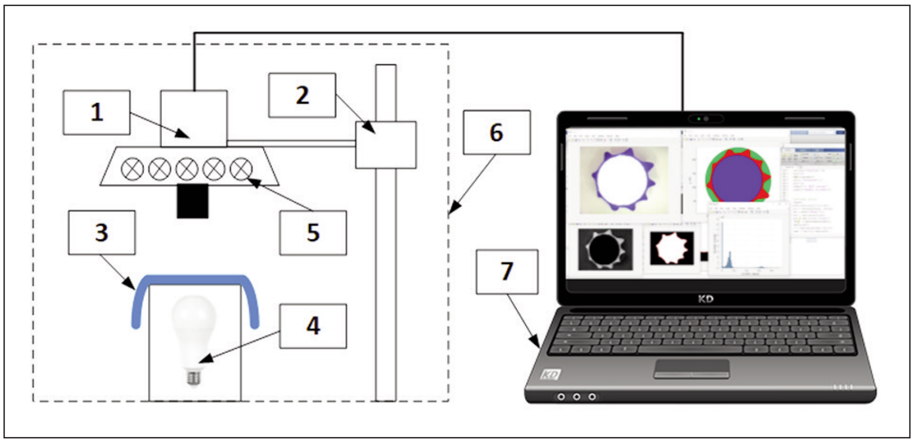


Fig. 1. Schematic of the experimental set-up used in the work: 1 – digit video camera; 2 – movable stand for changing the shooting height; 3 – measured sample; 4 – light source to illuminate the sample below; 5 – light source to illuminate the object from above; 6 – housing to reduce the influence of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

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

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:

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

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 $\alpha = 0.05$.

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:

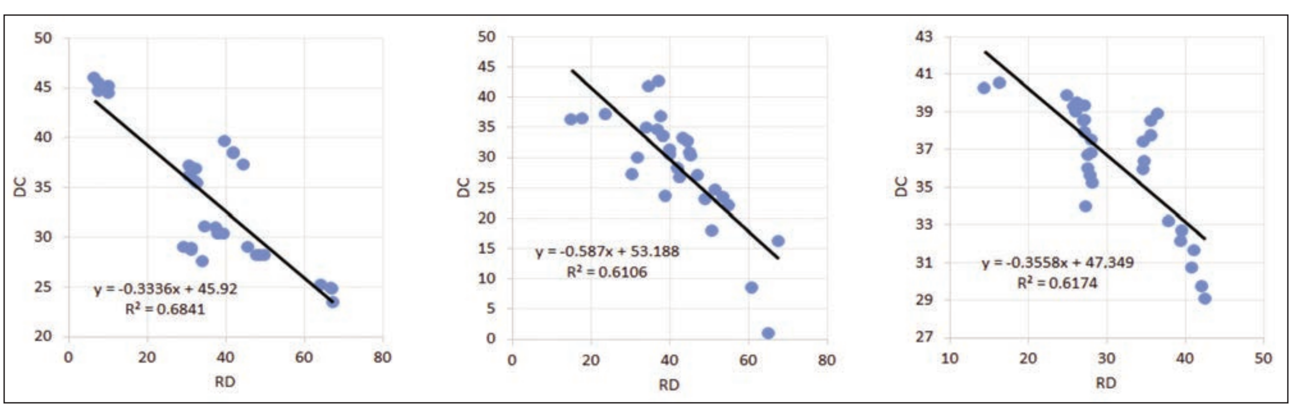
$$FV_2 = [\%Cotton, \%Polyester, \%Elastan, \%Polyamide, N] \quad (10)$$

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.

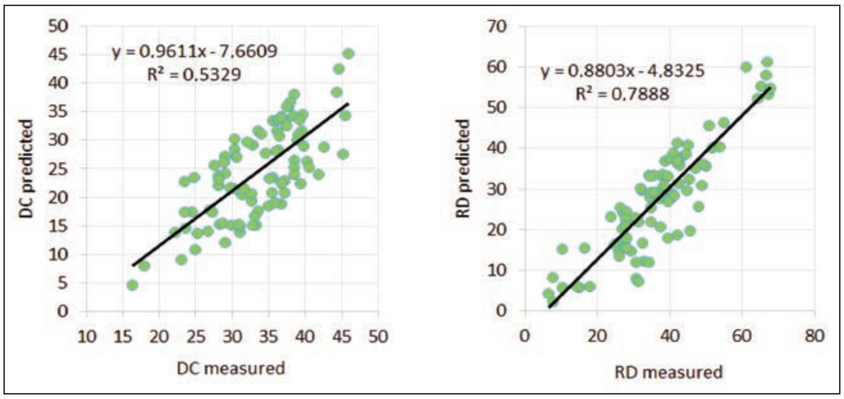
Table 8

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

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 $<< \alpha$. 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

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:

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

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

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

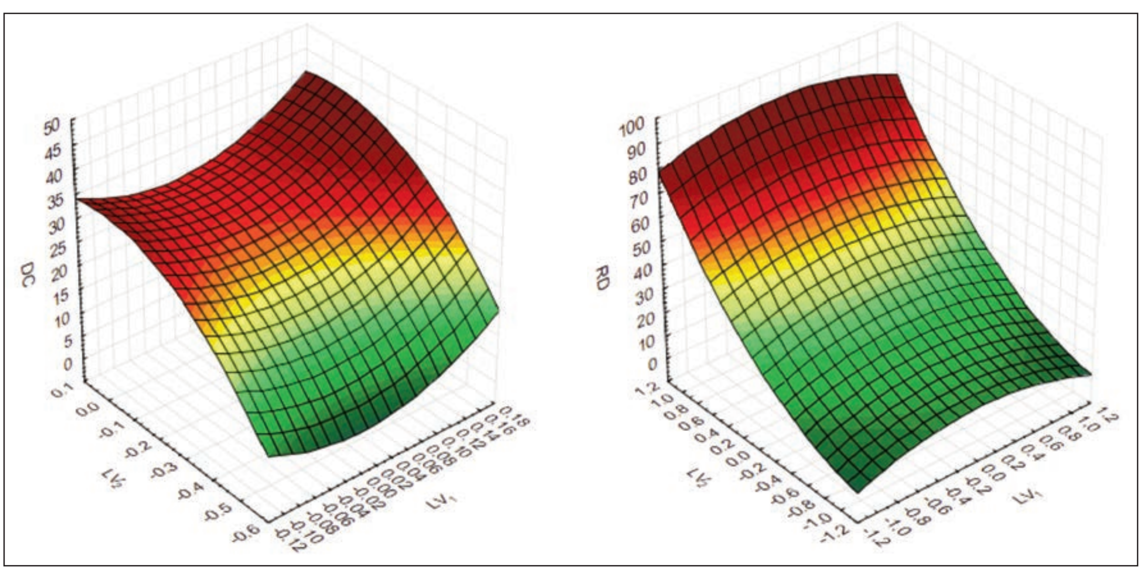
$$RD = 36{,}15 + 31{,}55\,LV_2 - 7{,}26\,LV_1^2 + 10{,}31\,LV_2^2 \qquad (12)$$

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

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.

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Non-contact clothing anthropometry based on two-dimensional image contour detection and feature point recognition

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ABSTRACT – REZUMAT

Non-contact clothing anthropometry based on two-dimensional image contour detection and feature point recognition

Developing the technology of estimating human body size from two-dimensional images is the key to realising more digitalization and artificial intelligence in the textile and garment industry. Therefore, this paper is an in-depth study of estimating body sizes from two-dimensional images in a self-collected database of human body samples. First, the artificial thresholds in the Canny edge operator were replaced by adaptive thresholds. The improved Canny edge operator was combined with mathematical morphology so that it could detect a clear and complete single human contour. Then a joint point detection algorithm based on a convolution neural network and human proportion is proposed. It can detect human feature points with different body proportions. Finally, front and side images and manual body measurements of 122 males aged 18–22 years were collected as the human sample database, calculating the length and fit of the girth size. Compared with manual body measurement data, the error of human length and girth size parameters within the national standard range of –1.5 ~ 1.5 cm can reach 91% on average. This study provides an accurate and convenient anthropometric method for digital garment engineering, which can be used for online shopping and garment customization, and has a certain practical value.

Keywords: *anthropometry, textile clothing, image processing, contour detection, feature point detection*

Antropometrie fără contact bazată pe detectarea conturului imaginii bidimensionale și recunoașterea punctelor caracteristice

Dezvoltarea tehnologiei de estimare a dimensiunii corpului uman din imagini bidimensionale este cheia pentru a facilita digitalizarea și inteligența artificială în industria textilă și de îmbrăcăminte. Prin urmare, această lucrare este un studiu aprofundat al estimării dimensiunilor corpului din imagini bidimensionale, într-o bază de date auto-colectată de eșantioane ale corpului uman. În primul rând, pragurile artificiale din operatorul de margine Canny au fost înlocuite cu praguri adaptative. Operatorul de margine Canny îmbunătățit a fost combinat cu morfologia matematică, astfel încât să poată detecta un singur contur uman clar și complet. Apoi, este propus un algoritm de detectare a punctului comun bazat pe rețeaua neuronală convoluțională și proporția umană. Se pot detecta punctele caracteristice umane cu diferite proporții ale corpului. În cele din urmă, imaginile frontale și laterale și dimensiunile corporale preluate manual ale unui număr de 122 de bărbați cu vârsta cuprinsă între 18 și 22 de ani au fost colectate ca bază de date pentru eșantioane umane, calculându-se lungimea și circumferința. În comparație cu datele antropometrice ale corpului preluate manual, eroarea parametrilor de lungime și circumferință a corpului uman în intervalul standard național de –1,5 ~ 1,5 cm poate ajunge la o medie de 91%. Acest studiu oferă o metodă antropometrică precisă și convenabilă pentru modelarea digitală a îmbrăcămintei, care poate fi utilizată pentru cumpărături online și personalizarea articolelor de îmbrăcăminte și are o anumită valoare practică.

Cuvinte-cheie*: antropometrie, îmbrăcăminte, procesarea imaginilor, detecția conturului, detecția punctului caracteristic*

INTRODUCTION

With the increasing popularization of digital and intelligent consumption patterns such as online clothes shopping and personalization, people have higher requirements for the style and fit of their clothing. Body size data have a decisive role in digital garment engineering. Therefore, it is necessary to conduct in-depth research to develop a fast and efficient anthropometric measurement method suitable for the garment industry.

Existing methods for measuring the human body include traditional manual measurement, non-contact measurement from three-dimensional data, and non-contact measurement from two-dimensional images [1, 2]. Manual measurement requires professional skills, whereas non-contact measurement from three-dimensional data requires the person to wear specific clothing. The equipment needed is large and expensive. Thus, these two methods are difficult for ordinary consumers and have low universality. In contrast, the non-contact measurement from two-dimensional images of the human body can obtain body parameters. Multiple photographs are taken from different angles by a user with a camera or mobile phone [3], which is convenient and quick to do. Two-dimensional anthropometry can be divided into three steps: contour detection, feature point detection, and girth fitting.

Several scholars have researched two-dimensional anthropometry. For example, Qin and Li [4] replaced the Gaussian filtering in the traditional Canny edge operator with median filtering. Xu [5] used the classical Canny edge operator and the Otsu algorithm to obtain human contours. Some scholars have applied traditional feature point detection algorithms, such as SURF and Harris, to human feature point detection [6, 7]. However, using a single algorithm is prone to the false detection of feature points. Zou et al. [8] defined the regions of feature points of each part according to the relative proportions of the human body. They calculated the maximum edge response points of each region and recorded them as feature points. However, this method relies too much on ergonomic proportions and has low positioning accuracy, so it is not suitable for people with atypical body proportions. Xia et al. [9] predicted the girth according to the shape of the characteristic section of the human body. Xing et al. [10] constructed a model for predicting human body dimensions using a multilayer perceptron neural network. The errors for these two methods were small, but three-dimensional scanning is still needed, and the process is cumbersome. Zhao et al. [11] constructed the three-dimensional human body in three different ways and then carried out anthropometry. The accuracy of the measurement results is high, but the main measurement size is the upper body size, which cannot provide a size reference for pants or skirts. In addition, the generation and processing of the three-dimensional human body require professionals to operate, and it takes 15 minutes to 1 hour, which is not suitable for the general public and takes a long time.

The above research indicates that the current methods for measuring the human body from two-dimensional images have problems, such as the need for complex calculations and limited applicability. The clothing industry urgently needs two-dimensional volume measurement technology that is simple to calculate, can be used by the public, and can be applied to different body proportions. Therefore, based on the improved Canny edge operator and mathematical morphology algorithm, this paper improves the robustness of detecting human contours from two-dimensional images. The resulting two-dimensional contours are clear and accurate. Then a method based on a convolution neural network for human joint point recognition and human proportion is proposed to complete feature point detection on contour image. This method can be applied to atypical body proportions and has strong universality. Finally, a self-collected human body database was established, which contains front and side photographs and manual measurements of 122 men aged 18–22. The data were used to estimate the length and girth parameters of the human body. A predictive girth regression model was creatively established based on width, thickness, and weight. The errors for the predicted length and girth parameters within –1.5 cm ~ 1.5 cm reached 91% on average. The method overcomes the problems of large size errors and low measurement efficiency. The estimated values agree well with the specifics of each individual, making it suitable for online clothes shopping and personalization.

FEATURE POINT RECOGNITION FROM TWO-DIMENSIONAL CONTOUR IMAGES

The key to obtaining accurate dimensions of the human body is correctly identifying the feature points of various parts of the body. These feature points must be detected from a single clear contour. Therefore, this section accurately identifies feature points based on two-dimensional contours, which lays the foundation for the subsequent calculation of length and girth parameters.

Human body image acquisition

To ensure the accuracy of dimensional data measurement, some requirements are put forward for users to take front and side photos. The specific requirements are as follows:

The shooting background should be as simple as possible, the light should be uniform, and there should be no serious reflection. Users try to wear more close-fitting, which can be clearly distinguished from the background colour.

Requirements for photographing posture: when taking frontal photos, stand upright with your arms open, and your legs and feet standing apart. When taking side photos, keep your body upright and your arms drooping naturally, but avoid covering the outer contour of your waist and hips, and stand with your legs and feet together. The shooting angle is required to be horizontal with the subject as far as possible to avoid problems such as portrait tilt and deformation.

Canny edge detection and mathematical morphology processing

Common operators for detecting the contours of a human body include the Laplacian operator, Sobel operator, Roberts operator, and Canny detection operator. In comparative analysis through the OpenCV module of Python, The Canny operator that can detect the real weak edge in the image and locate accurately is selected for contour detection, but the Canny edge operator will be affected by noise. and the edge of the object contour is generally determined by manually setting a double threshold [12], It is difficult to accurately grasp the size of the threshold. Therefore, an adaptive threshold is proposed to replace the traditional manually set threshold to avoid the uncertainty and complexity of manually setting the threshold. Then Canny edge operator is combined with mathematical morphology to reduce the impact of noise. The specific algorithm steps are as follows:

1. Greying RGB images.
2. Gaussian filter is used to smooth the image to remove high-frequency noise.
3. Calculate gradient amplitude and direction.
4. The gradient amplitude is suppressed by the non-maximum value.
5. At this time, an image with many discrete edge points is obtained, and then an adaptive threshold method is proposed to automatically detect and connect the real edge points. The high and low thresholds are constructed from the median of the pixel intensity for a single image channel [13]. First, we calculate the median pixel intensity in the image:

$$m = np.median(image) \tag{1}$$

Then, we use the median to calculate the high and low thresholds:

$$TH = \text{int}(\min(0, (1.0 + sigma) * m)) \tag{2}$$

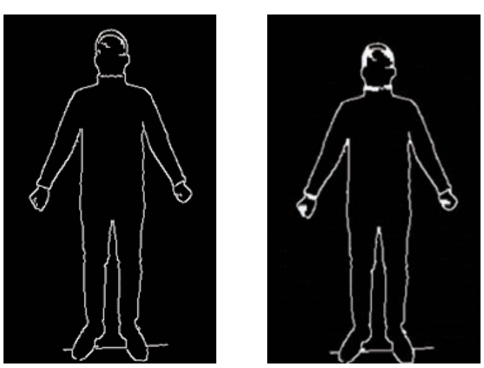
$$TL = \text{int}(\max(0, (1.0 - sigma) * m)) \tag{3}$$

where TH is the high threshold and TH – the low threshold. The function int ensures that the thresholds are integers. Here, $sigma$ = 0.33 is a fixed parameter [14]. The high and low thresholds are used in Canny edge detection, as shown in figure 1, *a*.

It can be seen from the figure that the improved Canny algorithm with adaptive thresholds can identify the real edge, but the head and other parts are still prone to stray edges. To obtain a single and complete human lateral contour, a method combining the Canny edge operator and mathematical morphology is proposed. To remove stray edges and noise, the closed operation method of expansion first and corrosion is adapted to process the image further. The results after this morphological processing are shown in figure 1, *b*.

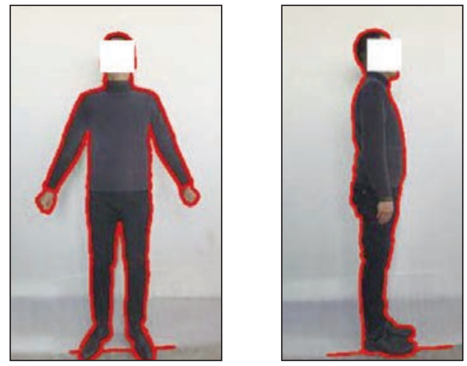
OpenCV module in Python is used to automatically detect the outer contour of the image after morphological processing, and the detected contour is displayed in the original image. The detection results are shown in figure 2.

It can be seen that for a subject standing against a relatively simple background and wearing their well-fitting clothes, the outline of their body was clearly



a *b*

Fig. 1. Edge detection results: *a* – adaptive thresholds; *b* – morphological processing



a *b*

Fig. 2. Detected front and side contours of a person: *a* – front red outer contour; *b* – side red outer contour

and completely recognized. After the closed operation, the contour is consistent with the original human image. Thus, automatic recognition can be realized without manual intervention, which is conducive to improving the efficiency of image detection while protecting the user's privacy to a certain extent.

Feature point detection based on convolution neural network and human proportion

Body length and girth parameters can be estimated accurately only if the feature points are correctly located and detected. To solve the problems of wrong detections, missing detections, and inaccurate positioning prevalent in current methods for feature point detection, a feature point detection method based on convolutional neural network VSSC (via soft gated skip connections) [15] human joint point recognition algorithm and human proportion is proposed.

Feature point detection based on MPII data set [16]. Python is used to test the joint points of a two-dimensional human image, in which the front image includes 12 points, and the side image includes 7 points on the right side of the human body. The experimental results after automatically marking the coordinate position of joint points are shown in the red dot in figure 4.

It can be seen from figure 4 that the joint point recognition algorithm can accurately locate the head, shoulder, arm, and knee, but cannot detect the chest, waist, or sole points, but these three parts are key for the human body measurements. Therefore, in this paper, we calculate the positions of these three parts using the relative proportions of a human body as used in engineering applications [17, 18]. That is, the chest coordinates (C_x,C_y) are calculated according to the relationship between the neck and the chest:

$$C_x = N_x \tag{4}$$

$$C_y = N_y + (Lf_y - top_y) * 0.15 \tag{5}$$

where: N_x is the abscissa of the neck, N_y – the ordinate of the neck, Lf_y – the ordinate of the bottom of the left foot, and top_y – the ordinate of the top of the head.

Calculate the characteristic points of the waist (W_x, W_y) according to the relationship between the waist and the hips:

$$W_x = (Lh_x - Rh_x)/2 + Rh_x \quad (6)$$

$$W_y = Lh_y - (Lf_y - top_y) * 0.105 \quad (7)$$

where: Lh_x is the abscissa of the left hip and Rh_x – the abscissa of the right hip, Lh_y – the ordinate of the left hip.

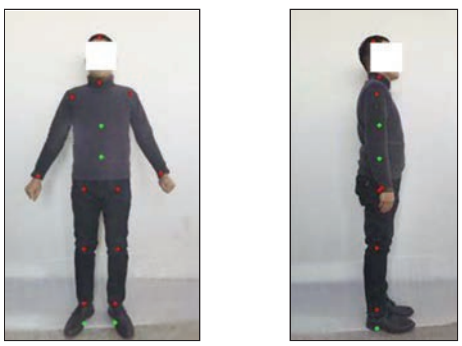
The coordinates of the sole points are (F_x, F_y). They were calculated from the coordinates of the ankle point:

$$F_x = Ra_x \quad (8)$$

$$F_y = 0.066\,(Ra_y - top_y)/0.934 + Ra_y \quad (9)$$

where: Ra_x is the abscissa of the right ankle and Ra_y – the ordinate of the right ankle. The left ankle point can be obtained in the same way.

The resulting joint points are shown in figure 3. The chest, waist, and sole points are marked with green points.

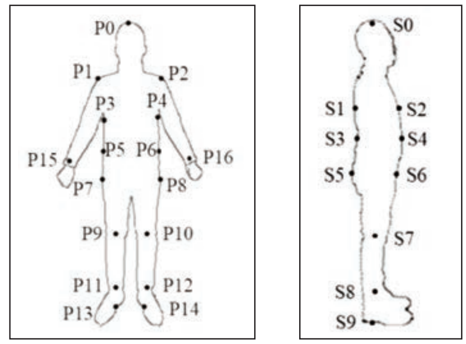


a *b*

Fig. 3. Detected complete feature points: *a* – front joint points; *b* – side joint points

Using the joint point coordinates shown in figure 3, the feature points were detected for the red contour image in figure 2. The obtained positions of the feature points are shown in figure 4. Those at the front and side are represented by P and S, respectively.

From the feature point detection results, it can be seen that the feature point detection method based on the combination of convolution neural network and human proportion proposed in this paper can accurately detect the feature points of the top of the head, shoulders, chest and waist, and the positions of the detected feature points of each part are consistent with the feature positions defined in the national standard. The positioning is accurate and the calculation is simple, which is suitable for groups with different body proportions.



a *b*

Fig. 4. Location of feature points: *a* – front joint points; *b* – side joint points

CALCULATION OF HUMAN BODY LENGTH AND GIRTH PARAMETERS

According to the key dimensions and actual needs of taking anthropometry, 122 male images aged 18–22 were collected by mobile phones and used a soft ruler and other tools to measure the body manually. The numbers of pixels for 10 parameters (height, arm length, shoulder width, chest width, chest thickness, waist width, waist thickness, hip width, hip thickness, and pants length) were obtained from the collected images. The above dimensions and the actual dimensions of the chest girth, waist girth, and hip girth were measured manually. The weight of each participant was recorded by a standard electronic scale. It is used to predict the length and circumference of the human body.

Calculation of lengths

The height measured manually for the subject is *H*, whereas the pixel value of the height in the image is based on the *y*-coordinates of two feature points. Thus, the pixel height of the front image is P_0P_{13}, and the pixel height of the side image is S_0S_9 (figure 4). Then, the ratios of the real height and the pixel heights in the front side images are *Pr* and *Sr*, respectively:

$$Pr = H/P_0P_{13} \quad (10)$$

$$Sr = H/S_0S_9 \quad (11)$$

The physical sizes of the other lengths were calculated by scaling. The formulas are listed in table 1.

Table 1

FORMULAS FOR THE IMAGE SIZE OF EACH PART

Position	Formula	Position	Formula
Shoulder width P_{sw}	$P_{sw} = Pr\ P_1P_2$	Waist width P_{WW}	$P_{WW} = Pr\ P_5P_6$
Arm length P_L	$P_L = Pr\ P_1P_{15}$	Waist thickness S_{WT}	$S_{WT} = Sr\ S_3S_4$
Trouser length S_L	$S_L = Sr\ S_3S_9$	Hip width P_{HW}	$P_{HW} = Pr\ P_7P_8$
Chest width P_{CW}	$P_{CW} = Pr\ P_3P_4$	Hip thickness S_{HT}	$S_{HT} = Sr\ S_5S_6$
Chest thickness S_{CT}	$S_{CT} = Sr\ S_1S_2$	-	-

Calculation of body girths

In this section, a regression model is established. Altogether, 100 samples were randomly selected from the database and used to build the model, and 22 samples were used to verify the model.

Correlation analysis

For the 100 men, the Pearson correlation coefficient was used to analyse the linear relations between the actual chest, waist, and hip girths (dependent variables) and the real weight and the real width and thickness of the corresponding body part (independent variables) [19]. The results are listed in table 2.

Table 2

CORRELATION COEFFICIENT BETWEEN EACH FACTOR AND EACH GIRTH			
Position	**Weight**	**Width**	**Thickness**
Chest girth	0.8727	0.7861	0.7513
Waist girth	0.7943	0.8012	0.8242
Hip girth	0.9122	0.79283	0.7897

It is generally considered that there is a correlation when the correlation coefficient is greater than 0.6. It can be seen from the table that the correlation coefficient between each girth and the weight, width, and thickness is greater than 0.6, indicating that these three factors can be used to establish a regression model with the girths.

Shape classification and model establishment

To improve the accuracy of size prediction, the section shapes of the chest, waist and hip are divided into a short circle, circular length and flat length according to the width thickness relationship. The ratio of the section shape is closer to the median value of the class, the stronger the linear relations are between the width and thickness and the girth, so the better the fitting degree of the prediction model. Therefore, the samples were divided into three classes using the width-to-thickness ratio r, as listed in table 3.

Establish regression model for each category:

$$W = a_0 + a_1 Z + a_2 K + a_3 T \quad (12)$$

where: Z is the weight, K – the width, and T – the thickness.

According to the classification, the multiple linear regression method is used to fit the regression model for each category of the three parts, and the judgment coefficient R^2 and adjustment R^2 of the regression model are listed in table 4.

It can be seen from the table that the adjusted R^2 of the regression model after classification has been improved, basically above 0.9, indicating that at least 90% of the effective information of the sample value is used to explain the regression equation, and the model fitting effect is good. Among them, the fitting degree improvement rate of the chest and hip is lower than that of the waist, mainly because the waist section shape itself has a large difference, and the characteristics of each category after classification are more significant and more relevant, so the fitting degree improvement rate is higher, while the cross-section shape difference of chest and waist is relatively small, and the fitting degree improvement rate

Table 3

SHAPE CLASSIFICATION						
Position	**Class A**		**Class B**		**Class C**	
	Number	Range	Number	Range	Number	Range
Chest	23	$r < 1.40$	53	$1.40 \le r \le 1.55$	23	$r > 1.55$
Waist	22	$r < 1.35$	43	$1.35 \le r \le 1.45$	35	$r > 1.45$
Hip	30	$r < 1.40$	51	$1.40 \le r \le 1.50$	17	$r > 1.50$

Table 4

REGRESSION EQUATIONS ESTABLISHED AFTER SHAPE CLASSIFICATION					
Position	**Class**	**Regression equations**	**R^2 before**	**R^2 after**	**Promotion (%)**
Chest	A	$W_{CA} = 1.9688 + 0.2798Z + 1.5161K + 0.9634T$	0.8571	0.9072	5.8
	B	$W_{CB} = 4.8169 + 0.2468Z + 1.4023K + 1.1134T$		0.9346	9.0
	C	$W_{CC} = 7.3438 + 0.2644Z + 1.0066K + 1.5727T$		0.9778	14.1
Waist	A	$W_{YA} = 2.5612 + 0.0920Z + 1.5554K + 1.4213T$	0.8284	0.9583	15.7
	B	$W_{YB} = 0.0789 + 0.1192Z + 1.7014K + 1.2349T$		0.9767	17.9
	C	$W_{YC} = 2.3875 + 0.0945Z + 2.1957K + 0.3998T$		0.9514	14.8
Hip	A	$W_{HA} = 31.8552 + 0.3339Z + 1.1864K + 0.0614T$	0.8553	0.9290	8.6
	B	$W_{HB} = 15.3843 + 0.3207Z + 2.5362K - 1.1982T$		0.9503	11.1
	C	$W_{HC} = 49.7284 + 0.3781Z + 0.9081K - 0.5501T$		0.8594	0.5

Table 5

LENGTH ERROR DISTRIBUTION DIAGRAM				
Part of the body	**Min error** (Image value – Manual value) (cm)	**Max error** (Image value – Manual value) (cm)	**Mean value of error**	**Accuracy within ±1.5 cm (%)**
Shoulder width	0.100	2.250	0.897	93.3
Arm length	0.060	1.968	0.869	91.1
Trouser length	–0.150	2.230	1.100	82.2

Table 6

GIRTH ERROR DISTRIBUTION DIAGRAM				
Part of the body	**Min error** (Image value – Manual value) (cm)	**Max error** (Image value – Manual value) (cm)	**Mean value of error**	**Accuracy within ±1.5 cm (%)**
Chest girth	–0.025	1.618	0.056	90.9%
Waist girth	0.034	1.548	0.665	95.5%
Hip girth	0.008	–1.671	0.729	86.4%

is lower than that of the waist, but it is generally improved, which indicates that the prediction error value after classification has been improved.

VERIFICATION AND ANALYSIS

To evaluate the reliability of the model, the proposed anthropometric algorithm is applied to 22 samples randomly selected. The length and three girths of body parts were estimated and compared with manual measurement. The reasons for the accuracy and error of the estimation are analysed. First, the measurement results of shoulder width, arm length and trousers length are verified, and the results are shown in table 5.

Table 5 shows the error distributions and average errors for the shoulder width, arm length, and trouser length. The accuracies of the dimensions are listed in table 5. The errors for shoulder width are mostly distributed within ±1.5 cm. The average error for the shoulder width was 0.82 cm and for arm length, it was 0.92 cm, both of which are reasonable. The errors for trouser length were relatively larger. There was an average error of 1.12 cm and a large deviation, mainly because the pixel distance in the leg image was calculated from the waist point to the ankle point. Any bending of the leg or deviation in detecting the waist will have affected the estimated size of the trouser length. Most of the estimated trouser lengths were smaller than the real values.

Then, the predicted girth values of the chest, waist and hip are compared with the manually measured values, and the results are shown in table 6.

It can be seen from the table that the girth values of the chest, waist and hip predicted by the regression model established in this paper fit well with the manually measured dimensions, and the overall error range is basically within ± 1.5 cm. Among them, the error value of the waist is the smallest, and the fitting degree between the predicted value and the manual value is the best. After the complete statistics of length parameters and girth parameters, the obtained data meet the requirements of adult human body size error of –1.5 ~ 1.5 cm specified in GB/T1335.2-2008. National Garment Size [20].

CONCLUSIONS

This paper uses anthropometry based on two-dimensional images to extract human body measurements. Existing measurement methods with two-dimensional images often produce inaccurate positions for the feature points and are appropriate for only a limited range of body shapes. The proposed method was based on a self-collected human sample database. It combined the Canny edge detection operator with a mathematical morphology algorithm to recognize contours automatically. The contours were clear, complete, and consistent with the size of the original image. Joint point recognition and human body proportions were used to locate feature points accurately. The method is suitable for individuals with atypical body proportions. The number of samples with the average error of the final length and perimeter data within ±1.5 cm accounts for 91% of the total number of samples, which meets the size requirements of garment manufacturing. This approach can conveniently provide users with their body data for online shopping and personalized customization.

Although this method is better at extracting feature points and calculating girths than previous methods, it could be further improved. On the one hand, in terms of the establishment of the database, due to the limitations of the experimental environment and conditions, the amount of data collection is relatively small, and the age range involved is relatively concentrated. Therefore, when it is applied, it will have a better experience for 18–22 years old youth and people of similar ages, while it will have a relatively weak experience for other people with large age differences. With the continuous expansion of the subsequent database, The measurement accuracy based on the algorithm in this paper will continue to improve, and the age range involved will gradually expand and become more refined. On the other hand, we should do further research on the human body in a complex background to further improve the two-dimensional image anthropometry method proposed in this paper.

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Pants design and pattern generation based on body images

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ABSTRACT – REZUMAT

Pants design and pattern generation based on body images

The personalized pattern generation method based on 2D body-measuring technology has considerable application potential in clothing e-commerce, remote clothing customization, clothing production, and other aspects. By inputting the front and side body images, this study proposed a new method of generating personalized patterns automatically. The silhouettes could be extracted from the body images to estimate body sizes and design style. The basic rules between the patterns and the body sizes were analysed, and the rules of the general pattern generation were established through a knowledge-based combination of the basic pattern and the style parameters. The sizes extracted from images were compared with the manually measured values, and the errors of these sizes were analysed. Sample pants were made and tried on with the automatic pattern generation system, and the experiments showed that the sample pants have a good fit at some key landmarks. As a result, this system can automatically generate personalized patterns and style designs based on 2D human body images, to improve garment fit and accelerate clothing customization.

Keywords: *size extraction learning, silhouette design, prediction model, body-garment relationship*

Designul pantalonilor și generarea tiparelor pe baza imaginilor corpului

Metoda de generare a tiparelor personalizate bazată pe tehnologia de măsurare a corpului 2D are un potențial considerabil de aplicare în comerțul electronic de îmbrăcăminte, personalizarea de la distanță a articolelor de îmbrăcăminte, producția de îmbrăcăminte și alte domenii. Prin introducerea imaginilor corpului frontal și lateral, acest studiu a propus o nouă metodă de generare automată a tiparelor personalizate. Siluetele ar putea fi extrase din imaginile corpului pentru a estima dimensiunile corporale și designul. Au fost analizate regulile de bază dintre tipare și mărimile corpului, iar regulile generale de generare a tiparelor au fost stabilite printr-o combinație bazată pe cunoștințe despre tiparul de bază și despre parametrii stilului de construcție. Dimensiunile extrase din imagini au fost comparate cu valorile măsurate manual, iar erorile acestor dimensiuni au fost analizate. Prototipurile de pantaloni au fost realizate și testate cu sistemul de generare automată a tiparelor, iar experimentele au arătat că produsele se potrivesc corespunzător în unele puncte cheie. În concluzie, acest sistem poate genera automat tipare personalizate și modele bazate pe imagini 2D ale corpului uman, pentru a îmbunătăți corespondența articolelor de îmbrăcăminte și pentru a accelera personalizarea îmbrăcămintei.

Cuvinte-cheie*: învățarea extragerii mărimii, designul siluetei, model de predicție, relație corp-îmbrăcăminte*

INTRODUCTION

With the rapid advancement of IT (Information Technology), the traditional clothing industry has stridden towards automation and digitization that drive the growth of electronic commerce and online retailing [1]. Now, the developing tendency of 3D GCAD technology mainly shows as follows: virtual sample manufacture (i.e., tailor-made), remote clothing fitting (i.e., virtual fitting), virtual clothing design, garment pattern generation with quick response, and so on [2]. Many technologies need to be used to realize the automatic generation of personalized garment patterns, such as 2D/3D body measurement, modelling, and parametric pattern design [3, 4].

Therefore, many researchers have focused on how to combine with the new technologies [5]. Early in 1972, the United States took the lead in developing the earliest GCAD system in the world – the MARCON system. Subsequently, Gerber Company developed a series of products, and many GCAD systems have been launched in the clothing industry [6–9], including, an individualized skin-tight garment pattern generation system based on kinematics 3D body models, 2D-3D virtual CAD design system (PGDSS), Optitex V-Stitcher and DC-Suite 3D CAD system, etc. These systems are widely used, which could be summarized as two methods (including A and B) of garment pattern generation. As for method A, the 3D human body model needs to be established according to the human body characteristics, and fashion design can be done based on the model to generate the patterns through parameterization and pattern combination. This method is very difficult to realize 3D garment modelling, and still lacks effective means so far. As for method B, the surface flattening technology simply depends on the computer simulation technology and inevitably has the problem of curve deformation in the mapping process. Therefore, the two methods cannot be well applied in apparel design and pattern generation.

Although 3D body scanning systems have been widely studied and used in institutional research, high price and other practical issues have slowed down their widespread applications [10–16]. There has been a need to explore more economical approaches for pattern generation [17–19]. The methods that simply use digital images taken from off-the-shelf cameras to extract human dimensions have been developed to meet this need and may be characterized as a 2D body-measured method [20]. This method can be mainly divided into four steps, including image acquisition, silhouette extraction, landmark recognition, and girth fitting [21–24]. According to the topic "Body size measurement based on body image", 448 papers were found in the database "Web of Science" from 2006 to 2019. Therefore, studies in this direction are attracting more and more attention, and the research results can be applied to the clothing manufacturing industry for garment customization. This study will focus on the rules between the human body sizes and garment pattern lines, and then develop a new approach to apply the 2D body measuring technology to pant apparel design and pattern generation [25, 26]. The research can realize the personalized generation of the Pant pattern, which is of great significance for promoting the development of the clothing industry.

METHODS

Research framework

Figure 1 shows the core scheme of the pattern generation system. First, the front and side silhouettes can be output by inputting the front and side images of the human body, and then some main landmarks of the silhouettes can be identified to estimate the body sizes and design the apparel styles. Size extraction can be realized by calculating the distance between the feature points of the landmarks and the girth prediction model in this process. Second, the rules between human body sizes and basic patterns were researched through experiments, and the mathematical models of style design were established between the feature points moving distances and the values of the pattern lines. Finally, the generation rules of personalized patterns can be obtained by combining the basic pattern rules and design parameters (ΔXi, ΔYi, and ΔGi). In this system, the personalized pattern can be output by inputting images and moving the feature points of the landmarks.

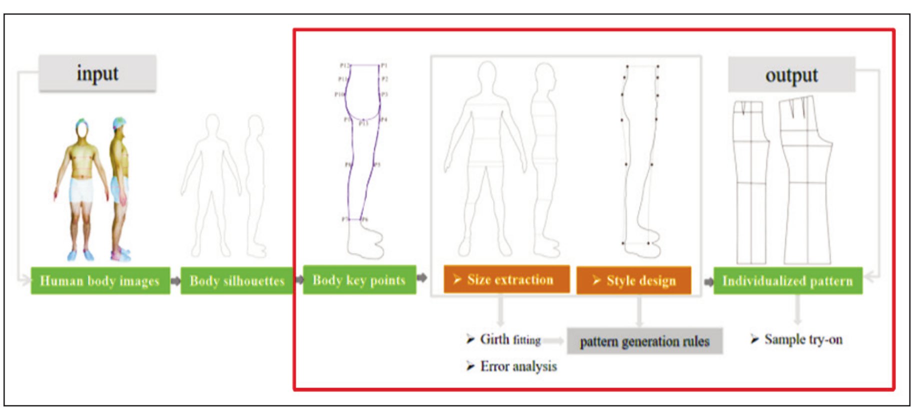


Fig. 1. Pattern generation system based on body images

Body size extraction

An imaging system was designed to get the front and side images of the human body in previous research, and the body sizes needed for basic pattern generation could be estimated [27]. The body images were processed through thresholding, filling, and opening functions, and then the smooth silhouettes could be obtained, as shown in figure 2.

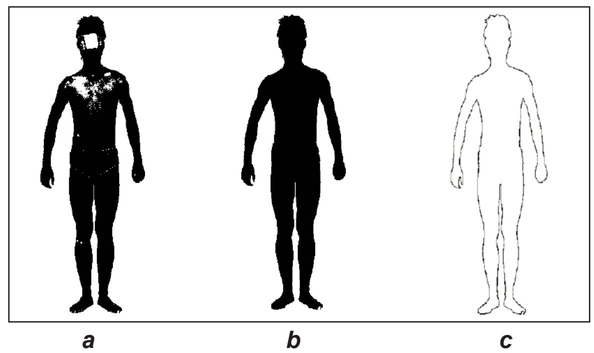


Fig. 2. Body silhouette extraction: *a* – segmentation; *b* – filling and opening; *c* – body silhouette

According to the body characteristics, the feature landmarks, namely waist, hip, thigh, knee, and ankle, could be determined, and then the feature sizes, such as the heights, lengths, widths, and depths could be obtained. The typical height range (i.e., Ri means the ratio between the landmark's height and the body height) was used to limit the general location of the landmarks by analysing the height measurements from 318 young men, and then the shape feature was analysed to locate the actual position, as shown in table 1 and figure 3, *a*.

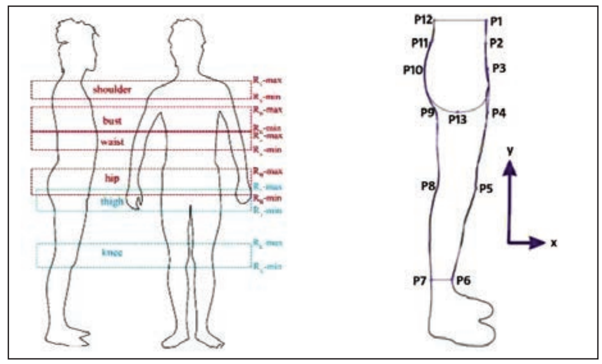
Take the hip landmark as an example. According to the statistical analysis of basic body proportion using the manually measured data, the hip height fell into a range between 45% and 52% of the body height, which is denoted as RH-max for the upper limit and RH-min for the lower limit. The hip is defined as the horizontal line at the widest point of the hip, and the hip feature normally is more obvious from the side view. When the landmarks were determined, the feature points could be determined to calculate the body sizes,

Table 1

DEFINITION AND TYPICAL HEIGHT RANGE OF THE LANDMARKS			
Landmark	**Definition**	**Ri-min**	**Ri-max**
Waist	The horizontal line at the natural waist, is the narrowest point around the torso, below the bottom rib and above the hip bones.	0.58	0.65
Hip	The horizontal line at the widest point of the hip, typically across the fullest part of the hip and over the upper end of the thigh bone.	0.45	0.52
Thigh	The fullest part of the thigh, high up on the leg, just below the crotch.	0.41	0.49
Knee	The horizontal line goes over the protruding bone at the inside of the knee and across the kneecap.	0.18	0.29

Note: Ri-min and Ri-max represent the minimum and the maximum value of the ratio between the landmark's height and the body height; i mean the waist (W), hip (H), thigh (T), and knee (K).

including the heights, widths, depths, and lengths, however, the girths of the landmarks could not be directly obtained. Considering that the width and depth at a landmark are the major parameters that reveal the shape information of the cross-section, the width-depth ratio (R = width/depth) can be used to classify human body shape. Therefore, the girth values of the characteristic parts were predicted based on the widths and depths.



a *b*

Fig. 3. The landmarks and Style design: *a* – the height range of the landmarks; *b* – pants' feature points

Apparel design based on body silhouettes

To realize the interactive apparel design online, we choose the side body silhouette for the pant design, as shown in figure 3, *b*. According to the relationship between human body characteristics and pattern structure, thirteen feature points at the side silhouette were defined, including waist, abdomen, hip, crotch, thigh, knee, and ankle. The front crotch is the base of the torso at its centre point between the legs. The ankle is the horizontal line that goes across the inside ankle's most prominent point. The definitions of the other landmarks were already shown in table 1.

Table 2 shows the feature points of the corresponding landmarks. For example, P1 is the front waist point, P12 is the back waist point, and the distance between P1 and P2 is the waist depth. According to the rules, these points can be identified in human body silhouettes. For other points which cannot be directly determined, such as P13, the relationship between the coordinate of the P13 and crotch depth is analysed.

These feature points can be moved up and down to change the height of the landmarks, or left and right to change the ease allowance of the pants. The change values which were defined as "ΔYp" of P in the vertical direction will affect the height of the landmarks, such as high-waist and low-waist. The changes at the knee and ankle lines mainly are in heights and widths, to generate the flared pants or tapered pants, and long or short pants, therefore, the change values which were defined as "ΔXp" of P in the horizontal direction will affect the girth of the landmarks, such as the flared pants or tapered pants. For the style design of pants, the change values of the width relevant with "ΔXp" for the pattern had been defined as "ΔGp", and then the rules between "ΔXp" and "ΔGp" was researched.

Table 2

THE CORRESPONDING LANDMARKS OF THESE FEATURE POINTS	
Pant points	**Landmark**
P1(XP1,YP1)/P12(XP12,YP12)	Front/back waist point
P2(XP2,YP2)/P11(XP11,YP11)	Front/back abdomen point
P3(XP3,YP3)/P10(XP10,YP10)	Front/back hip point
P4(XP4,YP4)/P9(XP9,YP9)	Front/back crotch point
P5(XP5,YP5)/P8(XP8,YP8)	Front/back knee point
P6(XP6,YP6)/P7(XP7,YP7)	Front/back ankle point
P13(XP13,YP13)	Crotch point

Note: Xi and Yi (i= P1-P13) mean the X-direction and Y-direction values of the key points. For the points of the pants, YP1=YP12, YP2=YP11, YP3= YP10, YP4=YP9, YP5=YP8, YP6=YP7.

Pattern generation rules

Fifty young men were selected as subjects to research the rules, the real sizes of the human body were calculated by the image measurements and prediction formulas, and their basic pants' patterns were obtained by draping experiments and mannequin modification, to analyse the rules between the basic pattern and human body size. Figure 4 shows the basic pants' rules, and the front and back patterns of the pant were placed against the body to connect the lines and curves with the sizes of the human body based on six main characteristic landmarks, including

Table 3

THE GENERAL PATTERN RULES

Lines	Body measurements	Lines	Body measurements
A1A2	ankle height+ΔYp6	B1B2	ankle height+ΔYp6
A1A3	knee height+ΔYp8	B1B3	knee height+ΔYp8
A1A4	thigh height+ΔYp4	B1B4	thigh height+ΔYp4
A1A5	hip height+ΔYp3	B1B5	hip height+ΔYp3
A1A6	waist height+ΔYp1	B1B6	waist height+ΔYp1
A7A8	Front waist girth/2+Front dart width	B7B8	Back waist girth/2+Back dart width
A8A9	Front centre length+ΔYp1+ΔYp3	B8B9	Back centre length+ΔYp10+ΔYp12
A9A10	(Front hip girth+ΔGFH)/2	B9B10	Back hip girth/2+ΔXp3+ΔXp10
A11A12	Front thigh girth+ΔGFT	B11A12	Back thigh girth+ΔGBT
A13A14	Front knee girth+ΔGFK	B12B13	Back knee girth+ΔGBK
A15A16	Front ankle girth+ΔGFAN	B14B15	Back ankle girth+ΔGBAN
A16A17	Inside leg length–ΔYp8–A12A16 curve length	B14B17	Inside leg length–ΔYp8–A12B14 curve length
A15A18	Outside leg length–ΔYp8–A11A15 curve length	B15B16	Outside leg length–ΔYp8–B11B15 curve length
A19-A21	Front dart design	B18-B23	Back dart design

Note: ΔYpi, i=1-16, means the height change at the key landmarks, ΔGi, i= FH (front hip), BH (back hip), FT (front thigh), BT (back thigh), FK (front knee), BK (back knee), FAN (front ankle) and BAN (back ankle) mean the girth change at the landmarks.

the waist, abdomen, hip, thigh, knee, and ankle. There are twenty-one key points (A1 to A21) for the front pant pattern and twenty-three key points (B1 to B23) for the back pant pattern. Thirty-two structural lines were selected for the pants' patterns, for example, A1A2 represents the position of the height at the pant hemline, which is related to the ankle position of the human body, A7A8 means the front waist girth of the pants' pant (including the front waist dart and girth ease). Since the darts of the pattern were designed based on experiences in practice, points A19-A21, and B18-B23 were determined according to the design requirements.

By combining the basic pattern rules with the changes in the heights and girths at the landmarks, the personalized pattern rules are expressed in table 3, to show the detailed pattern-making methods for the customized pants.

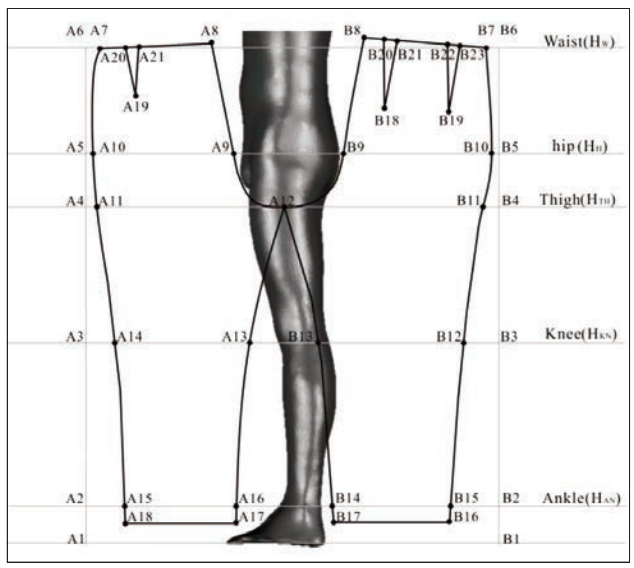


Fig. 4. Front and back patterns of pants based on the human body

RESULTS AND DISCUSSIONS

Girth prediction

The shape of the landmarks was classified according to the ratio between the widths and depths of 318 subjects, and the calculation rules of the girths at the waist and hip were shown in table 4.

Error analysis

The girths extracted from the system were compared with the manually measured sizes for error analysis. The absolute error (EA) and relative error (ER) were both used to verify the accuracy of this system, and the calculative models are in the following equations 1 and 2. Among these equations, G_S means the girths predicted by the system, and G_M means the girths measured manually.

$$E_A = |G_S - G_M| \quad (1)$$

$$E_R = \frac{E_A}{G_M}\ \% \quad (2)$$

Table 5 shows the relationship between the absolute error (EA) and relative error (ER) at each landmark, and the percentage (P) within the error ranges. When the ER value is less than 2%, the EA values at all landmarks were all less than 2 cm, and the EA values of hip girth are relatively higher. When the ER value is less than 3%, the EA value of the hip girth is 2.09 cm, and the others are still less than 2 cm. As for the percentage, it was found that about 80 percent of the samples can have their EA values within the range of

Table 4

CALCULATION RULES OF GIRTHS AT MAIN LANDMARKS									
Waist					**Hip**				
Width/Depth	**R2**	**a0**	**a1**	**a2**	**Width/Depth**	**R2**	**a0**	**a1**	**a2**
1.10~1.20	0.830	8.969	–8.826	10.070	1.10~1.20	0.972	–25.546	–5.862	8.700
1.21~1.30	0.952	–0.321	–0.393	3.198	1.21~1.30	0.909	1.12	1.87	1.325
1.31~1.40	0.900	–1.853	0.639	2.382	1.31~1.40	0.817	7.832	2.442	0.696
1.40~1.50	0.933	3.482	1.534	1.536	1.41~1.50	0.826	16.623	1.434	1.194
1.51~1.60	0.932	7.150	0.722	1.901	1.51~1.60	0.795	80.518	–5.273	3.442

Note: The form of calculation rules: Girth = a0 + a1 × depth + a2 × width, a0, a1 and a2 mean the coefficients of the regression model.

Table 5

ERROR ANALYSIS BETWEEN PREDICTED GIRTHS AND MEASURED MANUALLY										
ER (%)	**Waist girth**		**Abdomen girth**		**Hip girth**		**Thigh girth**		**Knee girth**	
	EA (cm)	**P (%)**	**EA (cm)**	**P (%)**	**EA (cm)**	**P (%)**	**EA (cm)**	**P (%)**	**EA (cm)**	**P (%)**
≤2	1.74	56.2	1.81	49.0	1.93	60.6	1.21	44.9	0.81	52.8
≤3	1.65	72.2	1.87	63.5	2.09	76.5	1.56	63.3	1.06	72.8

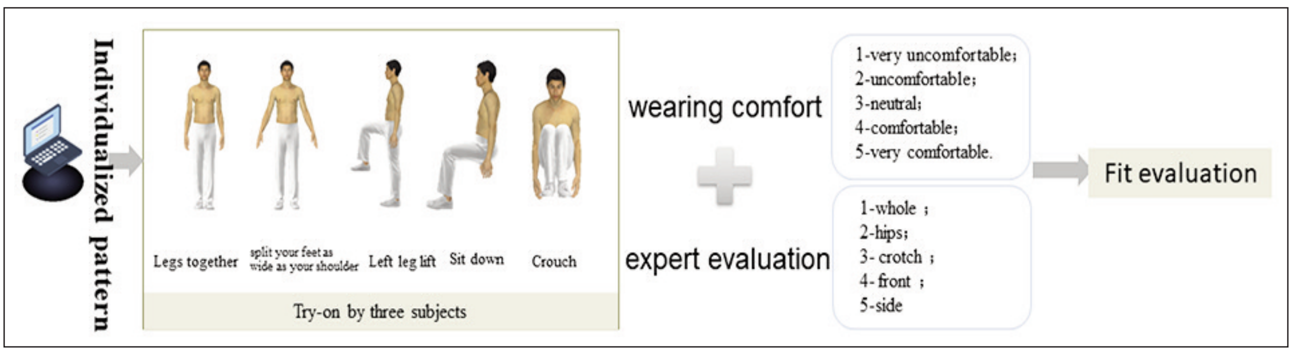


Fig. 5. Pants' pattern evaluation process

2 cm. Because the cross-sectional shape of the bust and hip is more complicated due to body characteristics, the prediction models may not be suitable for all people.

Garment evaluation

20 subjects with different body shapes were selected to evaluate the customized pants produced by the system effectively [28], by considering from two perspectives, including the expert evaluation and subjects' wearing comfort, and the evaluation framework was shown in figure 5.

For the expert evaluation, ten experts with at least five-year experience in the clothing industry were invited to evaluate the try-on effect at the feature landmarks, including waist, hip, crotch, outer and inner, and the experts gave a score with the range of 1–10 for each landmark, which means the higher the score, the better the effect. According to the final results, the mean of the score at the waist, outer, and inner is concentrated between 8 and 9, indicating that the fitting effect of pants at the waist, outer and inner is suitable. However, the mean of the score at the hip and crotch in under 8, which shows the pattern structure at the crotch and hip needs to be improved in further study.

For the subjects' wearing comfort, the pant fit was evaluated by the subjects to evaluate the comfort with five postures. In the questionnaire provided to the subjects, none of them chose "feel uncomfortable" during body movements. All the subjects reported "very comfortable" or "comfortable" during wearing the pants under the two postures, including 1-legs together and 2-legs apart as wide as your shoulder. When the posture changed to 3-sit down, 4-crouch, and 5-left leg lift, all the subjects reported "neutral" and "comfortable". Overall, the patterns generated with this method showed satisfactory fitting effects for the subjects with different body dimensions.

CONCLUSIONS

This study proposed a method for personalized pattern generation of pants by extracting body sizes and designing styles from body images automatically. For pants, 13 feature points were identified on the body silhouettes which were obtained by side image and then sizes extract and style design can be realized by moving these points. The models were built to predict girths from the 2D body sizes, and the rules between body sizes and patterns were researched. From the test results on 20 subjects, it was found that the body sizes predicted by the system were in good correlation with the manual measurements. The try-on test demonstrated the customized pants using this method could fit the subject's body well at important characteristic landmarks. All in all, this method can realize rapid and effective pattern-making, and meet the customers' demands for individuation and garment fit.

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Group consumers' preference recommendation algorithm model for online apparel's colour based on Kansei engineering

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ABSTRACT – REZUMAT

Group consumers' preference recommendation algorithm model for online apparel's colour based on Kansei engineering

The sales growth rate of men's plain-colour shirts dropped significantly online in China. Consumers first pay attention to the appearance design of clothing online. It only takes 7 seconds for consumers to determine a product, and the colour in its appearance design accounts for about 67% of the role. Thus, this study took the colour design of men's plain-colour shirts as an example in China, established the basic colour calculation scale and an algorithm model of group consumers' product preferences based on Kansei Engineering and scientific mathematics, to provide new sales ideas and methods for retailers and markets online. Firstly, this study obtained the crucial Kansei word pairs (emotional preferences) and colour design elements through interviews, literature, magazines and websites, word frequency statistics, card sorting and cluster analysis. Then, researchers established a basic colour calculation scale of cross-loading through Kansei Engineering and partial least squares (PLS). Finally, a recommendation set of products is obtained using the analytic hierarchy process (AHP), the weight of Kansei word pairs, and the distance calculation of comprehensive evaluation value based on consumers' emotional needs. That is, this study obtained consumers' aesthetic emotional preference for men's plain-colour shirts in China, colour design elements of shirts that are widely recognized and accepted, basic colour calculation scales, recommendation preferences algorithms and models for group consumers, and verified their effectiveness by PCA.

Keywords: *men's plain-colour shirts, Kansei engineering, algorithm model of recommendation, consumer's colour preference*

Modelul algoritmului de recomandare a preferințelor grupului de consumatori pentru culoarea îmbrăcămintei în mediul online, bazat pe ingineria Kansei

Rata de creștere a vânzărilor de cămăși bărbătești uni a scăzut semnificativ în mediul online din China. Consumatorii acordă mai întâi atenție aspectului estetic al îmbrăcămintei în mediul online. De fapt, consumatorii acordă doar 7 secunde pentru a alege un produs, iar culoarea reprezintă aproximativ 67%. Astfel, acest studiu a luat ca exemplu culoarea cămășilor bărbătești uni din China, a stabilit scara de calcul a culorii de bază și un model de algoritm al preferințelor de produse ale grupului de consumatori, bazat pe ingineria Kansei și matematica științifică, pentru a oferi noi idei de vânzări și metode pentru comercianții cu amănuntul și piețele online. În primul rând, acest studiu a obținut perechile de cuvinte cruciale Kansei (preferințe emoționale) și elemente de design ale culorii prin interviuri, literatură, reviste și site-uri web, statistici de frecvență a cuvintelor, sortarea cardurilor și analiza cluster. Apoi, cercetătorii au stabilit o scară de calcul a culorilor de bază pentru încărcarea încrucișată prin ingineria Kansei și analiza de regresie a celor mai mici pătrate (PLS). În cele din urmă, se obține un set de recomandări de produse utilizând procesul de ierarhie analitică (AHP), ponderea perechilor de cuvinte Kansei și calculul la distanță al valorii de evaluare cuprinzătoare pe baza nevoilor emoționale ale consumatorilor. Adică, acest studiu a obținut preferința estetică emoțională a consumatorilor pentru cămășile bărbătești uni din China, elemente de design ale culorii cămășilor care sunt recunoscute și acceptate pe scară largă, scări de calcul ale culorilor de bază, algoritmi de preferințe de recomandare și modele pentru grupul de consumatori și a verificat eficacitatea acestora prin PCA.

Cuvinte-cheie*: cămăși bărbătești uni, ingineria Kansei, model algoritmic de recomandare, preferința de culoare a consumatorului*

INTRODUCTION

Online shopping has become the leading retail channel for apparel products [1]. When the basic functional properties of clothing (protection against cold and warmth) are satisfied, more and more consumption demands are to meet consumers' aesthetic emotions and feelings. Since 2014, men's clothing, whose sales growth has exceeded that of women's clothing, has become the trend of online shopping consumption, among which men's shirts are the largest sales category [2]. However, since 2018, the sales growth rate of men's shirts on Alibaba (China's largest clothing sales platform) has declined rapidly. By 2020's Double 11, men's plain-colour shirts have become the men's clothing item with the lowest growth rate, especially in the inland regions [3]. In addition, in online sales, consumers first pay attention to the appearance design of clothing [4]. According to the "Seven-Second Rule" of the American Fashion Colour Research Association, it only takes 7 seconds for consumers to determine their likes and dislikes for a product, and the colour in its appearance design accounts for about 67% of the role. How to quickly identify and recommend the colour design preferred by the group of consumers has become a critical factor in improving the competitiveness of men's plain-colour shirt merchants and boosting the economy of men's shirts.

Research on identifying and recommending consumer preferences can be roughly divided into two categories. The first category is for individual consumers and mainly includes rule-based, content-based and collaborative filtering recommendation systems [5, 6]. Collaborative filtering recommendation is the most widely used, speculating on the preferences of specific individual consumers by analysing the preferences of similar consumers. For example, statistics of browsing and purchase records of similar consumers [7]. However, the first category of the method is mainly used to serve individual consumers by recommending products to help them quickly online shopping. In addition, the collaborative filtering recommendation may lead to bias because similar consumers do not necessarily have the same preference, especially for experiential products such as clothing based on feeling and aesthetic emotions [8]. The second category is for group consumers to understand the overall preferences of specific groups of clothing consumers. It mainly serves merchants to increase sales and is suitable for this study. In previous research, group consumers' preferences especially involve questionnaires, big data statistics and text mining [9].

Specific to research on men's shirt group preferences, Cao [10] surveyed 1,600 men's shirt consumers in 16 cities across the country and pointed out that blue and white are the two most popular classic colours. Zhou [11] compared the preferences of group consumers in Beijing and Shanghai on men's shirts through big data. He pointed out that Beijing consumers prefer black, blue, and brown; Shanghai consumers prefer black, grey and dark green. Wu [12] processed 1.5 PB of raw data through big data computing and statistics of Hadoop clusters and pointed out that white, dark green, blue, and black are the key colours of group consumer preference for men's shirts. In contrast, text mining is an approach to obtaining group consumers' preferences from the text content. Through text mining of tens of thousands of online reviews of men's shirts, Wang and Liang [13] pointed out that white, bright colour and dark colour are the highest word frequency mentioned by group consumers. Similarly, An & Park [14] collected 38,225 texts from blogs and analysed the frequency, centrality, and semantic networks. The result is that bright colours are the group consumers' preferences in colour design. Furthermore, Wang [15] proposed an evaluation method based on text-mining word vector clustering to construct group consumer preferences. They pointed out that emotional preferences such as bright, formal, casual, and gentle are suitable for consumers' demand for the colour design of men's shirts.

In these previous researches, questionnaires, big data, and text mining can only obtain consumer groups' preferences for certain shirt samples, design elements, or just emotional texts but cannot directly predict the preference ranking trends of other shirt sample sets.

Research with consumers as the main body is called "Voice of Consumers", and there are four main types of predictive research for the specific group of consumers: conjoint analysis, quality function deployment (QFD), the semantic description of environments (SMB) and Kansei Engineering [16]. Kansei Engineering (KE) is the only predictive method that can determine consumers' feelings and emotional preferences (Kansei words) and obtain the corresponding relationship between those emotional preferences and the design elements of the product specimens [17]. In addition, the analytic hierarchy process (AHP) can get the rank and weight among the multiple emotional preferences of a specific group of consumers, which is a standard data-sorting method [18]. Therefore, as shown in figure 1, this study will combine KE and the analytic hierarchy process

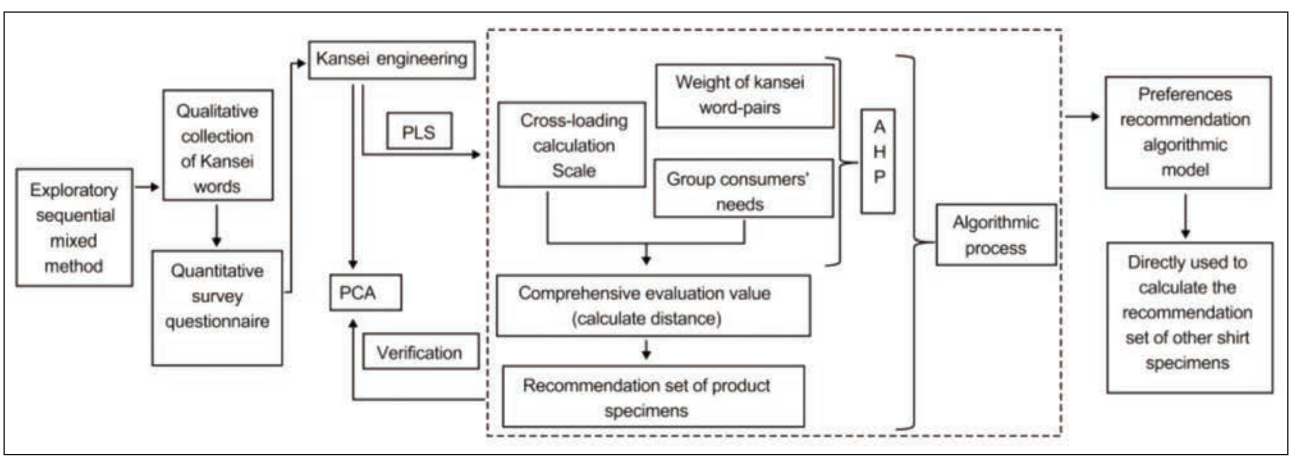

Fig. 1. Research design

(AHP), taking men's plain-colour shirts' colour design as a research object, to construct a preference recommendation algorithm model for group consumers, which can directly predict the preference ranking trends of shirt product sets, to increase sales and stimulate the economy for online clothing merchants.

EXPERIMENTAL PROCEDURE AND PREFERENCE RECOMMENDATION MODEL

Collected Kansei words and design element

This study first collected adjectives of emotional preference (Kansei words) and colour design elements consumers can identify and accept for men's plain-colour shirts. The researchers collected and selected Kansei words that appeared more than three times in word frequency statistics from consumer interviews, literature reviews, magazines, and websites with high click-through rates. Through the consumer's card sorting method and cluster analysis, the researchers can obtain the crucial Kansei word pairs that consumers were most interested in among the collected Kansei words.

In 1974, as shown in figure 2, Kobayashi discovered that the images of primary colours could be plotted on three axes: warm-cool, soft–hard, and clear–greyish. These three psychological axes of colour space are more recognized and accepted by consumers [19]. Among these, the soft-hard axis determines the value (bright/dark) parameter of colour and the clear-greyish axis determines the chroma of colours. Furthermore, as displayed in figure 3, Kobayashi [19] divided the 12 tons of colour into four types based on clear-greyish: clear, which contains V, B; clear with slightly greyish, which includes P, Vp; greyish, which contains S, Lgr, L, Gr, Dl; psychological greyish, which includes Dp, Dk, Dgr. In summary, this study will select representative colours for follow-up research based on the parameters of hue, warm-cool, soft-hard, and clear-greyish. Ou, Woodcock, and Wright [20] pointed out that the colour selected during the research should cover a wider classification space, and the span of colour parameters should be relatively large. Based on the plotted positions of colours on the warm-cool, soft–hard and clear-greyish plane (figure 2), researchers chose the colour of the classification of V, P, Dl, and Dk in figure1, which have different grayscales and large spans of warm and cold, soft and hard. Besides, researchers chose R (red), YR (yellow-red), Y (yellow), G (green), B (blue), PB (purple-blue), and P (purple) in hue, which

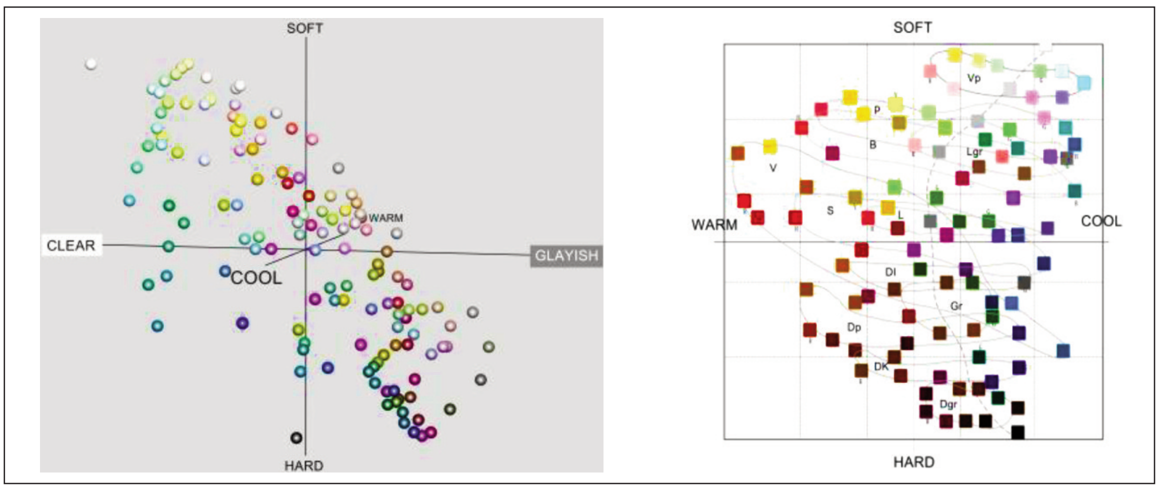

Fig. 2. Positions of colours on the warm-cool, soft–hard and clear-greyish

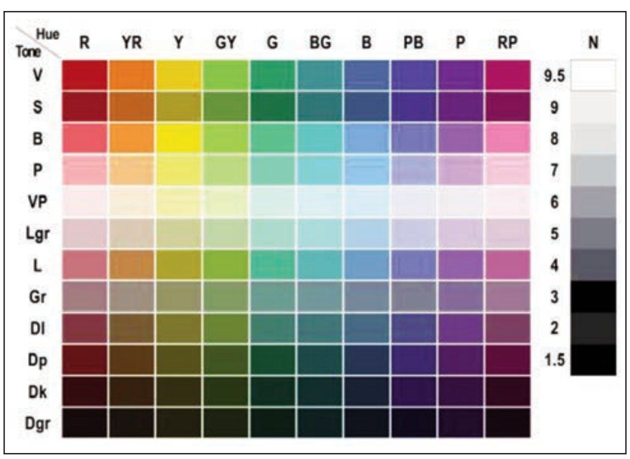

Fig. 3. 12 tons of colour

Fig. 4. 32 product specimens of colour design

has a more general acceptance for Chinese consumers. Last, researchers add the achromatic colour of black, white, and two greys. These two greys have large spans of soft and hard. Finally, a total of 32 colours were collected to conduct follow-up research, as displayed in figure 4.

Evaluation survey of a colour design questionnaire

Women consumers contributed nearly 50% of the consumption in the online menswear category. Men's clothing consumers online show a younger trend, with consumers aged 20–35 accounting for more than 80% [12]. In addition, each consumer is equally likely to be chosen in random sampling, which not be interfered with and influenced by the research team. Online questionnaires are the quickest and most effective way to collect data from lots of questions. There is no skewed data due to consumers' age and behaviour for the online questionnaires in this study because the consumers aged 20–35 are most accustomed to the Internet. Furthermore, the standard sample size is 385 for large populations based on the confidence interval approach. Therefore, focusing on consumers who have purchased men's plain-colour shirts online within one year and are aged 20–35, this study the random sampling to conduct the online questionnaire for more than 385.

In addition, Nagamachi [17] recommended the 5-level semantic differential scale questionnaire in KE, which is the most widely used. This scale of Kansei word pairs (Kansei word and denied Kansei word) has five positions, with scores of 2, 1, 0, –1, and –2, respectively. Thus, in this study, the consumers were required to select and provide the corresponding score on the Kansei word-pairs scale according to their feelings, emotions and aesthetic evaluations of the product specimens, as displayed in table 1.

Classification of product specimens

This step In KE is the design analysis of the product specimen, and it goes into a process called extraction of the design item and category. The design item refers to a certain characteristic of product design. For example, the hue, warm-cool, soft-hard, and clear-greyish are the design items. Category refers to the small groupings in each item, such as (1) red, (2) yellow-red, (3) yellow, (4) green and (5) blue for the hue item. In addition, the different categories are called design elements in colour design. As displayed in table 2, there are 18 design elements in this study. Based on that, this study classified all 32 product samples into different design items and categories for data analysis. For example, the first product specimen in figure 3 belongs to red (hue), warm (warm-cool), soft (soft-hard), and clear (clear-greyish).

Model of Partial Least Squares (PLS)

In this step, each shirt specimen in the questionnaire is decomposed into a set of design elements. For example, the design elements of the "i" shirt are represented by the set C_i, that is, $C_i = \{C_{i1}, C_{i2}, ..., C_{in}\} =$ $= \{\text{red}, \text{warm}, ..., \text{clear}\}$; the consumers' aesthetic emotional evaluation of the "i" shirt is represented by the set F_i, $F_i = \{F_{i1}, F_{i2}, ..., F_{in}\}$. Using the model of partial least squares (PLS) ($C \xrightarrow{f} F$), for any C_i, F_i can be calculated.

Analytic hierarchy process

The analytic Hierarchy Process (AHP) in this study is a quantification method for consumers' aesthetic emotional needs and importance. Its principle is to

Table 1

5-LEVEL SEMANTIC DIFFERENTIAL SCALE QUESTIONNAIRE								
Product specimen		**KW**	**2**	**1**	**0**	**–1**	**–2**	**KW**
	1	Practical	○	○	○	○	○	Unpractical
	2	Mature	○	○	○	○	○	Childish
	3	Distinctive	○	○	○	○	○	General
	4	Elegant	○	○	○	○	○	Inelegant
	5	Minimalist	○	○	○	○	○	Garishas
	6	Formal	○	○	○	○	○	Casual

Table 2

ITEM/CATEGORY CLASSIFICATION LIST OF COLOUR	
Item	**Category**
Hue	(C1) Red, (C2) yellow-red, (C3) yellow, (C4) green, (C5) blue, (C6) purple-blue, (C7) purple, (C8) black, (C9) white, (C10) grey
Warm-cool	(C11) Warm, (C12) cool
Soft-hard	(C13) Soft, (C14) hard
Clear-greyish	(C15) Clear, (C16) Clear with slightly greyish, (C17) Greyish, (C18) psychological greyish

compare the emotional preference (Kanword pairsairs) in turn according to a certain rule to generate a judgment matrix:

$$A = (a_{ij})_{n\times n} = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{pmatrix}, \quad (1)$$

$$(i,j = 1,2,...,n)$$

According to the judgment matrix A, by calculating the eigenvalues and eigenvectors, the researchers obtained the relative weights of the compared Kansei word pairs to the corresponding criteria in the upper level are obtained, which is $W = (\omega_1, \omega_2, ..., \omega_n)^T$.

$$AW = \lambda_{max} W \Rightarrow w_k = \frac{\sum_{j=1}^{n} a_{kj}}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{kj}} \quad (2)$$

The researchers conducted the CR test of the consistency ratio of the judgment matrix, calculated the total ranking weight of each Kansei word-pairs for the system, and sorted it.

$$CR = \frac{CI}{RI} = \frac{\lambda_{max}(A) - n}{(n-1)RI_n} \quad (3)$$

When $CR < 0.1$, it is judged that the pairwise comparison matrix A has satisfactory consistency.

Comprehensive evaluation value

This step is the most critical in the whole preferences recommendation algorithm model. After the researchers obtain the aesthetic emotional needs of consumers as $F_0 = \{F_{01}, F_{02}, ..., F_{0n}\}$, according to the result of partial least square (cross-loading calculation scale) in step 4 and the weight of Kansei word-pairs in step 5, the comprehensive evaluation value D of each men's shirt can be obtained.

$$D = \sqrt{W_0 \circ ((F_{i1}-F_{01})^2, (F_{i2}-F_{02})^2, ..., (F_{im}-F_{0m})^2)^T} \quad (4)$$

Researchers can rank specimens according to the comprehensive evaluation value. The D value represents the distance between the specimens and the aesthetic and emotional needs of the group of consumers, which means the smaller the D value, the closer the specimen is to the emotional need of the group of consumers. Based on this, a set of recommended shirts can be formed.

EXPERIMENTAL RESULTS AND DISCUSSION

Collected Kansei words

In this study, researchers interviewed 20 consumers and examined eight literature reviews, 47 electronic magazines and high-clicked websites to collect Kansei words concerning men's plain-colour shirts. Through word frequency statistics, the consumers' card sorting and corresponding cluster analysis, the crucial aesthetic emotional preferences (Kansei words-pairs) that consumers are most interested in the inland region of China are obtained. That is, practical—unpractical, mature—childish, distinctive—general, elegant—inelegant, minimalist—garishas, formal—casual.

Cross-loading calculation scale

A professional questionnaire website was responsible for inviting respondents to answer the questionnaires. A total of 549 questionnaire samples remained after screening. The Cronbach's alpha for this questionnaire is 0.871 (> 0.75), and the Kaiser-Meyer-Olkin (KMO) is 0.813 (> 0.75), indicating the reliability and validity of the samples in this study are accepted. Hence, the PLS can be further carried out. Partial least squares (PLS) can decompose the components, which reduces the dimension of the features, reconstructs the model, and obtains a simple linear regression model (Chin et al., 2013). This study uses SAS_9.4 as the data analysis tool and through PLS to construct the corresponding relationship between men's shirt colour design elements and consumers' emotional preferences (Kansei word pairs), as shown in table 3. According to the analysis result, one specific emotional preference F_i = {regression constant + $c1$* regression coefficient… + $c18$* regression coefficient}. This cross-loading scale can be used for the calculation basis of the group consumers' preference recommendation algorithm model for men's plain-colour shirts in the inland region of China, based on which other men's plain-colour shirt colour specimens can be calculated and recommended directly.

Weight of Kansei word-pairs

As shown in table 4, through the analysis of some parts of the questionnaire data, this study obtained the degree of attention of some groups of consumers to shirt aesthetic emotional preference to facilitate the description of the follow-up model method. Based on this, researchers rounded and unified the weight evaluation of the importance of Kansei word pairs by using the AHP method and obtained the weight W = {0.0712, 0.0712, 0.0345, 0.3330, 0.3330, 0.1571}, where random $CR = 0.028 < 0.1$, which can be determined that the consistency of the pairwise comparison matrix A is acceptable.

Recommendation ranking

As shown in table 5, this study obtained these some group consumers' aesthetic emotional needs as F_0 = {1,1,1,1,1,1}, according to the questionnaire analysis. The distance of each product specimen is calculated by comprehensive evaluation value D (as mentioned in Step 6 before). Thus, group consumers' preference and recommendation ranking for about 32 samples is obtained based on the principle of recommending shirt specimens with small distances. The calculation shows that this study's recommendation algorithm model recommends 31/30/20/17/18/19/22/26/2/32/14 as the product specimens set of consumer preference. In addition, the set of product

Table 3

CROSS-LOADING CALCULATION SCALE						
Elements	**Practical—Unpractical**	**Mature—Childish**	**Distinctive—General**	**Elegant—Inelegant**	**Minimalist—Garishas**	**Formal—Casual**
Intercept	–0.059	0.494	0.379	0.194	0.570	-0.319
c1	0.011	0.148	–0.021	0.371	0.399	0.184
c2	0.171	–0.264	–0.148	–0.356	–0.312	-0.447
c3	–0.042	–0.054	0.315	–0.446	–0.450	-0.274
c4	–0.370	–0.318	0.050	–0.204	–0.206	-0.268
c5	0.251	0.312	–0.444	0.446	0.453	0.468
c6	–0.083	–0.141	0.098	–0.047	–0.043	–0.013
c7	–0.224	–0.260	0.298	–0.121	–0.105	–0.091
c8	0.291	0.493	0.297	0.054	0.094	0.205
c9	0.518	0.600	–0.482	0.647	0.509	0.576
c10	0.114	0.514	–0.181	0.304	0.182	0.418
c11	0.005	–0.111	0.119	–0.215	–0.170	–0.260
c12	–0.005	0.111	–0.119	0.215	0.170	0.260
c13	–0.038	–0.260	0.014	0.335	0.116	–0.018
c14	0.038	0.260	–0.014	–0.335	–0.116	0.018
c15	–0.380	–0.154	0.271	–0.022	–0.023	–0.205
c16	0.215	–0.326	–0.139	0.345	0.131	0.074
c17	0.152	0.185	0.158	–0.131	–0.042	–0.372
c18	0.055	0.290	–0.369	–0.164	–0.054	0.609

Table 4

GROUP CONSUMERS' ATTENTION DEGREE TO KANSEI WORD-PAIRS					
Code	**KW**	**Medium**	**More**	**Fairly**	**Quite**
k1	Practical—Unpractical		✓		
k2	Mature—Childish		✓		
k3	Distinctive—General	✓			
k4	Elegant—Inelegant				✓
k5	Minimalist—Garishas				✓
k6	Formal—Casual			✓	

Table 5

GROUP CONSUMERS' AESTHETIC AND EMOTIONAL NEEDS						
Code	**KW**	**Medium**	**More**	**Fairly**	**Quite**	**KW**
1	Practical		✓			Unpractical
2	Mature		✓			Childish
3	Distinctive		✓			General
4	Elegant		✓			Inelegant
5	Minimalist		✓			Garishas
6	Formal		✓			Casual

specimens that the recommendation algorithm model least recommends is 11/7/12/8/25/9/5/15.

EXPERIMENTAL VERIFICATION

Principal Component Analysis

Principal Component Analysis (PCA) in Kansei Engineering is used to compress data into fewer dimensions, visually analysing the distribution of Kansei word pairs to determine and verify consumers' emotional preferences. It also can assess consumer preferences degree for product specimens based on their relative positions on the X/Y axis. This study uses PCA to verify consumer emotional preferences and rank the shirt specimens. As shown in figure 5, PCA's cumulative contribution to consumers' emotional evaluation of colour design is 77.8%, indicating that Kansei word pairs have significant weights. Kansei word pairs are distributed in the first, second and fourth quadrants of PCA. Since there is no distribution of Kansei word pairs in the third quadrant, PCA verifies that these six Kansei word pairs are all consumer preferences. The x-axis contributes 51.3%, while the y-axis contributes 26.5%. According to the contribution ratio of the x/y axis and the relative positions of the 32 product specimens, the order of importance of each product specimen to consumers is assessed in PCA, as displayed in figure 6.

PCA recommends 31/30/20/17/18/22/26/19/14/2/32 as the product specimens set of consumer preference. In addition, the set of product specimens that the PCA least recommends is 11/7/12/8/9/25/5/15. Although the recommended specimens order between PCA and the recommendation algorithm model of this study is slightly different, the recommendation trend for product specimens and the results of recommended product specimens set are consistent, thus verifying the validity of the recommendation preferences algorithm model in this study.

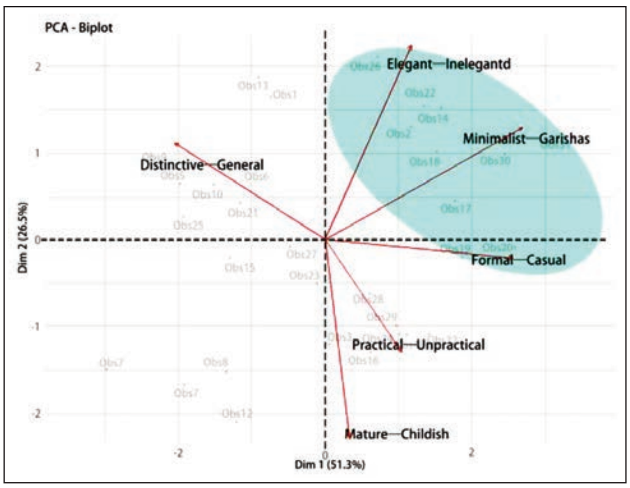

Fig. 5. PCA of men's plain-colour shirts

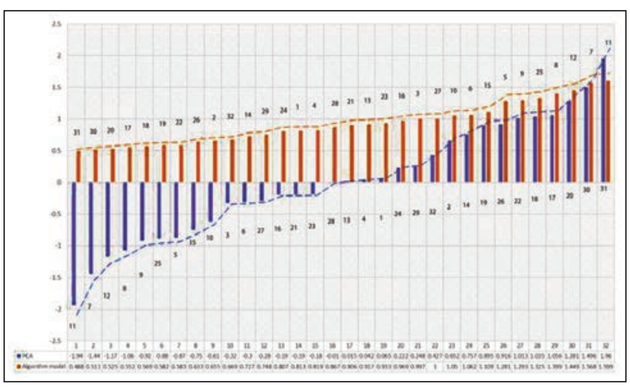

Fig. 6. Comparison between PCA and recommendation algorithm model

Case study

The Shan Dong area was selected as a specific case study to validate the proposed recommendation algorithm in this study. Researchers investigate the consumers of 20–35-year-olds and obtain group consumers' attention degree to Kansei word pairs and aesthetic emotional needs. Based on this, researchers rounded and unified the weight evaluation of the importance of Kansei word pairs by using the AHP method and obtained the weight W = {0.1175, 0.1175, 0.0316, 0.3080, 0.3080, 0.1175}, where random CR = 0.020 < 0.1. As 10 product specimens as research objects (figure 7), the order of product samples obtained according to this study's preference recommendation algorithm model is 9/6/5/2/7/3/1/8/10/4. At the same time, this study conducted a preference questionnaires survey of the same 10 samples among 437 consumers aged 20–35 and obtained the product sample preference order as follows: 9/5/6/7/2/3/1/4/8/10. It can be seen that the ranking trend of the product set calculated by the recommendation algorithm model is consistent with the consumer preference trend.

CONCLUSION

Innovation

As mentioned in the introduction, questionnaire surveys and big data are only summary statistics of consumer preference for specific product samples or particular colour design elements and features. If new product samples or design element appears, a large-scale survey and statistics must be carried out again. Text mining can count the emotional words (Kansei words) and specific design elements or features of group consumers' preference for colour design, but it cannot establish the relationship between these emotional words and design elements or features. Thus, they cannot calculate and score the consumer's preference for specific shirt product sets, and of course, they all cannot directly predict the preference ranking trends of other shirt product sets. Kansei Engineering can predictably establish the relationship between the emotional words and design elements or features, and form the cross-loading scale of clothing. On this basis, the preference ranking trend of clothing products is obtained

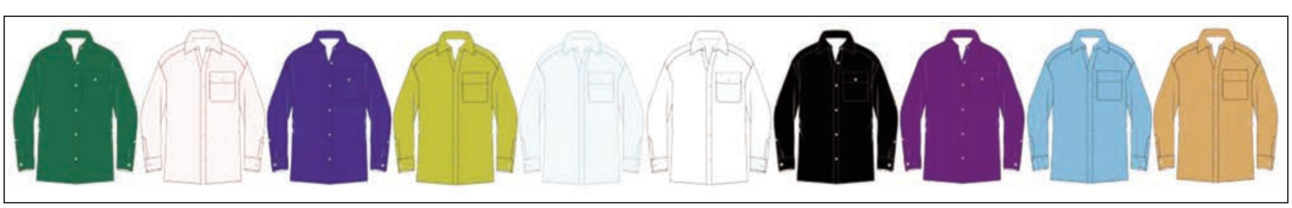

Fig. 7. 10 product specimens of the case study

through the weight analysis of AHP of emotional words and the distance calculation. That is, after getting the cross-loading scale of KE and the weight of the emotional words of consumers in a specific region, the preference score of any similar products and the ranking trend of the product set can be predictively calculated. Therefore, the combined recommendation algorithm model of KE and AHP to calculate the preference ranking trend of clothing products is the most significant innovation of this research. It is more predictive and efficient than traditional questionnaires, big data and text mining.

Main contributions

First, this study obtained the Kansei words of consumer groups' aesthetic and emotional preferences for men's plain-colour shirts in the inland region of China. That is, practical, mature, distinctive, elegant, minimalist, formal and casual. Second, this study obtained 18 colour design elements of shirts that are widely recognized and accepted. Third, the cross-loading scale between shirts' colour design elements and the emotional preferences of consumers was obtained through KE. That is the relationship between the consumers' preferred emotional words (Kansei words) and colour design elements. It can be directly used as a basic calculation scale to recommend men's plain-colour shirts to provide references for the online shirt designer and market. Last and most importantly, this study establishes the recommendation algorithm model for the preferences of the group consumers based on the cross-loading scale and AHP, which can directly calculate the sorting trend of men's plain-colour shirt products, and generate a set of recommended products to improve the sales of men's shirts for online merchants.

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Investments in digital technology advances in textiles

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ABSTRACT – REZUMAT

Investments in digital technology advances in textiles

The investments in digital technologies are expected to soon have a major impact on the textile and fashion companies' sustainability and competitiveness. Motivated by these trends empirical research on investments of the fashion and textile companies in ICT technologies-based advancement in the Serbian case was provided in 2022. Representatives of 423 textile and fashion companies were asked about their investments in various digital technologies in the previous three years and their digital transformation status. The research findings show that investments in cloud computing, IT, energy management, automation, robotics, and machine learning technologies have a significant impact on the digital transformation of companies. Most of them reached a medium level of transformation, fewer than a high level, with many textile and fashion companies just defining digital transformation. The contribution of the research findings to the investments in the companies' digital transformation can be seen in the significance of the textile's digital technology implementation, which enables manufacturers and retailers to respond directly to market demand by reducing product lead time and cost, increasing supply chain efficiency and profitability, and promising in terms of ensuring competitive advantage in the risk and challenging business environment.

Keywords: *artificial intelligence, cloud computing, digital technologies, innovation, textile and fashion industry, sustainability*

Investiții în progresul tehnologiei digitale în domeniul textil

Este de așteptat ca, în curând, investițiile în tehnologiile digitale să aibă un impact major asupra sustenabilității și competitivității companiilor din domeniul textil și de modă. Având motivația dată de aceste tendințe, în 2022 a fost furnizată o cercetare empirică asupra investițiilor companiilor din domeniul textil și de modă în progresul bazat pe tehnologii TIC în Serbia. Reprezentanții a 423 de companii din domeniul textil și de modă au fost chestionați despre investițiile lor în diferite tehnologii digitale, în ultimii trei ani și starea lor de transformare digitală. Rezultatele cercetării arată că investițiile în cloud computing, IT, managementul energiei, automatizare, robotică și tehnologii de învățare automată au un impact semnificativ asupra transformării digitale a companiilor. Majoritatea au atins un nivel mediu de transformare, câteva dintre acestea un nivel ridicat, multe companii din domeniul textil și de modă doar definind transformarea digitală. Contribuția rezultatelor cercetării la investițiile în transformarea digitală a companiilor poate fi văzută în importanța implementării tehnologiei digitale în domeniul textil, care permite producătorilor și comercianților cu amănuntul să răspundă direct la cererea pieței, prin reducerea timpului de livrare și a costului produselor, creșterea eficienței și profitabilității lanțului de aprovizionare, promițătoare în ceea ce privește asigurarea unui avantaj competitiv în mediul de afaceri riscant și provocator.

Cuvinte-cheie: *inteligență artificială, cloud computing, tehnologii digitale, inovație, industria textilă și de modă, sustenabilitate*

INTRODUCTION

The most significant technology trend that is changing the economy and society today can be identified as digitalization [1, 2]. Looking at the EU production of clothing and textiles whose turnover reached over 169 billion euros, it can be evident that the industry increases its investments in new digital technologies implementation, by 4 billion euros last year (Eurostat, 2022). The results can be seen in already 23% of the global online share of revenues, with only a fashion segment of the $2.5 trillion global industry [3–6]. By 2022, worldwide online apparel and accessories sales are forecasted to reach $765 billion, expecting around a 7.3 percent growth rate by 2025 (eMarketer, 2022).

94% of EU enterprises used a fixed broadband internet connection, and 78% had a website in 2021, providing, online ordering, order tracking, description of goods or services, price lists, and links to their enterprise's references to social media. E-business integration in the EU is increasing, 22% of firms had e-commerce sales, 38% of EU enterprises used ERP software applications (Enterprise resource planning), and 31% to 65% used software applications for CRM (Customer Relationship Management) [7, 8].

A review of the literature on the drivers of digital investments shows new efficiencies enabled by bottom-line and top-line growth of industrial companies, higher customer experience outcomes, and better addressing market needs with a combination of new and existing data and technologies. Key investment areas are automation of the entire value chain, from decision-making to operations, efficient use of resources, such as time, energy, raw materials, and assets, and initial specific efficiency objectives with the potential to expand to new business models and customer experiences rooted in privacy and trust, customer relationship management. Also, digital marketing and building a better understanding of the scalability potential of the value chain challenges [9–11]. IoT (Internet of Things), and robotics to automate processes and collect data, AI (Artificial Intelligence), 3D vision, and digital platforms to analyze data to identify incremental efficiencies, personalization by big data analytics, cloud to reinforce data management, mobile technologies, and social networks to improve engagement, are some of the most used and implemented enabling technologies by industrial and service companies. The Internet of Things is digital technology mostly used by EU enterprises, 29% used IoT devices, (Eurostat, 2022), for keeping their premises secure, cost reduction or efficiency increase, and radio frequency identification to monitor or automate the process of textile production. 3D digital printing is now widely used for roll-to-roll fabric printing, garment printing, and even electronic textile printing [12], and digitally printed fabric as banners is increasing the investments of these companies in IoT technologies implementation. Using IoT for customer service considers most often the smart cameras or sensors to offer customers a personalized shopping experience [13, 14]. The Internet of Things in the textile industry helps autonomously collect, evaluate, and send data in the textile industry. The new textile industrial transformation includes more now data management to support building efficient, predictive, and profitable models. Artificial Intelligence digital technologies are used by 8% of firms in the EU, most often for robotic process automation. AI with its branch of computer vision in textile manufacturing has increased. AI uses input images to make a computer understand and predict the real world based on the given data and applies probabilistic neural network (PNN) models, a system for detecting knitted fabric defects such as holes, oil stains, fallen-out stitches, and knots using image processing techniques and feature extraction and fabric defect detection with CNN using real images of printed fabrics, as more effective in detecting defects in real-time than conventional classification algorithms such as Support Vector Machine.

The higher productivity impact of robotics and mobile-social media could be explained by their higher maturity compared to IoT and cognitive technologies. They have better-defined use cases and clearer expected returns, and companies in the EU seem to have been more effective in translating bottom-line efficiencies from robotics and mobile/social media into higher operating margins. The less mature technologies appear to start creating value only when associated capabilities, such as data infrastructure, skills, and other intangible investments, are in place. The return on digital investments varies by industry, and industry leaders achieve a greater productivity increase from investments in new technology than followers. Asset-heavy industries realize more value from robotics; asset-light industries realize greater value from mobile/social media. Asset-heavy industries make greater investments in hardware-based technologies, such as IoT and robotics. Asset-light industries make greater investments in software-based technologies, such as mobile/social media and cognitive technologies. They have achieved greater productivity gains from mobile/social media than cognitive technologies.

Digitized production techniques in textiles include more and more computer-aided design (CAD), the usage of digital files, and computer-aided manufacturing (CAM), with the support of programming languages, sensors, servers, and electronic signals. Robotics and artificial intelligence have been widely adopted in weaving and preparation machinery compared to knitting and nonwoven. The application of intelligent robotics in technical sectors such as Robolap, Roboload, Robodoff, and Aerobotic is becoming more useful as AI is also making its way into technical sectors such as cotton colour sorting, weaving defect analysis, synchronization defect classification, knitwear hand development, intelligent design aids, and computer-aided instruction. Robots, as reprogrammable, multifunctional manipulators that move materials, parts, tools, or other devices through variable, programmed motions to perform a variety of tasks, are becoming very important to digitization in the industry. Machine vision technology is the key to the textile industry as it enables accurate analysis and control of fabric lay down. Apart from this, image processing technology has also found its application in the following sectors: colour grading of cotton, manual evaluation of knitted fabrics, virtual fitting systems for garments, classification of dyeing defects, analysis of blending irregularities in yarns, and classification of fabric defects [15–17]. Textile developments would include big data collection, improving reaching the better, smart flooring, for example, that accurately measures shopper movement in a store and from which could be learned how best to set up the store. With AI methods, it is possible to automatically classify body shapes and thus improve the development of perfectly fitting clothing. Or it enables trainable methods for automated visual quality control when it comes to detecting and classifying defects in textile surfaces. AI also offers a new dimension of individualized.

According to McKinsey (2022), fashion companies consider investing in digital marketing capabilities a top priority in the last years. Social media use is expanding by around 25% annually, with nearly 70% of users active on Instagram (in 2021, 59% of EU enterprises used social media). 86% of businesses utilize influencer marketing. 17% of brands had either implemented shoppable galleries or planned to do so in the following year (Statista, 2022). E-commerce marketplaces, and in general online platforms, may facilitate economic growth by enabling sellers to access new markets and reach new customers at a lower cost [18, 19].

Based on digital technologies implementation of powerful devices is going to be developed: clothing technology, intelligent, wearable, smart clothing. Emerging textile areas like beauty and cosmetic textiles based on microparticles; health textiles that monitor vital signs or are available to third parties for care purposes; safety clothing with an integrated indicator in the sleeve, working clothes with active lighting elements, textiles that generate energy, Adaptive Products, and connectivity improvement are further benefits of these investments [20–22].

The aim of the research and significance of the use of digital technologies in textiles are given in the first part of the study structure, digital transformation, and specific digital technologies used in the operations of the textile and fashion companies in Serbia as a case in the second section. After that are presented the methodology, key findings, and discussion are. Conclusions with the contribution to the theory and practice, possible future research, and the literature are given at the end of the article.

MATERIALS AND METHODS

The textile industry in Serbia is taken as the case sector for empirical research. The total gross value added (GVA) generated by the textile industry was 397.5 million EUR in 2020, which is 1.0% of the total GVA of the country and 0.9% of Serbia's GDP. Observed by activities, 219.4 million EUR was created by the manufacture of wearing apparel (55.2%) and 110.5 million EUR by the manufacture of textiles (27.8%). From 2016 to 2020, the GVA share of the textile industry in total GVA and GDP of the Republic of Serbia shows a downward trend. Export of textile products in 2021 amounted to 1.3 billion EUR which is 6.0% of total export but despite the negative effects caused by the pandemic, export of these products are around 0.7% higher than in 2019 (pre-pandemic level). The textile industry is hiring 61.9 thousand workers (2.8% of total employment) while most are employed in the manufacture of wearing apparel (36.2 thousand). The textile industry in 2021 was operating 1.9 thousand active companies and 6.2 thousand entrepreneurs, which is in total nearly 8.1 thousand (figure 1).

For this paper, empirical research was conducted on the attitudes of representatives of 423 companies from the textile industry in Serbia in 2022. The main goal of the research is to determine the level of digitalization of these companies based on their previous investments in new digital technologies (% of total revenues for the period, 2019–2021).

According to the profile of surveyed companies in the textile sector, 42.00% are engaged in production, 38% in services and trade in the field of textiles, and 20% in marketing and design. Most are micro and small companies, with revenues of up to 150,000 euros. The medium companies are 12.19% (17.00% with over 2 million euros of revenue per year in 2021). About 90.00% of the surveyed companies are private companies, entrepreneurial shops, and agencies. About 7.00% of them are part of an international chain, and about 2.40% have mixed capital. Most of the representatives of the surveyed companies who answered the interview questions were the owners and managers, which supports the credibility of the research results.

All surveyed companies have invested in the last three years in the digitalization of their business, products, and services but with different dynamics and different technologies. Thus, up to 10.00% of total revenues in the last three years, 24% of them allocated for the application of digital technologies, from 11–30.00%, 27.66% of them, and over 31.00%, and over that percentage, 7.09% of the interviewed textile and fashion companies.

Assessing the level of application of digital technologies based on these investments, the representatives of the surveyed companies made the following observations: most of them, 279 companies have partially implemented new digital technologies in their business and are in a medium stage of digital transformation.

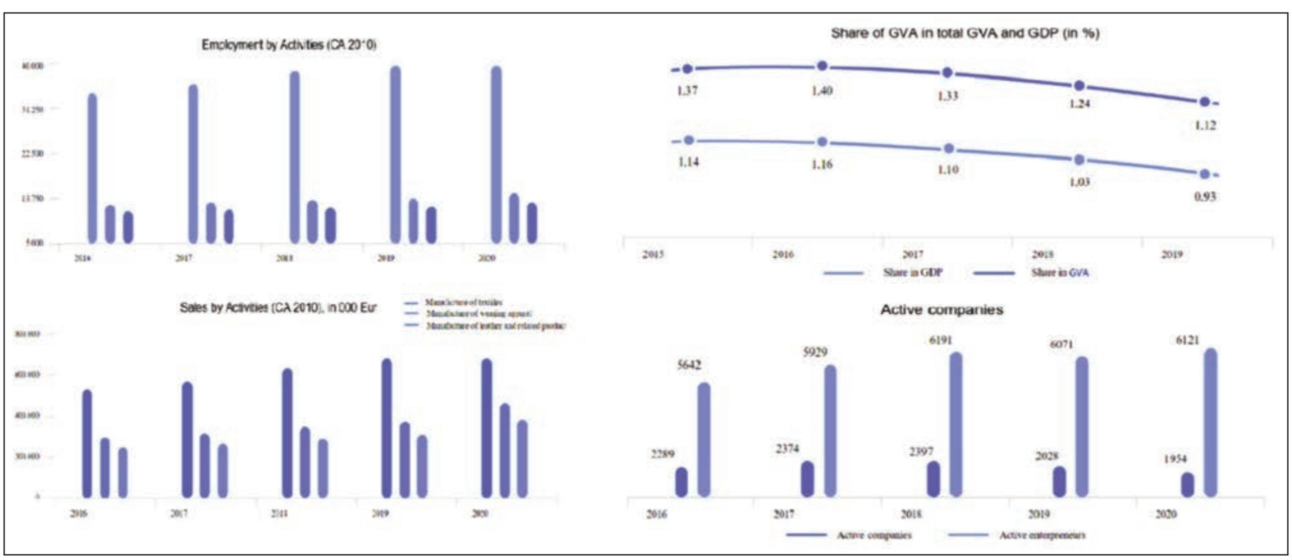

Fig. 1. Serbian textile industry indicators, 2016–2020

18.91% are on a high level of digital transformation with full use of implemented technologies, and 15.13% have just initiated the digital strategy, and are at the beginning of the implementation of digital technologies and their transformation process.

By technologies: Cloud technology is used by surveyed companies, 56.97% of them partially apply it, 13.47% are among those with advanced implementation, and 29.55% of them did not start using it at all or are in the early beginning phase. Technologies of automation, process optimization, and interoperability of functions are applied by surveyed companies so that, 70.00% of them partially apply, 14.89% are at the beginning, and 14.42% riched advanced implementation. Energy management technologies are popular, many companies have these technologies planned in their digital strategy. In practice, 30.26% of companies from the sector applied them on a high level, partially applied by 43.49%, and not 26.24% are at the beginning of the implementation. Algorithms and sophisticated machine learning technologies are generally applied in the practice of the digital transformation of textile companies, 25.76% of them partially apply them, 64.06% of them did not start using them at all, and 10.16% of surveyed companies applied this digital technology. IT technologies for managing business functions are the most 5 popular digital technologies in the digital transformation of textile companies, so 49% of them partially apply them, 29.07% are advanced in their implementation, and 27.42%, are at the beginning of the application.

To assess the statistical significance of the level of digitalization of textile companies in Serbia, the Hi test method was used, and further basic and alternative hypotheses were set:

- H_{01} = There is no statistically significant difference in the application of modern technologies in the digitalization of business operations concerning the level of investment, and that
- H_{a1} = There is a statistically significant difference in the application of modern technologies in the digitalization of business operations about the level of investment.

Besides that, five auxiliary hypotheses are defined concerning investments in a specific technology (H01/Ha1, H02 /Ha2; H03 /Ha3; H04 /Ha4; H05 /Ha5; H06/Ha6).

The hypotheses were tested on a sublimated example of research results related to the financial resources allocated to the total income of enterprises for investments in new digital technologies, individually by technologies, and the total impact of these technologies on the achieved level of digital transformation of enterprises (tables 1 and 2).

Table 1

CROSSTABULATION INDICATORS												
Indicator	**Level of digital transformation**											
The firm's investments	At the beginning of the implementation			Partially implemented			Advanced implementation			Total		
	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)
≤ 10%	42	65.63	15.22	213	76.34	77.17	21	26.25	7.61	276	65.25	100.00
11% – 30%	14	21.88	11.97	52	18.64	44.44	51	63.75	43.59	117	27.66	100.00
≥ 31%	8	12.50	26.67	14	5.02	46.67	8	10.00	26.67	30	7.09	100.00
Total	64	100.00	15.13	279	100.00	65.96	80	100.00	18.91	423	100.00	100.00
The firm's investments	Claud technology											
	Level of digital transformation											
	At the beginning of the implementation			Partially implemented			Advanced implementation			Total		
	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)
≤ 10 %	107	85.60	38.77	153	63.49	55.43	16	28.07	5.80	276	65.25	100.00
11% – 30%	11	8.80	9.40	79	32.78	67.52	27	47.37	23.08	117	27.66	100.00
≥ 31%	7	5.60	23.33	9	3.73	30.00	14	24.56	46.67	30	7.09	100.00
Total	125	100.0	29.55	241	100.0	56.97	57	100.00	13.48	423	100.00	100.00
	Automation, robotization, process optimization, interoperability of functions											
	Level of digital transformation											
	At the beginning of the implementation			Partially implemented			Advanced implementation			Total		
	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)
≤ 10 %	43	68.25	15.58	206	68.90	74.64	27	44.26	9.78	276	65.25	100.00
11% – 30%	13	20.63	11.11	83	27.76	70.94	21	34.43	17.95	117	27.66	100.00
≥ 31%	7	11.11	23.33	10	3.34	33.33	13	21.31	43.33	30	7.09	100.00
Total	63	100.00	14.89	299	100.00	70.69	61	100.00	14.42	423	100.00	100.00

Table 1 (*continuation*)

The firm's investments	Energy management											
	Level of digital transformation											
	At the beginning of the implementation			Partially implemented			Advanced implementation			Total		
	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)
≤ 10 %	90	81.08	32.61	157	85.33	56.88	29	22.66	10.51	276	65.25	100.00
11% – 30%	15	13.51	12.82	17	9.24	14.53	85	66.41	72.65	117	27.66	100.00
≥ 31%	6	5.41	20.00	10	5.43	33.33	14	10.94	46.67	30	7.09	100.00
Total	111	100.00	26.24	184	100.00	43.50	128	100.00	30.26	423	100.00	100.00
The firm's investments	Sophisticated machine learning algorithms											
	Level of digital transformation											
	At the beginning of the implementation			Partially implemented			Advanced implementation			Total		
	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)
≤ 10 %	201	74.17	72.83	51	46.79	18.48	24	55.81	8.70	276	65.25	100.00
11% – 30%	63	23.25	53.85	49	44.95	41.88	5	11.63	4.27	117	27.66	100.00
≥ 31%	7	2.58	23.33	9	8.26	30.00	14	32.56	46.67	30	7.09	100.00
Total	271	100.00	64.07	109	100.00	25.77	43	100.00	10.17	423	100.00	100.00
The firm's investments	IT technologies implementation in business operations											
	Level of digital transformation											
	At the beginning of the implementation			Partially implemented			Advanced implementation			Total		
	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)	N	Column (%)	Row (%)
≤ 10 %	93	80.17	33.70	152	82.61	55.07	31	25.20	11.23	276	65.25	100.00
11% – 30%	17	14.66	14.53	22	11.96	18.80	78	63.41	66.67	117	27.66	100.00
≥ 31%	6	5.17	20.00	10	5.43	33.33	14	11.38	46.67	30	7.09	100.00
Total	116	100.00	27.42	184	100.00	43.50	123	100.00	29.08	423	100.00	100.00

Table 2

HYPOTHESIS TESTING						
Level of digital transformation						
Test	ChiSquare (o)	Prob>ChiSq (o)	df	ChiSquare (t)	Prob>ChiSq (t)	Hypothesis H_{01}
Pearson	75.855	0.0001	4	9.488	0.05	not accepted
Claud technology						
Test	ChiSquare (o)	Prob>ChiSq (o)	df	ChiSquare (t)	Prob>ChiSq (t)	Hypothesis H_{02}
Pearson	75.238	0.0001	4	9.488	0.05	not accepted
Automation, robotization, process optimization, interoperability of functions						
Test	ChiSquare (o)	Prob>ChiSq (o)	df	ChiSquare (t)	Prob>ChiSq (t)	Hypothesis H_{03}
Pearson	31.696	0.0001	4	9.488	0.05	not accepted
Energy management						
Test	ChiSquare (o)	Prob>ChiSquare (o)	df	ChiSquare (t)	Prob>ChiSq (t)	Hypothesis H_{04}
Pearson	155.125	0.0001	4	9.488	0.05	not accepted
Sophisticated machine learning algorithms						
Test	ChiSquare (o)	Prob>ChiSq (o)	df	ChiSquare (t)	Prob>ChiSq (t)	Hypothesis H_{05}
Pearson	74.572	0.0001	4	9.488	0.05	not accepted
IT technologies implementation in business operations						
Test	ChiSquare (o)	Prob>ChiSq (o)	df	ChiSquare (t)	Prob>ChiSq (t)	Hypothesis H_{06}
Pearson	127.542	0.0001	4	9.488	0.05	not accepted

KEY RESULTS AND DISCUSSION

In this paper, one basic hypothesis, with its alternative (H01/Ha1), and five auxiliary hypotheses (H01 /Ha1, H02 /Ha2; H03 /Ha3; H04 /Ha4; H05 /Ha5; H06/Ha6, are tested by comparing it with the null hypothesis.

The null hypothesis is only rejected if its probability falls below a predetermined significance level, in which case the hypothesis being tested is said to have that level of significance. According to the results of the research, the exceptional importance of investments of companies from the textile and fashion industry in modern technologies, their application in business, and the modernization of functions for digital transformation is confirmed [2–6]. Also,

- H01: There is no statistically significant difference between the level of investment of a textile/fashion company in new technologies and the achieved level of digital transformation of its business.
- Ha1: There is a statistically significant difference between the level of investment of a textile company in new technologies and the achieved level of digital transformation of its business.

According to Pearson's test: the significance threshold is 0.05; the degree of freedom is 4, and the limit value for χ^2 = 9.488. The value for χ^2 = 75.855 was obtained. The obtained value is greater than the tabular χ^2 = 9.488, and the obtained significance of 0.0001 is less than the 0.05 threshold. Based on these parameters, the null hypothesis is not accepted, but an alternative one is that there is a statistically significant difference between the amount of investment of a company in new technologies and the achieved level of digital transformation of its business. Like all other hypotheses, an alternative was also accepted, according to which the levels of digital transformation of textile companies' business are distinguished based on the amount of invested funds (measured % of total revenue in the last three years, 2019–2021), in technological modernization of functions, production, and business, communication with consumers, market, supply chain, data. In all tested digital technologies applications in the textile companies, the significance threshold is 0.05, the degree of freedom is 4, the limit value for χ^2 = 9.488, and as follows:

- ***Cloud technologies (Ha2***), the obtained value is for χ^2 = 75,238 and is higher than the table χ^2 = 9,488, and the obtained significance of 0,0001 is less than the threshold of 0.05, so the null hypothesis (H2) – that there is no statistically significant difference between the amount of investment in technology cloud and reaching the level of digital transformation of his business is not accepted.
- ***Automation, robotization, process optimization, and interoperability of functions (Ha3***), the obtained value is for χ^2=31,696 and is higher than the table χ^2=9,488, and the obtained significance of 0,0001 is less than the threshold of 0,05, so the null hypothesis (H3), is that there is no statistically significant difference between the amount of investment in Automation, robotization, process optimization, interoperability of functions and reaching the level of digital transformation of its business is not accepted.
- ***In energy management (Ha4),*** the obtained value is for χ^2 =155.125 and is higher than the table χ^2 = 9.488, and the obtained significance of 0.0001 is less than the threshold of 0.05, so the null hypothesis (H4), is that there is no statistically significant difference between the amount of investment in energy management and reaching the level of digital transformation of its business is not accepted.
- ***Machine learning (Ha5),*** the obtained value is for χ^2=74.572 and is higher than the table χ^2 = 9.488, and the obtained significance of 0.0001 is less than the threshold of 0.05, so the null hypothesis (H5), is that there is no statistically significant difference between the amount of investment in Sophisticated machine learning algorithms and reaching the level of digital transformation of its business is not accepted, and
- ***IT (Ha6),*** the obtained value is for χ^2 = 127.542 and is higher than the table χ^2 = 9.488. The obtained significance of 0.0001 is less than the threshold of 0.05, so the null hypothesis (H6), is that there is no statistically significant difference between the amount of investment in IT technologies implementation in business operations and reaching the level of digital transformation of its business is not accepted.

CONCLUSIONS

The findings of this research on investments in digital technologies of companies in the textile sector and the achievement of different levels of business digitalization can contribute to the theory, support of knowledge, and benefits from the digital strategy of textile companies' implementation. Primary:

- *Automation technologies*, conversion of analogue to digital information in business in the initial phase of digitalization, with digital resources, the standard organizational hierarchy from top to bottom, growth strategy based on market penetration, metrics KPIs, ROI, and ROA, saving costs and resources for existing activities [2–4].
- *Robotization technologies,* the addition of digital components to products and services of textile companies, introduction of digital distribution and communication channels for medium-level business digitalization, with agile digital resources in the supply chain, organizational structure of separate agile units, digital growth strategy based on market penetration platform and its joint creation with other interest groups, metric-digital KPIs, and goals, which are primarily reflected in reducing costs and increasing revenue, reengineering business processes of the company and strengthening the user experience [7, 8] and

- *IT technologies* for introducing new business models in an advanced phase of digital transformation of textile companies, such as production and service digital platforms, business models based on big data and analytics, with organizational structure, flexible forms, IT internationalization, and analytically functional business areas, digital development strategies based on platforms, metrics; digital KPI, and new business model development [2].

Previous works on the impact of the ICT investments on the company's results)confirm the findings of the study emphasizing the further importance of these technologies in achieving strategic objectives of the textile enterprises in applications of digital technologies and achieving business and content metrics [1, 2, 16, 17].

The coverage of work limits does not include the elaboration of each phase of digitalization achieved by introducing certain digital technologies [2, 10, 11, 21].

The paper points to the need for new research related to fostering digital transformation in the Serbian textile sector, which would address the external guides of this transformation: digital competitiveness, the needs of digital consumers, and stakeholders, especially online distribution, and the interdependence of factors within the supply chain [4–7].

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The digital transformation of garment product development

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ABSTRACT – REZUMAT

The digital transformation of garment product development

Many clothing companies approach digital transformation by focusing on digitizing individual processes or operations. Digital transformation is often limited to specific initiatives or programmes that only impact a few departments. Significant opportunities or existential risks are often the main drivers for digital transformation. Moreover, leaders planning the future of their companies and industries should focus on the opportunity – or existential threat – that these changes present. It is essential to find the ideal balance between focusing on quick results with innovative ideas and laying the foundation for digital transformation, such as unleashing the potential of data and analytics, managing brand and reputational risk, controlling the entire supply chain and closing the digital technology gaps are not the only significant issues. A complete change in corporate culture that puts the customer at the centre is the key component of the ultimate digital challenge for clothing companies. This article presents the opportunities, benefits and challenges of developing garment models with digital tools from Gemini CAD, a Lectra company. These tools include (in addition to the pattern) the product data sheet, a detailed description of all fabrics, trimmings, and accessories, components needed for sourcing, purchasing, and determining the cost of the product, as well as the information needed to publish the product on e-commerce and interact with the customer, including customization.

***Keywords:** digital patterns, digital fabrics, trimmings, graphic resources*

Transformarea digitală a etapelor de dezvoltare ale unui produs de îmbrăcăminte

Din ce în ce mai multe companii de confecții textile abordează transformarea digitală a fluxurilor de fabricație prin digitalizarea proceselor sau a operațiilor. Transformarea digitală este adesea limitată la inițiative sau programe specifice, cu impact doar în activitatea unor departamente. Oportunitățile semnificative sau riscurile existente sunt factorii care stimulează transformarea digitală a proceselor de producție. Managerii companiilor, cei care planifică și orientează politicile firmei cu impact asupra modului de evoluție al industriei de îmbrăcăminte, ar trebui să conștientizeze ce schimbări sunt necesare în această industrie, ca rezultat al oportunităților sau provocărilor actuale. În acest context, este esențial să se identifice un echilibru optim între dorința de a obține rezultate rapide prin implementarea unor idei inovatoare și etapele necesare unei transformări digitale a proceselor de producție, bazate pe analiza datelor firmei, gestionarea riscurilor legate de brand și de lanțul de aprovizionare și de dorința de eliminare din activitatea firmei a diferențelor semnificative în materie de tehnologie digitală. O schimbare completă a culturii corporatiste, în care clientul devine elementul central al activității unei firme de confecții textile, reprezintă o provocare pentru transformarea ei digitală. În acest articol sunt prezentate oportunitățile, beneficiile și provocările determinate de dezvoltarea modelelor produselor de îmbrăcăminte cu ajutorul instrumentelor digitale ale firmei Gemini CAD, o companie Lectra. Instrumentele digitale sunt următoarele: modelul produsului în format digital și fișa tehnică a acestuia, descrierea detaliată a tuturor materialelor și accesoriilor necesare realizării produsului, componentele activității de aprovizionare și de achiziție a celor necesare procesului de producție, elementele de calcul al costului de produs, informații pentru promovarea pe platforme virtuale al noului model, fie în scopul comercializării așa cum a fost elaborat sau pentru a facilita personalizarea modelului de către client.

***Cuvinte cheie**: modele digitale, țesături digitale, accesorii digitale, resurse grafice*

INTRODUCTION

Industry 4.0 is a topic that is being intensively discussed and analyzed by experts from education, business, industry, economics and research. The German government launched the concept at the Hannover Fair (2011) and was quickly taken up by all European countries and a slew of other ones from the rest of the world. It was defined as an industrial revolution in manufacturing, where production processes are changed by digitalization, robots and artificial intelligence. This industrial revolution is underway and will be marked by advances in artificial intelligence, the Internet of Things, next-generation robotics, 3D printing, wearable technology, software engineering, nanotechnology, advanced materials, biotechnology and much more. Industry 4.0 is the future of manufacturing technology and a major development in automation and data exchange. The "smart factory" results from Industry 4.0, which includes cyber-physical systems, the Internet of Things, cloud computing and cognitive computing. The best way to produce high-quality products is to use advanced technologies, digital platforms and automated processes.

Industry 4.0 provides real-time information on various processes/applications in organizations, ensuring a better understanding of current operating conditions, errors and failures, and areas for improvement. It relies on various technology components that are interconnected through ICT tools. As a result, companies need to undergo a digital transformation to fundamentally rethink and redesign their business processes to adapt to the latest wave of technology.

Digital transformation, which involves changing supply and production chains and providing new products and services while overcoming structural changes and obstacles in the transformation process, can be achieved via the digital technologies of digitization and digitalization of data and processes [1]. The entire supply chain of the clothing sector is affected by the digital revolution, which is bringing about profound changes in customer service and supply chain operations [2–5]. To streamline distribution and production and shorten lead times, the clothing industry is digitizing product design, advertising and manufacturing in response to the growing trend towards customization and personalization. Mass customization is leading to a fundamental shift in the culture of the apparel industry, driving the industry towards an on-demand production model [6].

The clothing industry still has a lot of issues to address, from scanning materials to 3D product development and creation, from sales to production and distribution. Carrying out a digital transformation in all areas of corporate culture and operational procedures will transform the company activity into a sustainable business, able to ensure full transparency and understanding of its social responsibility by monitoring and ensuring that its suppliers commit to adhering to the brand's principles and policies. They will also be able to rely on data and concrete evidence to demonstrate their efforts to minimize polluting gas emissions and environmental damage at each stage of the supply chain [7].

The World Economic Forum (WEF) has highlighted the important feature of digital technology – sustainability. Digital technologies can improve resilience to global warming and natural disasters, reduce emissions and improve people's ability to take the necessary steps to achieve zero waste [8, 9].

The solutions that can make the garment industry a sustainable one are: 3D virtual sampling (this will enable one to digitally verify an entire collection and reduce waste in both design and product development); alternative textiles (eco-friendly textiles); automation and fashion-on-demand (design and manufacture on demand will reduce returns and guaranteed sales will offset these costs over time); mobile body scanning (mobile apps allow companies to design garments that fit different body types); virtual dressing (AR and VR offer virtual dressing experiences while shopping virtually); circular fashion (to keep waste out of the product and production system and keep materials and products in use as long as possible); re-commerce (resale offers wardrobe rotation without waste, upcycling allows new garments to be made from old).

This article presents how one can use the digital tools of Gemini CAD – a Lectra company – to develop a production sheet for a garment model that includes (in addition to the pattern) a detailed description of all fabrics, trimmings and accessories, the elements needed for costing, sourcing and purchasing, and the information needed to publish the product on e-commerce and interact with the buyer, including customization.

WORK METHODOLOGY

General information

The fashion and clothing industry has started integrating Industry 4.0 technology by using interconnected ICT tools and algorithms to design new collections, predict fashion trends or identify market requirements. The digital transformation process must be approached from multiple perspectives to cover each supply chain stage. It is not enough to digitize only certain processes, such as purchasing; one must tailor every stage of the creation, production and buying processes to the digital age. The secret to success is to build a consistent, synchronized omnichannel system that coordinates physical and digital activities and provides an interactive, engaging experience for the customer from conception to conversion and beyond. Even though it may seem daunting, this is ultimately the direction in which the market is moving.

In line with what is necessary for the manufacturing industry, the producers of digital technologies have developed new solutions to help this sector exist and evolve sustainably. Several providers have developed specific and innovative technologies for the clothing sector.

Lectra has launched a new concept, “Fashion On Demand by Lectra”. This solution includes Lectra's Digital Cutting Platform and Virga, a single-ply fabric cutting solution. It is a turnkey solution that automates on-demand production from receiving the order reception to cutting the pieces. This breakthrough offers fashion companies a 360° view of the entire on-demand process, from small series to one-off production runs [10].

Gemini CAD – a Lectra company has developed a complete digital product solution that includes (in addition to the patterns) the product data sheet, a detailed description of all fabrics, trimmings and accessories, all the elements needed for sourcing and purchasing and to determine the production costs, a step-by-step production flow chart, labelling information, all the data necessary to publish the product in e-commerce and interact with the buyer, including customizing, etc. [11].

Optitex Company offers a vendor solution that unifies the entire process of making a garment, putting it at the heart of the future of this market. Creating agile workflows, saving valuable resources, increasing

ROI and moving to on-demand manufacturing are closer than ever. Due to the high complexity of a large enterprise, modern collaboration tools are essential for fast delivery and sustainable production cycles [12].

Assyst Company has become a leading solution provider for the digitization of the apparel industry. The company is the only provider offering integrated and breakthrough solutions for fashion industry processes. With the introduction of a 3D Vidya module, Assyst, the new model suite, has taken a decisive step forward and removed the last obstacle preventing the digital sale of fashion [13].

CLO 3D offers a Virtual Fashion end-to-end solution for the virtual simulation of garments while providing its partners with data on other designs and trends. The technology allows one to visualize the users' creations with the ability to create unlimited graphic placements, colourways and technical print layouts while accurately emulating drape-sensitive fabrics, reducing lead time [14].

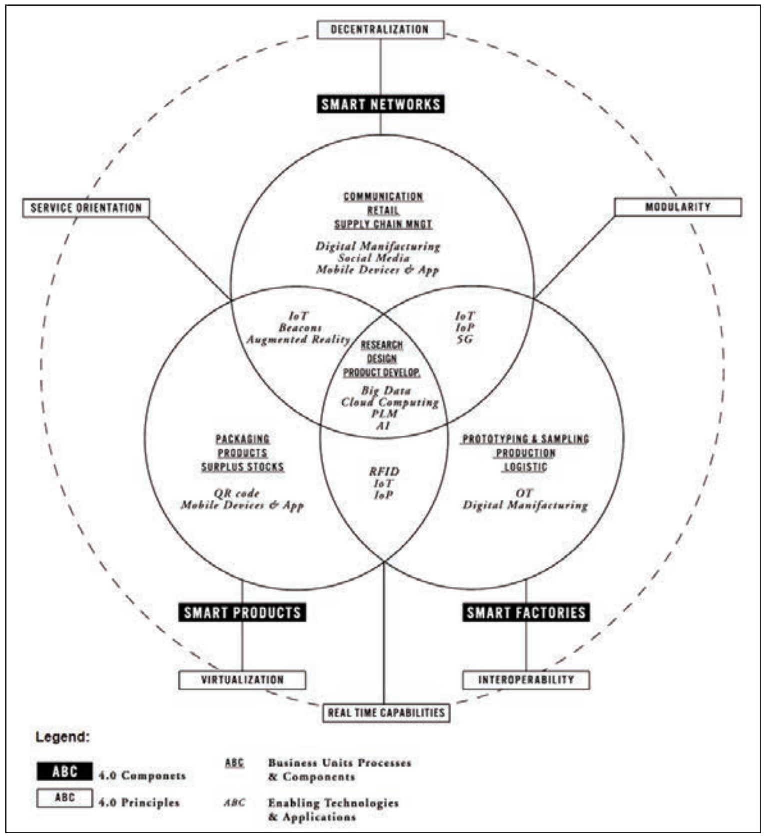

Fig. 1. The components and principles of a fashion business [15]

Digital technologies allow the transmission of data on the availability, accessibility, and use of local resources and the condition of materials and products in real time. The product development process must be decentralized, modular, and service-oriented (see figure 1).

We can presume that technology has a significant impact on how we interact, communicate, teach, work and learn. To cope with the challenge and seize the opportunities that the digital age holds for the apparel industry, a business in the fashion and clothing area has to change its business approach and modernise its processes.

Work procedure

One of the biggest problems currently facing the garment industry is overproduction. Garment companies have been overproducing for a variety of reasons. Some of these include changing consumer attitudes, unreliable market forecasts and doubts about suppliers' ability to deliver clothing on time. While some of the unsold clothing can be donated, resold or sold at a discount, the majority of unsold clothing is buried or burned in landfills, contributing to the industry's ongoing environmental crisis.

Industry 4.0 brings important changes to the fashion and apparel industry in terms of the development process of a new model based on IoT, augmented reality, cloud computing, mobile devices and apps etc. (figure 1).

The main steps to develop a production sheet of a garment model that includes (in addition to the pattern) using specific instruments of Gemini CAD – a Lectra Company are described in the next five steps.

1. *Design the patterns*

The designer analyzes the details and structure of the model and the customer's requirements and decides which design solution is better for developing its patterns.

For the model presented in figure 2, the garment pieces are designed as 2D customized ones using the principles of the geometric method [17, 18]. In this case, the designer needs information about the customer's body shape (the values of the anthropometric parameters, conformation, posture), and their preferences regarding the features of the model (length, fitting degree, position of different decorative elements, cutlines, materials, colours or motifs).

Fig. 2. Dress model [16]

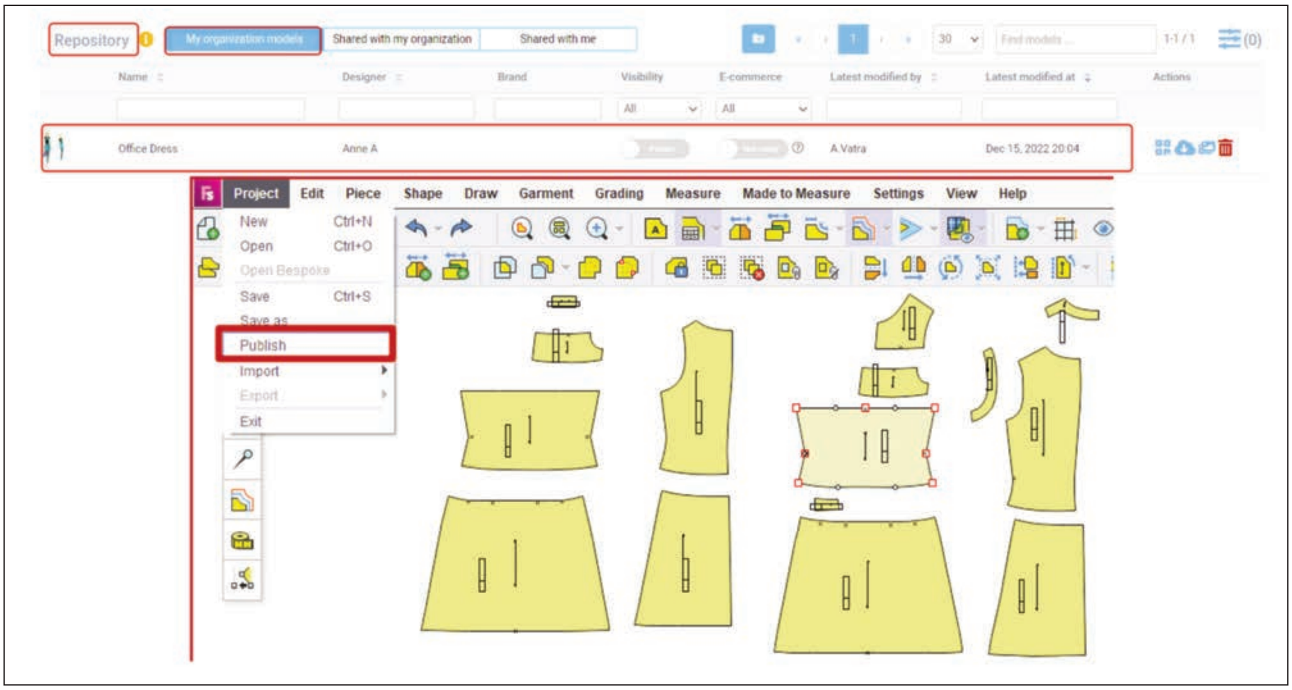

Fig. 3. The model patterns

The garment pieces are designed by using specific functions of Fashion Studio. Fashion STUDIO provides suitable options for the construction of the shapes, depending on the user's preferences: free, assisted, or parametric methods, or a combination. It provides one with the possibility to use native Bezier curve shapes, corner angle control, and other methods in its geometric platform for linked components while maintaining the freedom to move, rotate and flip the pieces on the digital workspace.

The model patterns that are saved and published in *Fashion Studio* are visible in the *Repository* list. In this section, the designer has the possibility to visualize further details of the developed model: its name, the name of the designer who drafted the patterns, the measurements, the styles (if defined for this model), and the decorative elements (if any have been applied) (figure 3).

Developed models can be found under "My organizational models". They can be shared with other technicians for their use or be kept visible only to the person who developed them.

2. *Creating the mood board*

A mood board is an important visual tool for any design and fashion project. It is a traditional design tool which depicts all the layers of inspiration needed for a design project (figure 4). It motivates the designer and serves as a project manual for all design teams.

Moodboards should be visually appealing, and easy to understand and they should illustrate design elements. The designer can develop mood boards from different angles and express their thoughts using a variety of materials.

The key steps in designing a mood board are:

a) Develop a Creative Idea That Goes Beyond Aesthetics.

Creating mood boards must be a stimulating creative process. This goes beyond simply compiling appealing images and arranging them without a solid, cohesive explanation. A creative concept is not a theme like "flowers", "sea" or "forest", but rather a combination of creative components from different sources, harmonized and adapted to create a stronger intellectual argument and greater aesthetic depth.

b) Choose a representative colour scheme for your project.

Every design project must include colours. They set the mood and give the mood board a certain "feel". Colours can influence inspirational images or vice

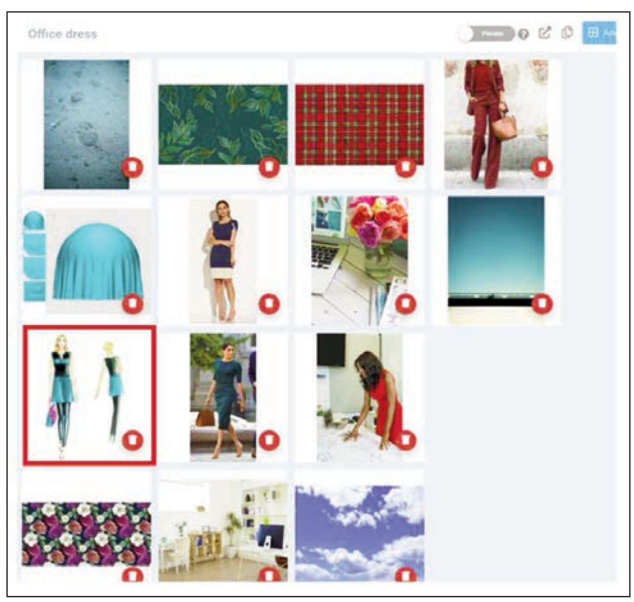

Fig. 4. Mood board

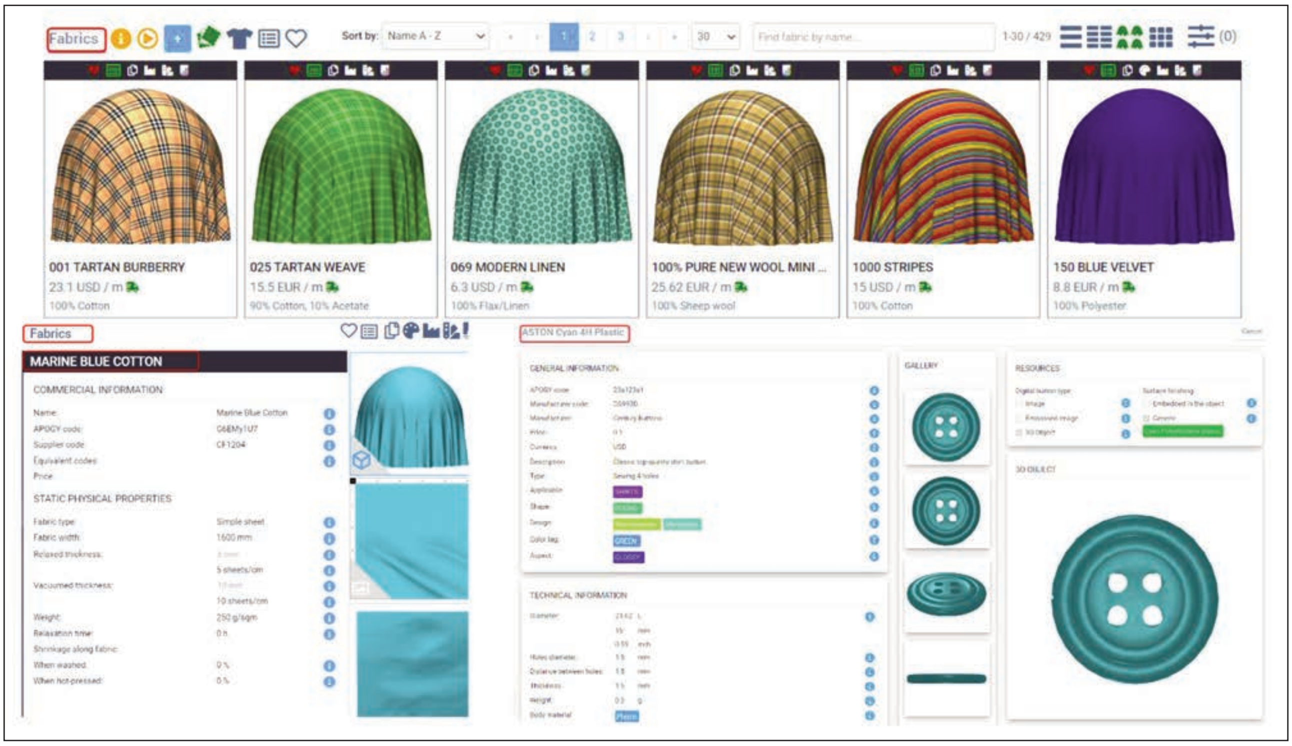

Fig. 5. Digital fabrics and accessories

versa. Colours can be changed during the development of the mood board.

c) Choose a typography series for each piece of writing.

For each graphic, logo and text element, use the appropriate typeface to convey the desired tone. Different typographic families interpret typefaces in different ways.

Include visual elements that match the chosen typography. In this way, one can ensure that the images and the typeface design complement each other and stay true to the original idea.

d) Create prints and textures in light of your colour scheme.

Mood boards can contain raw materials, finished prints and textures that enhance the final product. They are used to add depth and variation to a design presentation. Colour blocks are fantastic, but prints always add vibrancy and a new feel to a project.

e) Use inspirational images to tell a visual story.

The image will tell the 'story' of what the designer is trying to do. The designer will use inspirational images to inject emotion into the mood board presentation (use detailed images to zoom in and describe the sensations).

Working on a project with mood boards is both difficult and fun. A mood board is a versatile, highly creative tool that the designer can use to communicate concepts and show all facets of the project.

3. Create/enrich digital materials and accessories libraries

The designer can create or use the digital library of raw materials (*Fabrics*), materials and accessories (e.g. *Creative Assets Buttons*) within the company. Their digital format contains the following information:

Fig. 6. Adding a new material in the digital library of fabrics

an image of the textile material/accessory, code, brand name, manufacturer, physical-mechanical properties (for textile materials), etc. (figure 5).

If the textile material that is going to be used for the development of a new model has a certain drawing ratio, the designer photographs an area of the material with maximum resolution and brightness, determines the size of the ratio, its physical-mechanical properties and enters the data into the digital library (figure 6).

The material that has been used to determine a certain drawing ratio can be used in developing new models (using the patterns of the reference model) with certain positional constraints for the components that ensure the continuity of the drawing ratio between two adjacent pieces (*Piece-to-Piece*) or *Piece-to-Fabric*. After selecting the material, the user sets the matching rule, and the created rule is applied to the selected parts (*Create matching rule*) (figure 7).

Depending on the ratio of the drawing and the region of the model that it depicts, the assignment rules can

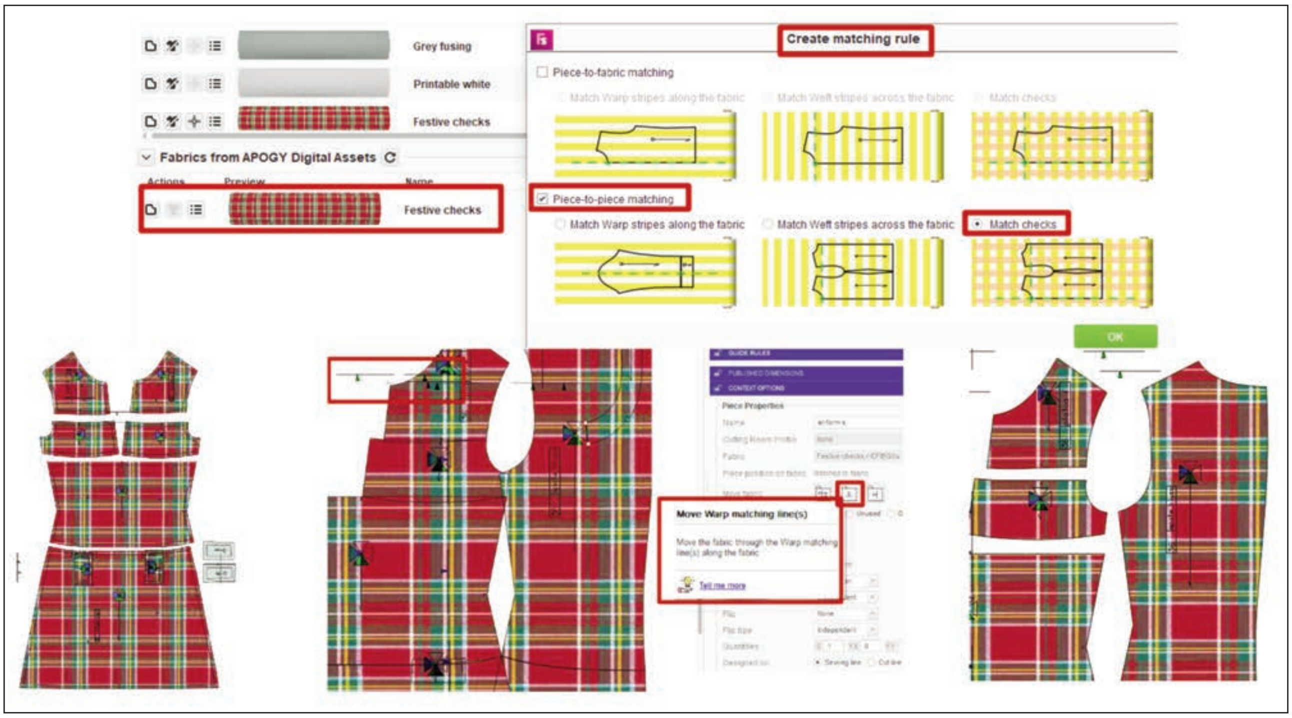

Fig. 7. Creating matching rules for adjacent pieces

also be altered (*Move fabric*) so that the two pieces get attached along the designated important areas (e.g. Piece-to-Piece).

Another solution for developing new models is to share graphic resources on garment pieces. The user creates the desired graphic model, saves it and manages it as an external resource. Select the graphic resource in the model, select the parts for which the graphic resource is to be shared and view the result (figure 8).

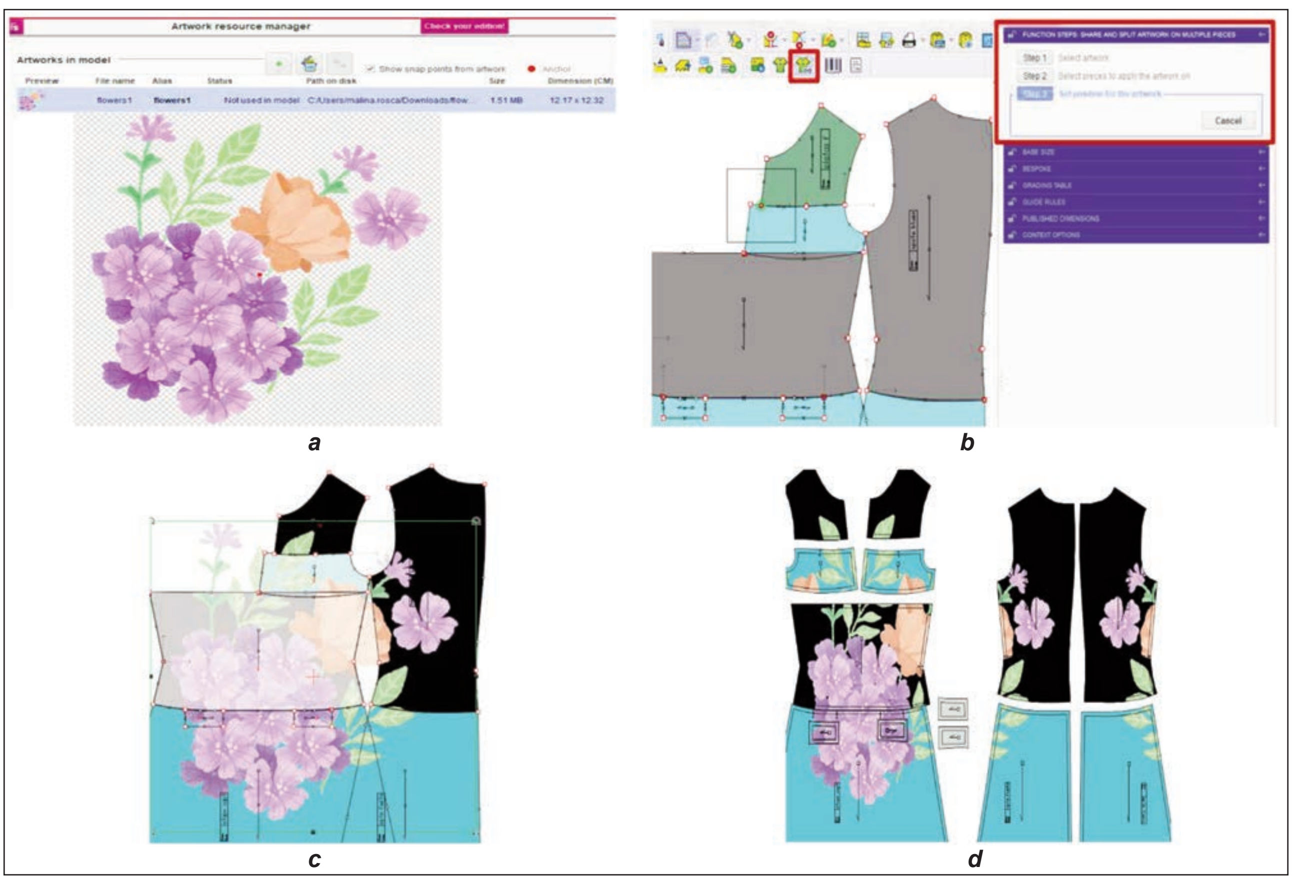

Fig. 8. Sharing graphic resources on selected pieces: *a* – design the wanted artwork; *b* – select the pieces where the graphic resource is distributed; *c* – the intermediate phase of the shared graphic resources on the selected pieces; *d* – final aspect

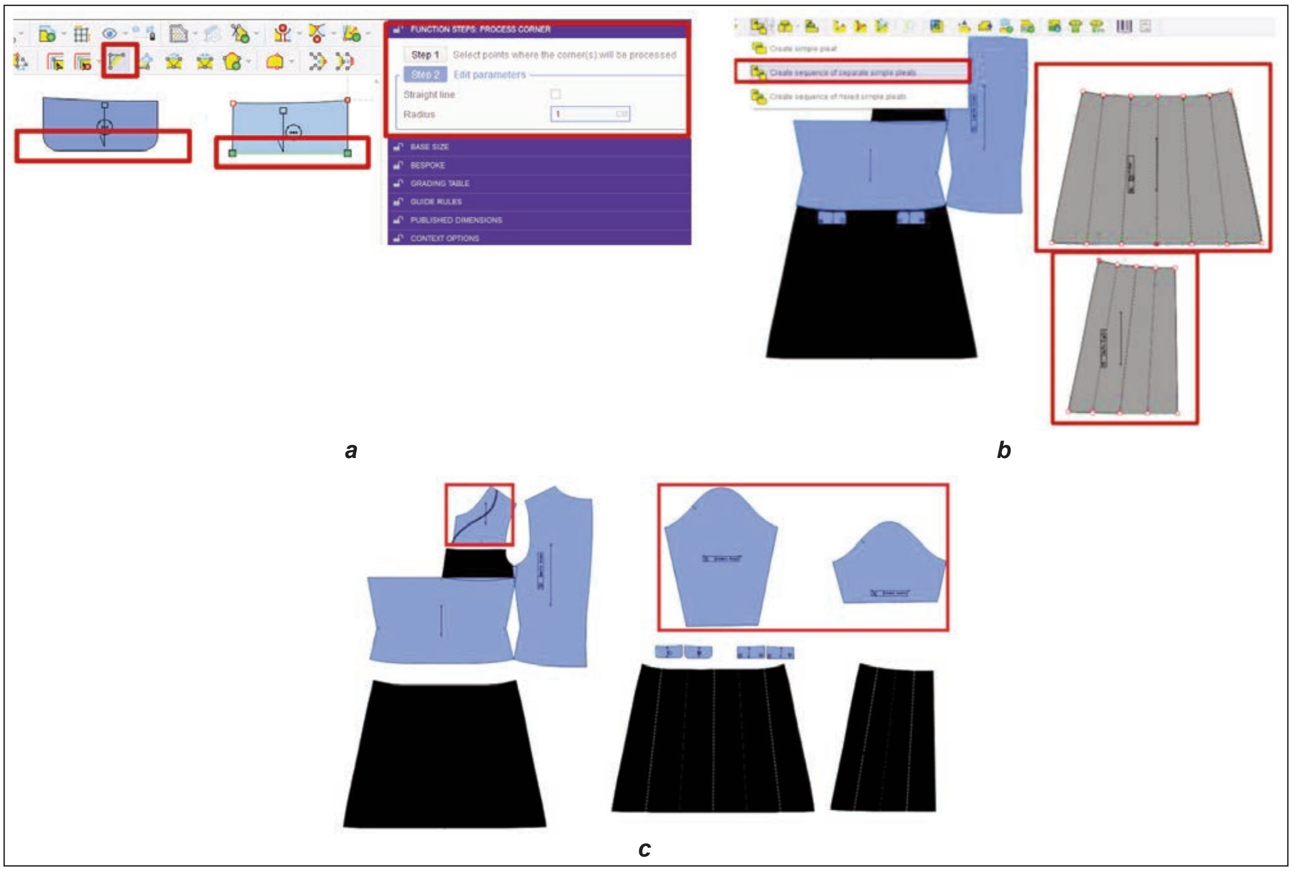

Fig. 9. Create new styles (Fashion Studio): *a – Shape mode* → change the corner shape of the flaps; *b – Industrialization mode* → create a sequence of separate simple peats (skirt); *c – Pattern design* → design the sleeve patterns and *Industrialization mode* → adding decorative seams

Samples and product photos are necessary for brands and manufacturers to start marketing and selling in their physical or online shops. Brands that manufacture their products digitally will undoubtedly use digital materials. Digital textiles can easily be fed into a render pipeline to achieve consistent quality. Due to their scalability, 3D renders can replace actual photo shoots, saving significant time, resources and costs.

4. Create new styles

The designer can change the stylistic features of the model. They can choose to alter the geometry of some parts (*Shape mode*) or their surface (*Industrialization mode*) (figure 9).

Starting from the reference model, the designer can draft the sleeve pattern (long or short) or add decorative seams (e.g. on the upper front part).

5. Publishing models for online purchasing

Nowadays, consumers play the role of active trend makers rather than passive observers of culture. They are aware that fashion items are more than status symbols and objects that represent the ideals of the person who owns them, and they demand interaction and a product made to suit their preferences.

For online purchases, the designer creates a form (Creation form) regarding which the user can specify certain preferences, either by selection or based on possible questions and answers (the customer personalizes the selected model) (figure 10). All possible options and all answers to the questions are entered into the form. Along with them, the number of components corresponding to the selected option/the desired answer is inserted. The created models are published, so that they become available for online purchases (the models are displayed in the *Repository, Style Options* menu).

CONCLUSIONS

Digital technology is a tool whose purpose is to address the real challenges of the garment industry. It does not solve problems by itself but can influence the direction of a business. To carry out a digital transformation and make the necessary changes, a company must go through numerous transitional stages. The base of the organization, the technological components and, of course, the customer base can be expanded according to the needs of the company after developing a strong infrastructure.

It is important to lay the foundations for the 3D implementation of the design process and to train staff to create a digitally skilled workforce. Once the teams are created and their members acquire the necessary skills, a framework is created in which digital product development can be effectively carried out. At this point, the organization can start sharing digital resources that can then be used on the consumer front.

The employees of the organization must be proficient in using specific tools for creating digital products and must maintain a collaborative environment between the stakeholders (from design teams to vendors).

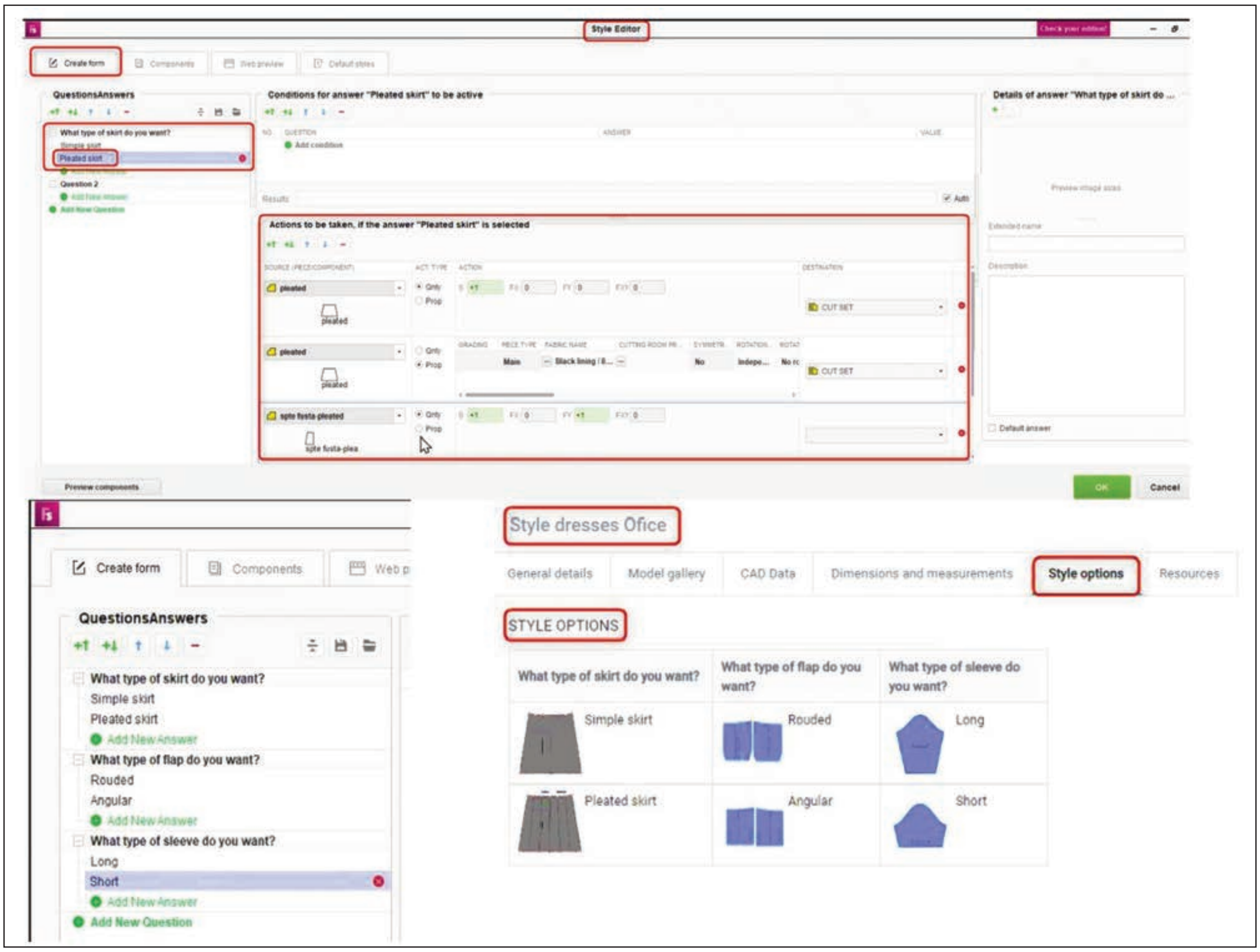

Fig. 10. Create a form for online purchases

Digital product creation must be focused on: prototyping (including the 3D virtual model), fitting (validating the size and the shape of the product about the shape of the customer's body, the details of the model, the interaction of the textile materials of the final product with the body), vendor cooperation (the vendors and manufacturers have to participate in the developing process of the product and understand the details of the 3D garment that they are going to receive) and sellability (digital tools provide a cost-saving estimation and prevent errors and waste).

The specific tools used for designing digital fabrics, accessories, or trimming allow the designer to explore multiple combinations of colour schemes or motifs to prepare seasonal collections. In this way, the organization can plan how to meet the customer's demands before the physical products are made. Besides this, these digital assets can be used to create interactive catalogues or photorealistic showrooms as an end-to-end digital workflow from the design stage to the customer.

Digital products which are published on virtual platforms become accessible for online purchasing. The customers can personalize the selected model or contribute to its creation process (creation forms), enjoy a marvellous shopping experience, and in the end, the customer and the manufacturer will develop a business relation (customer fidelization). On the other hand, digital catalogues ensure a virtual alternative to in-person meetings, reduce the costs of physical sample production, eliminate additional costs, and mitigate risks.

The secret to success lies in building a consistent, cross-channel and synchronized system that coordinates physical and digital processes to deliver an interactive, engaging customer experience from the design stage to its acquisition.

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Digital solutions for bespoke apparel achieving mass customization in as service business models

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ABSTRACT – REZUMAT

Digital solutions for bespoke apparel achieving mass customization in as service business models

The Information and Communications Technology sector may be organized into individual technologies or solutions. Theoretical literature review argues digitalization technologies make up enterprise architecture and shape business processes or business models. It also shows contemporary business models market solutions for a given value or impact, rather than sell individual technologies per se. Empirical data confirms enterprise architecture is the market for system integration. Market data shows the market leader is Software AG. The goal of this article is to build a theory with an emerging case example of more technologically and business model sophisticated solutions than the theoretical and market benchmark. The methodology is a dual case study on important market players, Siemens and PTC. The standalone cases allow for similar solutions which cannot be otherwise tested or validated. Reference is also paid to other market players within the article. The empirical data analysis is compared to acceptable benchmarks, theoretical literature review and the enterprise architecture market leader Software AG. Findings show emerging technologies add capability maturity levels to accepted system integration. Network business models with a quantifiable and provable customer value proposition: bespoke or personalized products, reasonable cost per item, and zero inventory achieve the vision of mass customization. The business models are enabled by the highest level of digitalization capability maturity, not considered in the status quo literature review and at the leading enterprise architect. They place the textile industry at the forefront of technological innovation and extended reality-based marketing.

Keywords: *bespoke products, enterprise architecture, platform business models, as a service business models*

Soluții digitale pentru îmbrăcăminte la comandă care realizează personalizarea în masă în modele de afaceri ca serviciu

Sectorul Tehnologiei Informației și Comunicațiilor poate fi organizat în tehnologii sau soluții individualizate. Din analiza literaturii teoretice rezultă că tehnologiile de digitalizare formează arhitectura întreprinderii și modelează procesele de afaceri sau modelele de afaceri. De asemenea, prezintă modele de afaceri contemporane despre comercializarea soluțiilor de piață pentru o anumită valoare sau impact, mai degrabă decât despre vânzarea tehnologiilor individuale în sine. Datele empirice confirmă că arhitectura întreprinderii este piața pentru integrarea sistemică. Datele de piață arată că liderul de piață este Software AG. Scopul acestui articol este de a construi o teorie cu un exemplu de caz emergent de soluții mai sofisticate din punct de vedere al tehnologiei și modelelor de afaceri decât standardul teoretic și cel al pieței. Metodologia este un studiu de caz dublu pe jucători importanți de pe piață, Siemens și PTC. Cazurile independente permit soluții similare care nu pot fi testate sau validate altfel. În articol se face referire și la alți jucători de pe piață. Analiza datelor empirice este comparată cu benchmark-uri acceptabile, revizuirea literaturii teoretice și liderul de piață al arhitecturii de întreprindere Software AG. Constatările arată că tehnologiile emergente adaugă niveluri de maturitate a capabilității de integrare sistemică acceptată. Modelele de afaceri sunt în rețea, cu propunerea valorii cuantificabilă și demonstrabilă pentru clienți: produse la comandă sau personalizate, cost rezonabil pe articol, inventar zero. Astfel se realizează viziunea personalizării în masă. Modelele de afaceri sunt activate de cel mai înalt nivel de maturitate a capacității de digitalizare, care nu este încă inclus în recenzia literaturii teoretice general acceptate și nici în oferta de referință a leaderului pieței arhitecturii informaționale. Ei plasează industria textilă în fruntea inovației tehnologice și a marketingului bazat pe tehnologiile numite realitate extinsă.

Cuvinte-cheie: *produse la comandă, arhitectura întreprinderii, modele de afaceri tip platformă, modele de afaceri ca serviciu*

INTRODUCTION

Digitalization and digital transformation may be defined as the impact of a mix of technologies on businesses, industries, and society. Capability maturity indices are used to conceptualize digital transformation and the technologies, and other resources grouped in capability maturity levels which describe solution architecture. Literature review shows capability maturity indices are tied to the levels of value which they create, capture and deliver. Advanced digital business models involve marketing solutions rather than selling products; the value created, captured and delivered by solutions is computed during the marketing process. Stipulated in customer contracts and guaranteed to the customer. Integrated solutions with defined input, output, outcome and impact may be defined via as a service business model. The following article tackles several new technologies, extended reality ER and generative artificial intelligence networks GANs, which advance the scholarly and market reference of leading system integration and enterprise architecture. Within enterprise architecture, platform business models achieve mass customization and the customer value proposition of personalized products mass-produced at standard cost. Late in 2021, Facebook and Microsoft [1–3] launched the Metaverse, where virtual reality VR and augmented reality AR will be used for leisure, learning, work, and omnichannel commerce, beginning with the fashion industry. Market analysts like IDC [2, 3] argue that extended reality ER, that is VR, AR or mixed reality MR are the latest trend in omnichannel commerce and favours highly personalized products as new use cases. The textile industry has already noted the implementation of Information and Communication Technologies ICT [4]. These technologies include those who analyse the pattern of the human body measurements enabling clothing design [5, 6]. These body measurements are used for customized apparel [7]. Bespoke apparel has long been an objective in the textile industry, and in 2022 technologies have been integrated into designated solutions by major ICT vendors. The vendors create the solution and customer value proposition. The goal of this article is to create a complex causal loop diagram of the solution and enterprise architecture that creates bespoke products and advances the literature for digital solutions with a theory-building case study. The methodology is an explanatory, systems-based, theory-building and instrumental case study. It uses a complex causal loop diagram which is the conclusion of empirical data and is presented upfront in figure 1.

The dependent variable is the customer value proposition created, captured and delivered: bespoke (or personalized or individualized) apparel available in mass at standard cost. The independent variables are all the elements of enterprise architecture as they are integrated into the elements of the business model canvas.

Findings show several benefits. Empirical data advances the leading proposal for enterprise architecture with technologies that enrich all processes (research and development, customer relationship management, supply chain management). This gives the article its theory-building value. Empirical data illustrates the functionality of the as a service business models used to architect these integrated solutions and thereby brings fresh examples to recent theories. Solutions which include ER provide the first products for the Metaverse, launched in 2021. These are argued here as having significant benefits compared to other products; the value created, captured

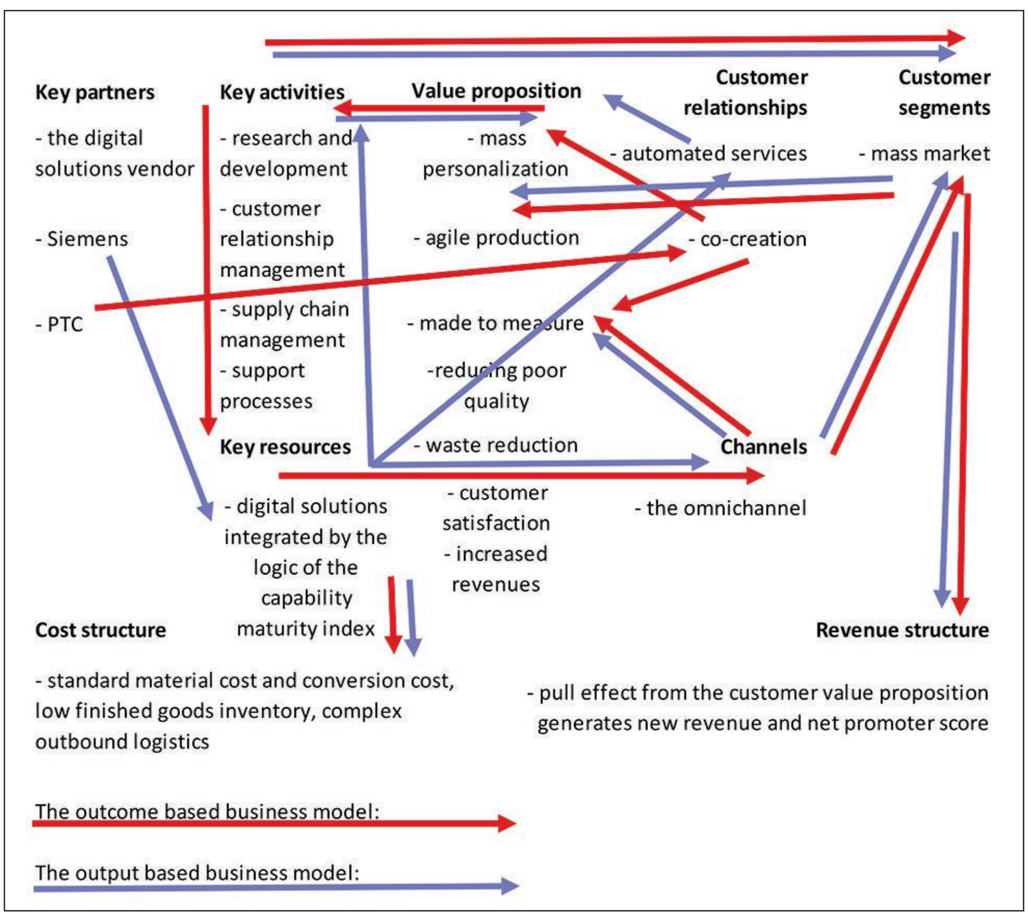

Fig. 1. Complex causal loop diagram based on the elements of the business model canvas

and delivered for customers should motivate buying and loyalty. There are strong limits to the approach: the case study needs extensive references, yet cannot demonstrate the validity of the assertions about technology, which belong to vendors. To mitigate this shortcoming, four case studies have been used in parallel and compared to the others. Findings from all four sources show personalized products are recently emerging solutions that integrate technologies, which technologies are consistent at all vendors and include ER as a marketing interface. Furthermore, the case study is extensive, uniting several topics that normally belong in individual articles with clear demonstrations.

LITERATURE REVIEW

The digital transformation journey is typically represented by a maturity index, a management tool that represents future digital transformation scenarios alongside capability maturity stages in a progressive manner. Each stage summarizes the organizational dimensions of digital transformation capability and provides a scale-based assessment of the level that they have reached to date. Digital maturity indices are used as an assessment and control tool to manage the digital transformation process. Acatech, the Industry 4.0 working group, provides the most important maturity index [8, 9]. In it, the *stages* of digital transformation capability maturity include computerization, connectivity, visibility, transparency, predictive capability, and adaptability. The *dimensions* of digital transformation capability maturity include resources, information systems, organizational structure, and culture. The digital transformation capability maturity index begins with rigid value chains supported by automation-hierarchy business information systems and progresses to flexible value networks supported by distributed digital networks [9–11]. Horizontal integration across the entire value creation network describes "…the cross-company and company-internal intelligent cross-linking and digitalization of value creation modules throughout the value chain of a product life cycle and between value chains of adjoining product life cycles…" [9]. The new vision interlinks smart factories with smart supply chains, which are integrated and driven by customer order [12–15]. In the most common vision, mass customization, the customer order is individualized in the batch size of one. As the customer places the order on the Internet, all supply chain activities are scheduled to meet this demand. The cost of producing individual units matches the standard cost. Manufacturing is conceived to be agile. By 2020, Industry 4.0 technologies are progressively united into solutions that match specified value drivers by the Industry 4.0 capability maturity index (figure 2) [8]. The index means that mature technologies can only be used in combination with less mature technologies. It also involves specified value drivers matching each capability maturity level, where agility is the main key performance indicator. The new business models are to have great customer pull, while maintaining reasonable cost, for example, standard cost, and scalable quantities which can be mass.

The first stage of digital maturity is computerization, that is, connecting Product Lifecycle Management PLM software and adjacent modules to Enterprise Resource Planning ERP functions, such as Customer Relationship Management CRM and Supply Chain Management SCM. Together, they form the business information system infrastructure, shape business activities and business processes, and form operating models [10, 11].

In the second stage of the digital transformation of capabilities, these business systems are placed in the cloud [5, 6, 15, 16]. The next three stages involve [3] sensors that send information to the cloud, generating big data [1] that analytics technology can mine for patterns [5, 6, 16, 17]. These are descriptive, diagnostic and predictive analytics. One definition of the

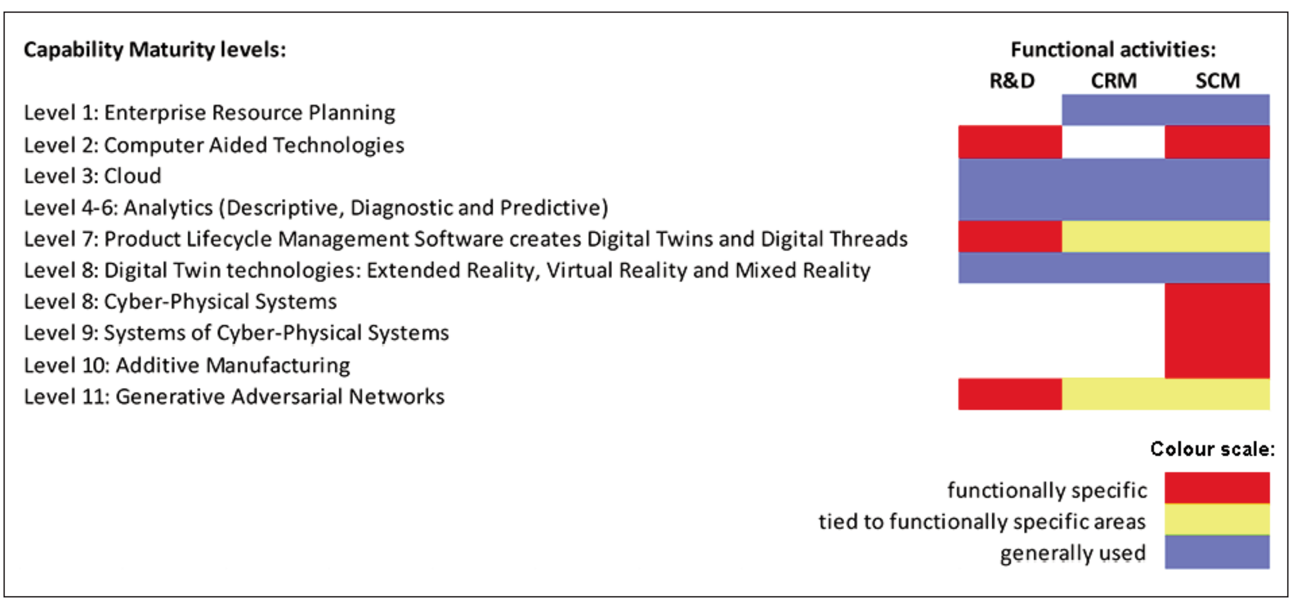

Fig. 2. Technologies and business processes in the Industry 4.0 capability maturity index

digital twin is essentially a software model that uses sensor data to mirror a machine or series of processes within a business to provide a deeper understanding and reveal which changes will lead to better performance [5, 6, 16, 17]. These technologies upgrade the enterprise resource planning ERP-based architecture [17–19].

The first process to be digitalized is PLM software, based on the preceding stages of digital transformation capability maturity. In 2003, Daum [11] defined PLM as activities including market research, collecting customer feedback, technological research, prototyping, initial customer tests, business planning, go or no-go decisions, development/implementation, market and business development, beta testing, pilot testing, and release. The digital twin, a concept introduced by Grieves in 2003, directly relates to PLM software because the digital twin is an indistinguishable virtual copy of a physical product [18], and PLM software is defined as the virtualization of the physical world as a combination of physical products in real space, virtual products in cyberspace, and data and information that tie the virtual and real products together. Uniting several digital twins generates the digital thread, and the digital twin and digital thread are subject to the ISO/TC 184 standard [20, 21]. PLM software comprises two main types of programs: product design (producing the bill of materials) and production planning (producing the routing or bill of the process) [22]. Innovative PLM systems now fully enable the transmission of the digital twin of product design and production manufacturing, in a digital thread, to the manufacturing execution stage [18–21]. PLM systems transmit product design (i.e., material content) and production planning (i.e., machine minutes and labour minutes) to operations [19, 20], thus creating the digital thread [18–21]. In 2022, PLM is implemented on cloud platforms, and the information in the digital twin may be shared within the enterprise and with suppliers, open innovation partners, retailers, and customers [22].

In the next stage, manufacturing execution and SCM are digitally transformed. For these functions, artificial intelligence AI and autonomy are needed to reach the level of full cyber-physical systems CPSs [22–25], which can make autonomous, highly complex decisions for themselves and the chain of systems they are embedded in [23–26]. In the smart factory, CPSs collaboratively decide the manufacturing schedule. If the entire supply chain is based on CPSs, the internet-based customer order will determine the full supply chain scheduling. Previous research has addressed the relevance of digital twin-based EA for CPSs [27–36]. Digital transformation moves the automation hierarchy to the digitalized distributed network [7, 8, 21, 24, 25, 36, 37]. It enables new products, such as smart connected products [38]. In other words, rigid value chains are replaced with flexible value networks [39], which may become the next critical competitive advantage in the global fashion industry. Scholarly research has identified several Internet of Things architecture models, including Reference Architecture Model Industry 4.0, Industrial Internet Consortium Open Architecture, IIC Security Framework, and OpenFog Reference Architecture [40]. In 2019, Pasqual et al. [40] developed a digital twin-based EA that creates platform business models.

Going beyond the Industry 4.0 capability maturity model, a complementary technological innovation is additive manufacturing AM, in which the manufacturing process is designed as a distributed network rather than an automation pyramid. Digital twin-based EA facilitates AM applications [40–44], so a need has emerged to accelerate further efforts to develop and standardize a digital thread for AM [45]. Following the framework of the IIC, systematic efforts should be made to identify, assemble, test, and promote best practices to hasten the development of an AM digital thread. Research and support from industry, government, and academic partners worldwide can contribute to the development of prototypes and ensure the digital collation, processing, and storage of information, leading to informed, effective decision-making. Rather than be operated by traditional computer-aided manufacturing, AM is now managed by CPSs.

Other technologies have recently emerged that shape the customer experience. In line with [13], CRM aligns lead generation, customer engagement, closing, after-sales service, and ongoing customer service. In the age of pull business models, the customer experience is enriched by other technologies that rely on digital twins and AI. Digital twin technology supports AR, in which digital information, such as 3D CAD models or data captured by sensors or calculated by IT systems, is placed in the context of a real-world environment [8]. This is where digital twin technologies become more sophisticated and encompass ER, AR, VR and MR.

Furthermore, generative AI is used to support collaborative co-creation [46, 47]. In 2014, Goodfellow et al. [47, 48] proposed a generative model called the generative adversarial network (GAN), comprising a generator and a discriminator. The generator is responsible for producing samples and the discriminator for determining the authenticity of samples. Because the goal of each side is to defeat the other, the model that optimizes itself is continuously modified, and, after the final training, the generator can produce a nearly real sample through any input. The goal of a generative model is to study a collection of training examples and discover the probability distribution that generated them, and GANs [47] are an AI algorithm designed to solve the generative modelling problem. They are subsequently able to generate more examples from the estimated probability distribution. Generative models based on deep learning are common, but GANs are among the more successful generative models (especially in terms of their ability to generate realistic high-resolution images). GANs [46–50] provide a way to discover deep representations without extensively annotated training data. To achieve this, backpropagation signals are derived through a competitive process involving a pair of networks [51]. The goal of GANs is to estimate the potential distribution of real data samples and generate new samples from that distribution. GANs [51, 52] have been widely studied due to their enormous potential for applications. These applications include the fashion industry, typically in creating new apparel [52–54].

As the capability maturity index shows, digital technologies are hosted as software as a service on cloud platforms as a service. Theoretical literature review shows that, in business-to-business markets, business models move from selling products to providing services. Business models may mean selling individual products. As a service business models, however, involve tailoring integrated solutions to customers' needs. As a service business models additionally specify the key performance indicators created, captured and delivered by the solutions [55–58]. These performance indicators range from availability to return on capital employed [55–58]. In as a service business model, the customer value created and delivered by the solution is calculated by the vendor, stipulated in customer contracts and guaranteed to be achieved at the customer business by the vendor. Typically, computations treat the purchase cost and investment and compute the return on the investment given by key performance indicators above a hurdle rate. Thereby, commercial agreements interact with the realm of management accounting [59]. The new, as a service business models involve all these elements: integrated solutions and the business value they create, capture and deliver. From a technological perspective, this moves from individual technologies to system integration. From a business perspective, this involves close cooperation between the vendor and the buyer.

EMPIRICAL DATA ANALYSIS

Methodology

The standard methodology looks at a dependent variable and a simple formula of one or several independent variables in several stances. The article parts from a theoretical literature review, where several concepts are treated in individual articles with logical connections that may be inferred but missing in scholarly literature. Business practices however show a holistic approach that requires a new methodology to be researched to be consistent with the most recent trends in the ICT sector: as a service business model, meaning integrated solutions and customer value proposition. The methodology of this article looks at complex relationships between many independent variables outside formulae. This is motivated by the complexity of as a service business models, which part from selling individual products to integrating solutions and the customer value proposition they create, capture and deliver. The methodology will have to weigh in complexity, in the form of the number of variables and logical relationships induced. In this systems approach, mass-produced bespoke products at low cost are the customer value proposition and the dependent variable. The independent variables explain the dependent variable and refer to technologies converging into solutions and business activities that shape business processes and other elements of the business model canvas. The numerous independent variables require a systems approach, an actualization of the Peter Senge systems approach to business and complex business loops. A causal loop diagram may be created to represent the causal relationships between the various elements of the system, as in figure 1. The causal loop diagram has two stances, the output-based business model (shown in blue) and the outcome-based business model (shown in yellow). Two main vendors are considered in their solutions for bespoke products: Siemens and PTC. These technologies are studied at two ICT vendors: Siemens and PTC. They are compared between themselves, highlighting the similarities and differences. The case study refers to the market-leading enterprise architecture at Software AG [60], the systems integration of Industry 4.0 technologies into business processes and business models. The solutions for bespoke products are compared to this. Furthermore, PTC and Siemens are compared to IDC (market analyst) and Oracle (ICT vendor). The data in the multiple case study is available on the Internet. It comes from a wide variety of sources that have been searched systematically by keywords and match the technologies in the solution, their names, maturity indices, bespoke products, and personalized products. Vendors provide clear statements about the technologies integrated into these business solutions, which are referenced to as an argument. The variables considered in the empirical data analysis cover all the elements of the business model canvas, as in figure 1. They form interdependent systems. At Siemens, technologies shape activities and customer value propositions in output-based as a service business models. This means the solution is pre-architected for business customers and the business model solutions will create, capture and deliver business value to be stipulated in contracts. At PTC, the outcome-based business model is used, meaning customer value requirements and demands initiate the vendor's design of the integrated solutions which are to create, capture and deliver the desired value. This forms two logical connections between the dependent and the independent variables. These connections may be reciprocal when the choice of business value drives the co-creation of the solution architecture to meet these customer demands. Both business models integrate all elements of the business model canvas. A large number of variables and the complex, changing relationships amongst them however pose serious limitations to evidencing this research fully, although arguments do exist.

Integrated business process management solutions for bespoke apparel

Capability maturity indices and the capability maturity levels in solution architecture

Newly emerging technologies enable end-to-end solutions for bespoke products, which means predefined product design that is adapted to the volumetric requirements of each customer, which are size or measurement. Market analyst IDC rates personalized products as a newly emerging use case with a notable future in omnichannel commerce or digital marketing [2, 3, 61, 62]. Both Siemens and PTC use digital maturity indices to show the progressive integration of technologies into solutions [63–66]. The index means technologies are integrated progressively into solutions, where each progressive step requires the completion of its predecessors. The indices are highly similar [63–66]: the first level of digital maturity is given by the cloud; the second level of digital maturity is given by analytics; the third level of digital maturity is given by digital twins, AR, VR, MR and the digital thread they create; artificial intelligence advances and reaches CPSs; finally AM and blockchain add on. PTC [65] offers a collaboration between PTC, Blacksmith International and Henderson Sewing Machine to create the Intelligent Apparel Manufacturing Platform. Both Siemens and PTC refer to their solutions for bespoke products or intelligent apparel as integrated solutions comprising several convergent technologies. This shifts the focus on solutions and their system integration rather than stand-alone products and technologies. The solutions are cumulated in the progressive order of the capability maturity index (figure 3).

Service business models and the role of solutions and key performance indicators therein

The as a service business model begins with identifying the key value drivers or key performance indicators that shape the integrated solutions. Both Siemens and PTC proceed this way. Siemens advertises a new end-to-end solution for mass-manufactured bespoke products at low cost [67–70]. At PTC, the solution is marketed with clear quantified benefits [71]: mass personalization; agile production; made-to-measure; reducing poor quality; waste reduction; customer satisfaction; increased revenues. The benefits are intended to create a customer pull that attracts and retains a high number of customers while

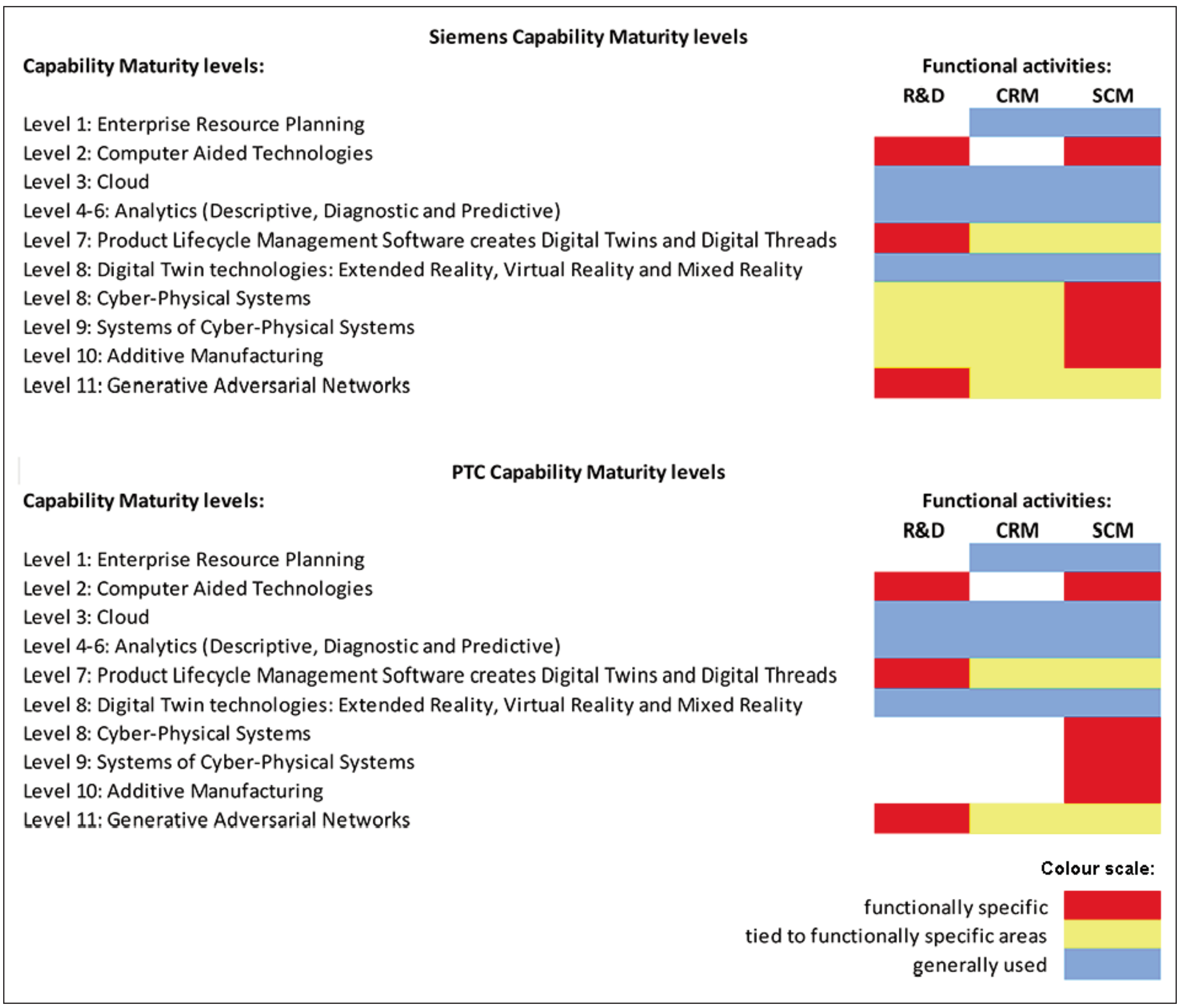

Fig. 3. Technologies and business processes in the Siemens and PTC capability maturity index

maintaining efficiency and assuring agile production. Customer pull indicators are mass personalization; made to measure; customer satisfaction; increased revenues. Mass personalization means: "younger consumers, especially millennials, want personalized products rather than mass-marketed products that don't reflect their individuality". Made to measure involves: "What comes to mind when you think of making a garment specific to an individual? Most people think of a seamstress or tailor, but today, an apparel company can do just that. Because of the Internet of Things, store managers, designers, and developers communicate in real-time, so orders with measurements specific to one consumer can be made and delivered without interrupting the entire supply chain". Customer satisfaction may be understood as: "When an apparel company can provide quality products at a good price while offering immediate delivery, customer satisfaction increases. Not only will they be satisfied, but they are much more likely to remain your customer for life". Increased revenues are driven by: "providing the right garments to the right consumers, you will increase customer loyalty, retail contracts, and market share". Efficiency indicators are: reducing poor quality and reducing waste. Reducing poor quality signifies: "The cost of poor-quality falls between 5 and 30% of total revenue. With Industry 4.0, poor-quality garments can be a thing of the past. Smart Factories will now have access to real-time quality data, and information sharing that tracks processes, machines, and people. Because of this, apparel companies can increase the speed of improvement and decrease the cost of quality". Reducing waste entails: "Prior to Industry 4.0, the fashion industry process that started with a fashion show in Paris and ended on a production line could take two years or more. When finally produced, many of these clothing trends do not sell well, leading to thousands of pounds of waste. According to the Fashion Industry Waste Statistics, the clothing industry is the largest world polluter next to oil. With real-time feedback, companies can now change their garments to meet consumer needs with little waste". Besides customer intimacy and operational efficiency, the integrated solution will guarantee agile production. Agile production is defined as: "Industry 4.0 lets apparel companies visualize the apparel process from design to production and automated processes allow multiple product lines. This means that an apparel company can still produce a mass-marketed permanent collection while offering smaller capsule and limited edition collections without sacrificing quality". Both Siemens and PTC create a blend that delivers personalization at low cost and in mass capacity. Both corporations advertise and guarantee these benefits to customers in the event their solutions are purchased. Both have global service units to assist customers in computing return on their investment (purchases). At Siemens Financial Services, 2800 tackles the issue of customer return on investment amongst others [72]. At PTC, 1400 employees address the same issue and help compute the customer return on investment [73]. This is done via key value drivers or key performance indicators that shape the investment. Solutions are architected with the goal of creating, capturing and delivering business value. At Siemens, the pre-architected solutions create customer value in the form of key performance indicators. At PTC, outcome requirements drive the co-created solution architecture for the textile customer.

The digital technology solutions at Siemens, PTC, Oracle, Accenture, and Software AG, the business processes they underpin and their relation to value stipulations in as a service contracts

The first business activities in the business model are research and development and involve PLM and GANs. This stage is not included in the reference enterprise architecture at Software AG [59], but both Siemens and PTC offer extensive solutions for it. It is also included in the solutions for highly personalized products at IDC [2, 3, 61, 62]. These solutions are placed in the Cloud and encompass PLM for product design and production planning and GAN to adapt this product design to requirements and constraints. At Siemens, the implicated PLM systems are Simcenter, NX and Teamcenter [74–76]. Siemens' innovation strategy is the digital thread [64], which integrates digital twins across the product lifecycle and extended enterprise. In 2015, Siemens' smart innovation strategy aims to create products that vary (such as in their size parameters) in response to customer input. A digital collaboration platform is used for AM [77], whose functions are based on the digital twins of product, production, and performance [77]. AM can print any given product design, but adapting the product design to customer volumetric requirements is achieved via GANs [78, 79]. In the future, Siemens intends to use these technologies for completely new forms of customer experience with autonomous functions in which generative design is combined with AI in Simultenigence [80, 81]. PTC has a similar research and development solution, where PLM is placed in the cloud and combined with GANs. These stages are achieved by the Internet of Things platform Thingworks and the PLM software solution Flex PLM together. At PTC, the standard PLM solution for all markets is Windchill [82–84]. Flex PLM is a designated PLM Software for the retail, footwear and apparel industry [83]. PTC argues the retail, footwear, and apparel product development process is fundamentally different from that of discrete manufacturing, which has driven the development of traditional PLM [83]. PLM is complemented by GAN PTC Creo [85–90]. PTC [89] offers a generic design for a set of alternatives which engineers can refine and explore to produce the best design that fits requirements. These requirements may be volumetric requirements. In their turn, in the textile industry, these are the customer measurements that the textiles need to compare to, typically the size. Furthermore, PTC Creo is a generative design solution that allows users to input their requirements and constraints for the product to be designed and then manufactured via AM [91].

Operational activities comprise CRM and SCM processes and successful research and development. IDC [2, 3, 61, 62] markets use cases about digital marketing that is based on ER. The future of digital marketing and omnichannel commerce also includes personalized products [61, 62, 72, 73]. At Software AG [60] reference enterprise architecture, CRM processes are called “market to cash” and comprise digital twins and augmented sales bots. The end-to-end solution overarches all technologies and shapes all business activities needed to market bespoke products, for example, the helmet [70]. The digital twin in CRM activities is preceded by technologies which shape it according to customer requirements. At Siemens [67], CRM activities involve, in this order: generating the digital twin or scan of the customer’s head, via mobile phone, augmented reality, a mobile phone application, a 30,000 point cloud of the customer’s head; ordering the product online, via the company website; matching the design of the product to the volumetric requirements of the customer’s head to obtain a customized helmet. The bespoke helmet is a pioneer product enabled by Siemens for its customers, who will be the producers of the helmet. Other bespoke products also emerge from bespoke spectacles, and bespoke shoes [67–70]. At PTC, Vuforia is the solution for AR [92–99]. This may involve several interface technologies: Vuforia Instruct via tablets, Vuforia Expert Capture via special glasses, Vuforia Studio also via special glasses, Vuforia Engine via mobile phone, Vuforia Chalk via a tablet, and Vuforia Spatial Toolbox. AR may be used for manufacturing solutions, service solutions, and sales and marketing solutions. In sales and marketing solutions, Vuforia Ventana is ascertained to transform the marketing function. AR is “an interactive experience that combines computer-generated perceptual overlays on real-world physical objects or environments with digitally presented information”. The solution is intended for build-to-order and configurable products, whose design is decided by the customer. Via the Visual Line Collaboration App, users can access all product-relevant data from one source, including data in ERP and e-commerce systems [100]. A similar ER Cloud comes from Oracle as a new form of marketing or CRM. This will allow people to collaborate in gaming, design, marketing, and commerce [101–103]. The architecture of Oracle Cloud comprises several layers: visual browser, Internet of Things, sensors, beacons, edge computing, AR cloud (point cloud, data storage, web services), the aesthetic layer (computer vision, image and remote sensing, cameras, facial recognition), the functional layer (visualization, mapping and analysis, localization), and the intelligence layer (artificial intelligence, object detection, spatial pattern detection, predictive modelling, clustering).

SCM management involves manufacturing and supplying the customer order, which comes in the form of the digital twin. In the reference enterprise architecture at Software AG [60], SCM involves processes demand to operate (CPSs, logistics cobots) and source to pay (3D printing, digital rights). At IDC [2, 3, 61, 62], personalized products may be 3D printed or managed via ERP. At Siemens, the digital twin is 3D printed exactly as per the customer order in several manufacturing stages; then it is shipped to the customer [67]. Siemens claims the manufacturing activities may be scaled from 1000 units to 70,000 units without difficulty. The product will be of measurable high quality and low cost. At the Intelligent Apparel Manufacturing Platform [103–105], a collaboration between PTC, Blacksmith International and Henderson Sewing Machine, PTC complements its Internet of Things platform Thingworks, Product Lifecycle Management software solution Flex PLM with automated sewing machines that are upgraded to Industry 4.0. Blacksmith International brings manufacturing level Industry 4.0. A smart factory uses Industry 4.0 technology, such as robotics, AI, the Internet of Things, and analytics. The pattern of the product will be 3D printed. Conventional textile manufacturing methods will be used to cut and sew textiles giving any design and any fabric. At Oracle, the ER cloud is intended to be used together with 3D printing machines in a joint venture with Xerox [101, 102]. This aims to make new types of products possible. Siemens notes that the combination of technologies enables new products and new production processes [106]. In traditional manufacturing, activities are sequenced as stages of engineering, manufacturing, and storage. With the AM network, the process steps change to engineering, distribution, manufacturing, and tracking [100, 101, 107–111]. The AM network connects part buyers via the cloud with part suppliers, machine vendors, materials vendors, software vendors, and engineering consultants [100, 107, 111]. The process steps [80, 81, 86, 87, 100, 108–111] include requirements, generative design, adaption, performance validation, manufacturing validation, pre-processing, 3D printing, part finishing, and quality control. These processes create an AM network, which may involve customer co-creation. Thus, Siemens creates AM digital transformation centres. This pioneering solution is intended to be followed by many in the future.

AT Siemens and PTC, GANs are used to adapt predefined apparel design to customer volumetric requirements. Accenture [112] offers a more sophisticated marketing interface for the apparel industry, where customers combine existing product designs into new product designs. This gives new dimensions to co-creation. Accenture technology is not known to be integrated into a full solution.

On the PTC website, there are four approaches to exploring customer offerings: selling products, technologies, pre-architected solutions or architecting solutions based on key performance indicators [113]. PTC Creo is used together with other technologies for a special type of textiles, and space suits [114]. Other technologies in textiles target the digital transformation of traditional fibres into integrated technol-

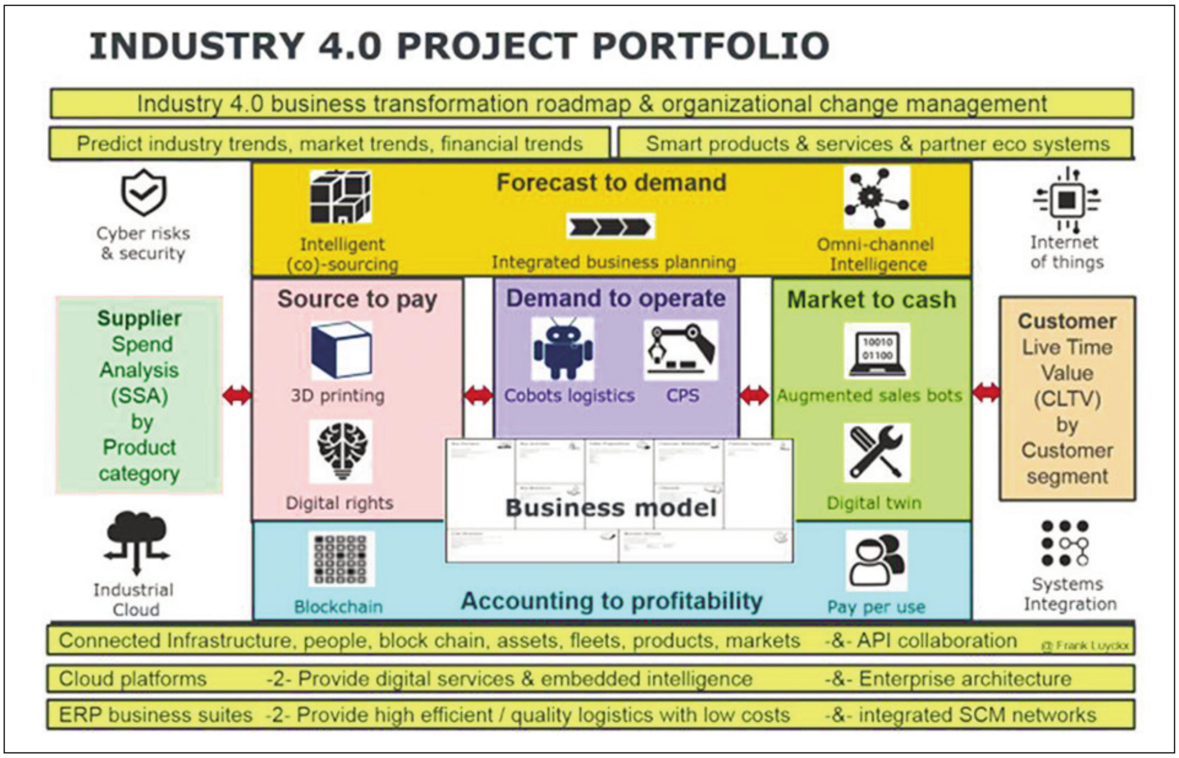

Fig. 4. Enterprise architecture according to the market leader [60]

ogy systems for consumer and military use [115]. The solution involves other, unconventional technologies: the integration of semiconductors, smart yarns and other networked devices or systems. The value drivers are innovations in energy storage and conversion; temperature regulation; health monitoring; colour-changing garments (figure 4).

Enterprise architecture at Software AG [60] involves digital technologies that are placed in the cloud and integrated into new business processes triggered by the customer order in the entire supply chain: market to cash, demand to operate, and source to pay. Market to cash is catered by digital twins and augmented sales bots. Demand to operate is managed by cyber-physical systems and logistics cobots. Source-to-pay processes are conducted by 3D printers and digital rights. Support processes involve finance and strategy and oversee operational customer relationship management and supply chain management.

CONCLUSIONS

This article is extensive and addresses a plethora of topics. Scientific literature review writes about capability maturity models and the progressive integration of the capability maturity levels therein. The levels of the capability maturity index show the progressive integration of technologies and the business processes they underpin into solutions. When this integration is complete, the concept of enterprise architecture describes the overview. Distinct literature review refers to as a service business models, where the object of the trade agreement is not an individual product, but a bundle of products and services integrated into solutions. Articles are focused on individual topics and the ties in between are scarcely explored. However, empirical data shows that as a service business models and enterprise architecture may be closely connected. The article methodology is an explanatory systemic case study. It tackles two as a service business models, where bespoke products are the customer value proposition: the output business model, where solutions are pre-architected along with their output, and the outcome business model, where solutions are co-created based on outcome agreements. Empirical data analysis reveals and illustrates the pattern in figure 2. There are complex causal loops between the elements of the business model canvas, as in the causal loop diagram. Customers may choose from existing solutions or co-create solutions based on value requirements; value is important as it provides the business rationale for customers to purchase/invest in these solutions. By comparing the solution architecture to the literature review, it shows the elements of the Industry 4.0 capability maturity model are used and the same goes for the additional technologies added on top as recently emerging. These solutions may span all business processes, shape all elements of business models (including the customer value proposition) and be integrated into a novel enterprise architecture concept.

The levels of sophistication of these solutions differ at Siemens, PTC, Oracle or Accenture. However, the comparison of the literature review and the market leader in enterprise architecture reveals the reference level of enterprise architecture used and elaborated. The similarities between the four empirical cases, literature review and market leader enterprise architecture show the most advanced technologies are systems integrated realistically and credibly. The add-on of ER and GAN technologies by the two highlighted solution providers shows the solution for bespoke products is more technologically advanced than the market leader and enabled by new commercial realities such as the Metaverse. ER marketing interface makes it possible for customers to get a 3D look at the apparel as it suits their size. At IDC, they may try it virtually. Unlike the staple enterprise architecture, these recently emerging technologies make bespoke products possible online. The research will impact customers who use these solutions or competing solutions. There are strong limitations to this approach in the sense of using the space and scope of an article; demonstrating vendor assertions. New research opportunities may be created by new products, services and solutions for ER interfaces, such as the Metaverse; of them, bespoke products for couture or haute couture stances may be included; integrated solutions have synergetic capabilities that may differ strongly from stand-alone technologies and, as such, deserve further research.

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Protective clothing system for interventions in emergency situations

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ABSTRACT – REZUMAT

Protective clothing system for interventions in emergency situations

Emergency workers are exposed to many different risks at the same time and possible consequences for their safety and health may be manifold. Many emergency workers suffer from accidents and injuries in the course of their jobs, as well as other negative health effects that lead to severe deterioration of their physical and psychological well-being. The use of specific personal protective equipment (PPE) according to the given risks is of great importance in preventing adverse health effects among emergency workers. This research aimed to develop, for emergency workers, a PPE system, in a modular structure consisting of: i) modular layer 1: the inner layer, in contact with the skin/Underwear PPE, with the function of sensorial and thermophysiological comfort and which ensures thermal protection; ii) modular layer 2: the intermediate (basic) layer/Duty uniform – with the function of limited protection to the specific risk factors of an unpredictable intervention action (thermal risks: convection heat, flame; risks from the external environment: liquid splashes; mechanical risks: cutting, abrasion, etc); iii) modular layer 3: the outer layer/specialized PPE, with a function of barrier against specific risk factors for fire intervention missions, extreme weather conditions etc. This modular approach provides some advantages, including preserving comfort and flexibility until the intervention mission requires the use of the next level of protection. This helps ensure that emergency responders are not in the position of choosing between their safety or mission effectiveness.

Keywords: *protection, duty-uniform, mission-specific layers, modular layers, emergency workers*

Sistem de îmbrăcăminte de protecție pentru intervenții în situații de urgență

Lucrătorii în situații de urgență sunt expuși la multe riscuri diferite în același timp și posibilele consecințe pentru securitatea și sănătatea lor pot fi multiple. Mulți lucrători în situații de urgență suferă accidente și vătămări în cursul muncii lor, precum și alte efecte negative asupra sănătății care duc la deteriorarea gravă a bunăstării lor fizice și psihologice. Utilizarea echipamentului individual de protecție specific (EIP) în funcție de riscurile date este de o mare importanță în prevenirea efectelor negative asupra sănătății în rândul lucrătorilor în situații de urgență. Scopul acestei cercetări a fost de a dezvolta, pentru lucrătorii de urgență, un sistem de EIP, într-o structură modulară compus din: i) strat modular 1: stratul interior, în contact cu pielea/EIP subvestimentar, cu funcția de confort senzorial și termo-fiziologic și care asigură protecție termică; ii) strat modular 2: stratul intermediar (de bază)/uniforma de serviciu – cu funcția de protecție limitată la factorii de risc specifici unei acțiuni de intervenție imprevizibile (riscuri termice: căldură prin convecție, flacără; riscuri din mediul extern: stropiri lichide; riscuri mecanice: tăiere, abraziune etc.); iii) stratul modular 3: stratul exterior/EIP specializat, cu funcție de barieră împotriva factorilor de risc specifici pentru misiunile de intervenție la foc, condiții meteorologice extreme etc. Această abordare modulară oferă câteva avantaje, inclusiv păstrarea confortului și flexibilității până când misiunea de intervenție necesită utilizarea următorului nivel de protecție. Acest lucru ajută la asigurarea faptului că lucrătorii de intervenție în caz de urgență nu sunt în situația de a alege între siguranța sau eficacitatea misiunii lor.

Cuvinte-cheie: *protecție, uniforme de serviciu, straturi specifice misiunii, straturi modulare, lucrători de urgență*

INTRODUCTION

Current environmental, economic, and political developments and trend data all suggest an increase in the severity and frequency of disasters in the future. Phenomena that support this assumption include increased energy use, progressive global warming, climate change and pollution, population growth, dispersal of industrialization around the globe, expansion of transportation facilities, and the growing spread of terrorism. Emergency workers' priorities are to protect human life, property and the environment, and their most common fields of action include everyday emergencies (road accidents, crime scenes, gas explosions, fires); natural disasters (floods, storms, fires, earthquakes, volcanic eruptions); industrial accidents (involving hazardous materials, such as in the nuclear and mining sectors); transport accidents (major car crashes, plane crashes, rail accidents); terrorist and criminal attacks (bomb attacks, gas attacks, shootings); massive public events (negative events during concerts, sports events, demonstrations) [1, 2]. The nature of the work of emergency responders puts them at the top of those professions who have to deal with a considerable number of occupational health and safety hazards which are often unavoidable. Frequently they do not face one single safety risk, but a complex combination of risk factors, including the unpredictability of the situations they are required to work in.

The purpose of protective clothing and equipment is to shield responders from injury while operating efficiently in hazardous environments and provide the highest level of protection against a range of possible threats. The specificity of intervention missions makes emergency workers face, during incidents, a multitude of known and unknown threats. That is why there are frequent situations in which they are not outfitted with the best and/or the most appropriate personal protective equipment (PPE) against the risks specific to the intervention action. Responders consistently expressed a desire for a modular system built upon a duty uniform that provides limited protection and physiological benefit in combination with a series of modular, mission-specific layers to provide specialized protection.

A systems or modular approach allows emergency responders to move beyond a “one size fits all” solution and allows for the customization of their PPE ensemble in varied response environments [3]. This helps ensure that responders are not in the position of choosing between their safety or mission effectiveness.

Today, advanced computer simulation techniques and virtual garments prototyping are indispensable for the development of garments and their fitting on the 3D body models within a virtual environment, as well as real-time virtual clothes try-on [4].

This paper discusses a personal protective clothing system for emergency responders built upon a duty uniform that provides limited protection and physiological benefits (for example, moisture wicking) in combination with a series of modular, mission-specific layers, to provide specialized protection.

DEVELOPMENT OF THE PROTECTIVE CLOTHING SYSTEM FOR INTERVENTIONS IN EMERGENCY SITUATIONS

The methodology used for designing and achieving the modular PPE system for interventions in emergencies is based on a multidisciplinary approach to developing and managing “complex systems”. Starting from the needs analysis, the key needs of the PPE system were identified, which were the basis for establishing the key performance parameters and the high-performance parameters. The established performance parameters were translated into design requirements, based on which the raw materials, realization technologies, and PPE system's conception (design) were identified.

The analysis of the needs/capabilities identified for the health and safety of the emergency responders, to prioritize, highlights the following key needs to be met by the PPE system, in the modular structure, for emergency response actions: User Comfort; Certification of protection properties by the legislation in the field of PPE; Durability for Daily Wear; Usability/Functionality; Aesthetics; Multi-service Applicability; User acceptability; Reasonable cost [5].

Starting from the analysis of the types of aggressions against which protection must be ensured: thermal risks (flame, heat, contact with incandescent materials, etc.); mechanical risks (abrasion, tearing, etc.), risks specific to working in cold conditions (low temperatures, air currents, temperature fluctuations, contact with cold surfaces, etc) the solution for accomplishing of the PPE system for intervention in emergency situations, adopted is a multi-layered structure consisting of:

- *modular layer 1*: the inner layer, in contact with the skin/ Underwear PPE, with the function of sensorial and thermophysiological comfort [6, 7] and which ensures thermal protection;
- *modular layer 2*: the intermediate (basic) layer/Duty uniform – with the function of limited protection to the specific risk factors of an unpredictable intervention action (thermal risks: convection heat, flame; risks from the external environment: liquid splashes; mechanical risks: cutting, abrasion, etc.);
- *modular layer 3*: the outer layer/specialized PPE, with a function of barrier against specific risk factors for fire intervention missions, extreme weather conditions etc.

To ensure the protective function, the clothing used for this purpose must be designed and manufactured in accordance with the essential health and safety requirements established in Annex II of Regulation (EU) 2016/425 of the European Parliament and of the Council of 9th of March 2016 regarding on personal protective equipment and repealing Council Directive 89/686/EEC.

Considering the essential health and safety requirements, specific to the risk of protection against heat and/or fire, have been established the minimum performance requirements that must be met by the materials used in the production of:

– the base layer (Duty uniform) of the PPE system for intervention in emergency situations, namely: limited flame spread coding letter A1: the mean value of after flame time ≤ 2 s, the mean value of afterglow time: ≤ 2 s; convective heat transfer index, 2 performance levels; radiant heat transfer index, 2 performance levels; dimensional changes ± 3%; tensile strength min. 450 N in both directions; tear strength, min. 25 N in both directions; seam strength, min. 225 N;

– the modular protective layer – specialized PPE for fire intervention missions, namely: thermal resistance after exposure to a temperature of 180°C for 5 minutes; limited flame spread coding letter A1: the mean value of after flame time ≤ 2 s, the mean value of afterglow time: ≤ 2 s; convective heat transfer index, 2 performance levels; radiant heat transfer index, 2 performance levels; dimensional changes ± 3%; tensile strength min. 450 N in both directions; tear strength, min. 25 N in both directions; seam strength, min. 225 N; resistance to penetration of liquid chemical substances, rejection rate, min. 80%.; resistance to water vapour, 2 levels of performance, resistance to water penetration, 2 levels of performance.

Considering the essential health and safety requirements specific to the risk of protection against the cold associated with the presence of bad weather with or without mechanical risks the minimum performance requirements that must be met by the materials used to manufacture the modular protective layer – Specialized PPE for intervention missions in extreme weather conditions, namely: the resulting effective thermal insulation Iclor, min. 0.310 m^2°K/W; air permeability, 3 performance classes, min 100 mm/s; resistance to water penetration, 2 performance classes, min 8000 Pa; water vapour resistance of the combination of layers, max. 55 m^2Pa/W; tear resistance of the outer material, min. 25 N; tensile strength, min. 450 N; dimensional changes, max ± 3%; seam strength, min. 225 N.

The operational requirements were defined considering the following attributes of the PPE system: i) the garments included within the PPE system; ii) the key performance parameters of each PPE garment; iii) other performance requirements of PPE components or the system; iv) any physical requirements of PPE components or the system and v) any requirements for interoperability and/or maintenance [7].

Materials

Based on the performance requirements imposed for each modular layer of clothing in the component of the intervention PPE system, execution materials were selected (table 1).

Physical-mechanical and physical-chemical characteristics of the fabrics were determined in the accredited laboratories of INCDTP (table 2).

Design of the garment's modular layers of the PPE system for interventions in emergency situations

Based on the protection requirements and the specified minimum necessary performance parameters, the assortment range of the possible intervention PPE system was established, as follows:

a) **Underwear PPE** – the inner layer of the intervention PPE system consists of a long-sleeve blouse, made of two parts (front and back) assembled on the side line, straight sleeves provided at the end with a hem and long pants adjusted at the waist with elastic, provided with a slit made of two identical gussets in the shape of a hexagon and with a hem at the end. The joints are made by sewing with flame-retardant sewing thread.

b) **Duty uniform** – intermediate/base layer of the intervention PPE system in the two-piece structure

Table 1

BASIC PROPERTIES OF THE SELECTED TEXTILES SUPPORTS				
Component	**Material**	**Structure**	**Thickness (mm)**	**Weight (g/m^2)**
Underwear PPE (inner layer)				
Knit fabric	Meta-aramid 93% Para-aramid 5% Antistatic 2%	weft interlock	0.95	215
Duty Uniform (base layer)				
	Aramid 29% FR viscose 59% Polyamide 10% Antistatic 2%	1/1 plain ripstop	0.44	219
Specialized PPE for firefighters				
Outer fabric	Para-aramid 78% Meta-aramid 20% Antistatic 2%	1/1 plain ripstop	0.45	212
Thermal moisture barrier	Thermal barrier: 3-D spunlace non-woven: aramid Membrane: ePTFE/PU BI-component	-	1.41	170
Thermal liner	Non-woven: FR viscose/aramid Fabric: viscose FR/aramid/polyamide	-	0.972	229
Specialized PPE for interventions in extreme weather conditions				
Outer fabric	Laminated material in 3 layers Layer 1: Fabric, 100%PES Layer 2: 100% PTFE Layer 3: Knit, 100% PES	-	0.52	227
Removable lining	Fabric 100% PES Non-woven 100-% PES Fabric 100% PES	-	-	61 155 61

Table 2

PHYSIC-MECHANICAL AND PHYSIC-CHEMICAL CHARACTERISTICS OF FABRICS (SELECTION)

Characteristic		UM	Values obtained in the accredited laboratories of INCDTP						Reference document
			S1	S2	S3.1			S3.2	
					S3.1.1	S3.1.2	S3.1.3		
Mass per unit area		g/m^2	215	219	212	170	229	227	SR EN 12127
Thickness		mm	0.95	0.446	0.45	1.417	0.972	0.52	SR EN ISO 5084
Tensile strength warp		N	-	905	2653	-	-	1326.6	SR EN ISO 13934-1
Tensile strength weft		N	-	796	2056	-	-	939	SR EN ISO 13934-1
Tear strength warp		N	-	36.2	245	-	-	51.8	SR EN ISO 13937-3
Tear strength weft			-	34.6	213	-	-	52.8	SR EN ISO 13937-3
Bursting strength		kPa	449.3	-	-	-	-	-	SR EN ISO 13938-2
Bursting distension		mm	45.1	-	-	-	-	-	SR EN ISO 13938-2
Resistance to abrasion		cycles	120000	80000	26245	-	-	87144	SR EN ISO 12947-2
Dimensional change when washing	long.	%	–0.33	–0.46	–0.79	–2.05	–0.06	–0.86	SR EN ISO 6330 SR EN ISO 5077 SR EN ISO 3759
	trans.		–0.5	–1.52	–0.26	–1.19	–0.33	–0.59	
Air permeability		l/m^2s	1390	111.1	64.48	-	-	1.237	SR EN ISO 9237
Water-vapour resistance, Ret		m^2Pa/W	5.97	5.43	6.93	21.84	8.37	17.74	SR EN ISO 11092
Thermal resistance, Rct		$m^2°K/W$	0.0418	0.0214	0.0214	0.0629	0.0442	0.0219	SR EN ISO 11092
pH of aqueous extract			6.94	7.05	-	-	-	6.34	SR EN ISO 3071
Resistance to surface wetting (spray test)		note	-	-				5(100)	SR EN ISO 4920
Resistance to water penetration		mm col. water	-	-	Over 9950			Over 9950	SR EN ISO 811
Resistance to limited flame spread			– no test specimen burns up to the top and side edges – no test specimen produces melted or ignited remains – no test specimen forms the hole – the mean value of after flame time: 0 s – the mean value of afterglow time: 0 s					-	SR EN 15025

Note: S1 is knitted fabric made of yarn 93/5/2% meta-aramid fibres/para-aramid fibres/antistatic fibres; S2 – woven fabric 29/59/10/2% aramid fibres/FR viscose fibres/polyamide fibres/antistatic fibres; S3.1.1 – woven fabric 78/20/2% para-aramid fibres/meta-aramid fibres/antistatic fibres; S3.1.2 – 3D spunlace non-woven made of para-aramidic/meta-aramidic fibres + ePTFE/PU-bicomponent membrane; S3.1.3 – non-woven made of FR viscose fibres/aramid fibres + viscose FR/aramid/polyamide fibre fabric; S3.2 – laminated material in 3 layers: 100% PES fabric + PTFE film + 100% PES knit.

consists of: a blouse with classic sleeves with cuffs with buttons, frontal closure system with a zipper covered with slit fixed with velcro tape, 2 pockets with closed flaps with buttons applied to the chest and straight trousers, adjusted at the waist with a belt, slit with zipper and button, 2 pockets with an oblique opening at the upper part of the front, 2 pockets with an oblique opening at the upper part of the back, 2 straight pockets provided inside the oblique ones at the back, 2 pockets with bellows and flaps on the sides, collars, knee pads. The joints are made by sewing with flame-retardant sewing thread.

c) **Specialized PPE for intervention missions in case of fires** – the outer layer of the intervention PPE system, made in a modular structure: Outer suit + removable lining.

The outer suit consists of: a jacket with a tunic collar closed with a flap from the base material and velcro tape, with the back cut from a single piece, the chest cut from two symmetrical pieces, the right sleeves, from two longitudinal pieces provided with a gusset, adjusted at the wrist with a clamp from the base material fixed with velcro tape; front closure system with zipper and slit in the base material fixed with velcro tape, 3 pockets applied to the chest with flaps closed with velcro tape, one on the upper part of the left chest and two on the lower part of the chest. It has retro-reflective and fluorescent horizontal bands applied by sewing that wrap around the blouse at chest level and the end and around the sleeves; pants with right end, adjusted at the waist with two bands positioned laterally from the base material; provided with adjustable elastic straps with buckles; slit closed with a zipper; 2 pockets applied to the thighs with flaps closed with velcro tape. It has retro-reflective and fluorescent horizontal strips applied by sewing that wrap around every leg.

The removable lining consists of: a jacket with a back cut from a single piece, chests cut from two symmetrical pieces, a frontal closure system with velcro tape, straight sleeves, from 2 longitudinal pieces finished with a patent tricot cuff; trousers with right end, adjusted at the waist with Velcro tape, slit closed with Velcro tape. The consolidation of the 2 clothing layers (outer suit and lining) is done with Velcro tape.

d) **Specialized PPE for intervention missions in extreme weather conditions** – the outer layer of the intervention PPE system – Short coat with removable hood and lining – consists of the chest, back, sleeves, front plate, back plate, slits (upper and lower), hood, collar, epaulettes, slanted slits and pockets, pockets with flaps and flaps, cuffs. On the inside, a short coat is provided with a removable lining top using zippers.

The design of the basic and model patterns for the garment's modular layers included within the PPE system was based on the geometric method of pattern construction, using Gemini Pattern Editor's special CAD design software.

Verification of patterns matching designed according to individual body dimensions was accomplished by modelling 2D/3D patterns and simulating garments modular layers, included within the PPE system, on the parameterized mannequin, by using Optitex PDS software for visualization, modelling and fitting the virtual body of the prototype.

The development of new PPE systems is complex, costly, and time-consuming. The use of modelling and simulation can reduce the development time and production costs of new PPE systems [8, 9]. Therefore, in the first step, we made virtual prototypes of integrated systems of modular protection layers using the OptiTex software suite.

The stages completed were the following: i) 2D design of the basic patterns by the data from the size table of the model and in correlation with the real dimensions of the products using the Pattern Design Software (PDS); ii) Simulation of PPE systems on a virtual mannequin using the Optitex 3D Suite software. The 2D patterns made with the PDS software were placed on the parameterized model and the types of seams were defined for the virtual assembly by simulating their sewing. The landmarks were deformed according to the shape of the human body; iii) Evaluation of the fit of the product on the body: after the completion of the 3D simulation process of the product, the appearance of the product and the way it sits on the surface of the body (its fit or product-body correspondence) were analysed (figures 1–4) [10].

RESULTS ADN DISCUSSION

The evaluation of the performance of the modular protection layers from the component of the PPE system for emergency intervention was carried out through specific laboratory tests to verify the protection parameters imposed by the specifications of the applicable standards [11–15], namely SR EN ISO 11612:2015 (EN ISO 11612:2015) – Protective clothing. Clothing to protect against heat and flame.

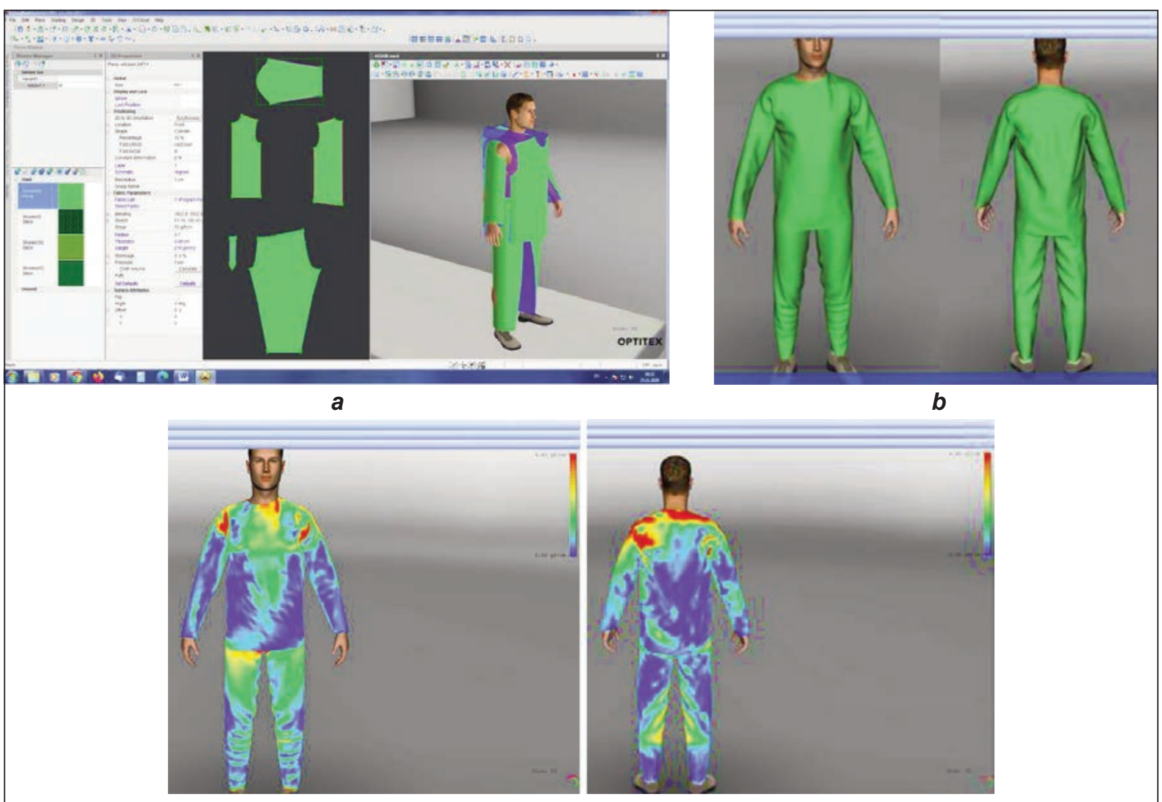

Fig. 1. Modular layer 1 – Underwear PPE: *a* – the 2D patterns with seam lines; *b* – virtual try-on verification; *c* – tension map

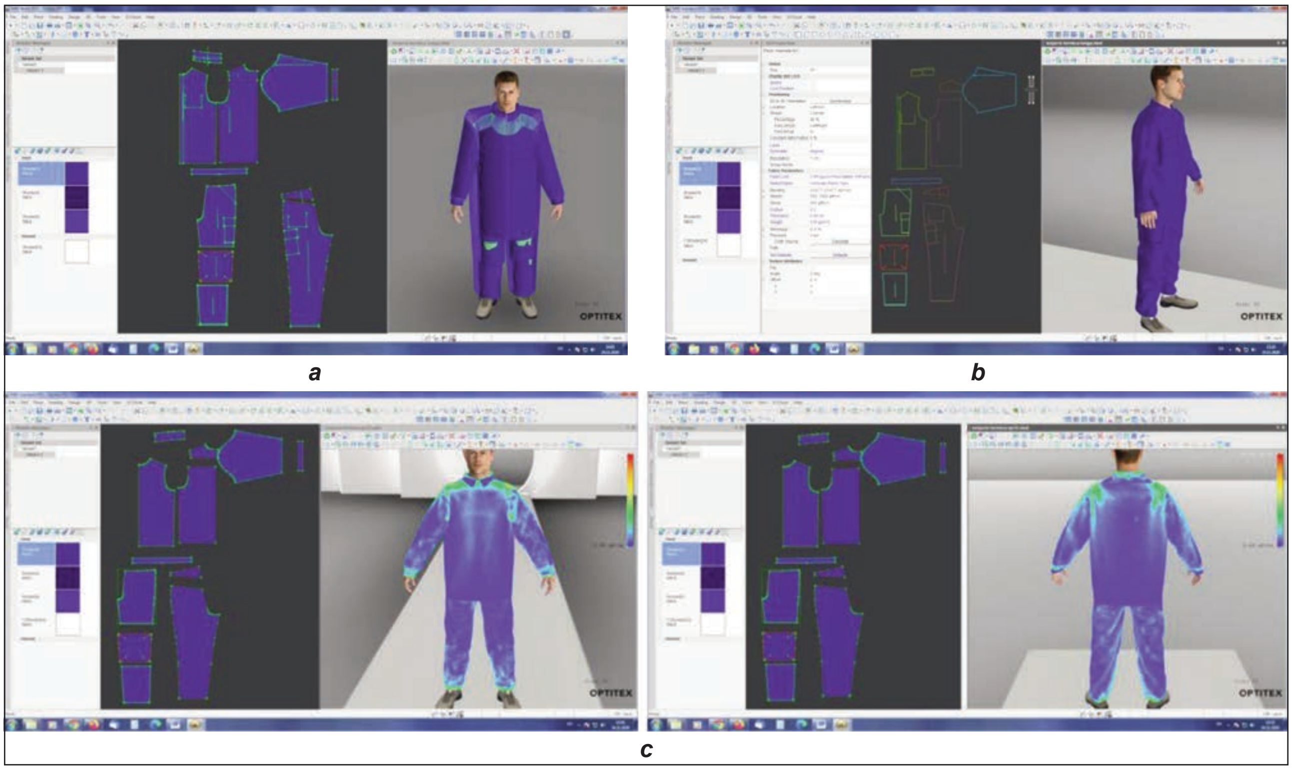

Fig. 2. Modular layer 1 (Underwear PPE) + Modular layer 2 (Duty Uniform): *a* – the 2D patterns with seam lines; *b* – virtual try-on verification; *c* – tension map

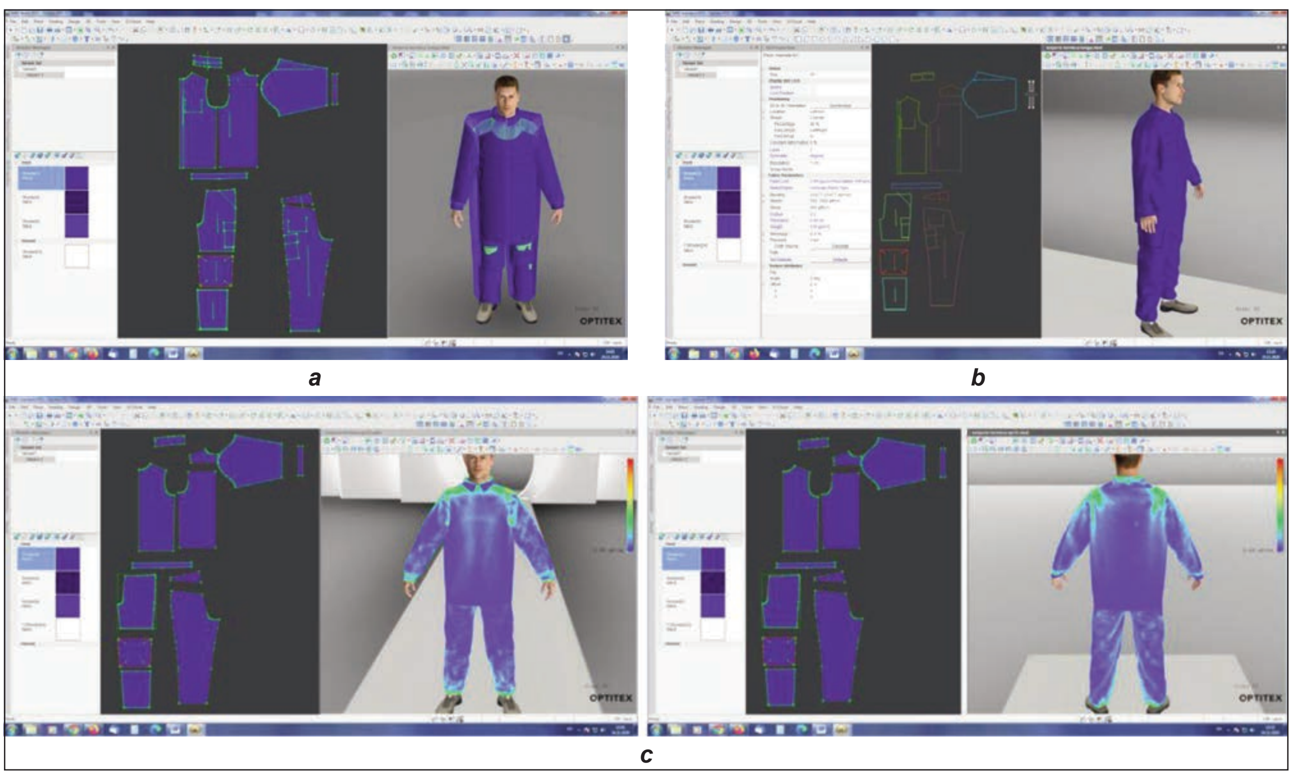

Fig. 3. Modular layer 1(Underwear PPE) + Modular layer 2 (Duty Uniform) + Modular layer 3.1 (Specialized PPE for firefighters): *a* – the 2D patterns with seam lines; *b* – virtual try-on verification; *c* – tension map

Minimum performance requirements; SR EN 469: 2020 (EN 469:2020) Protective clothing for firefighters. Performance requirements for protective clothing for firefighting activities; SR EN 342: 2018 (EN 342: 2018) – Protective clothing. Ensembles and garments for protection against cold; SR EN 343:2019 (EN 343:2019) – Protective clothing. Protection against rain; SR EN ISO 13688:2013 – Protective clothing – General requirements.

The performance evaluation carried out, based on the results obtained in the laboratory tests, highlighted that:

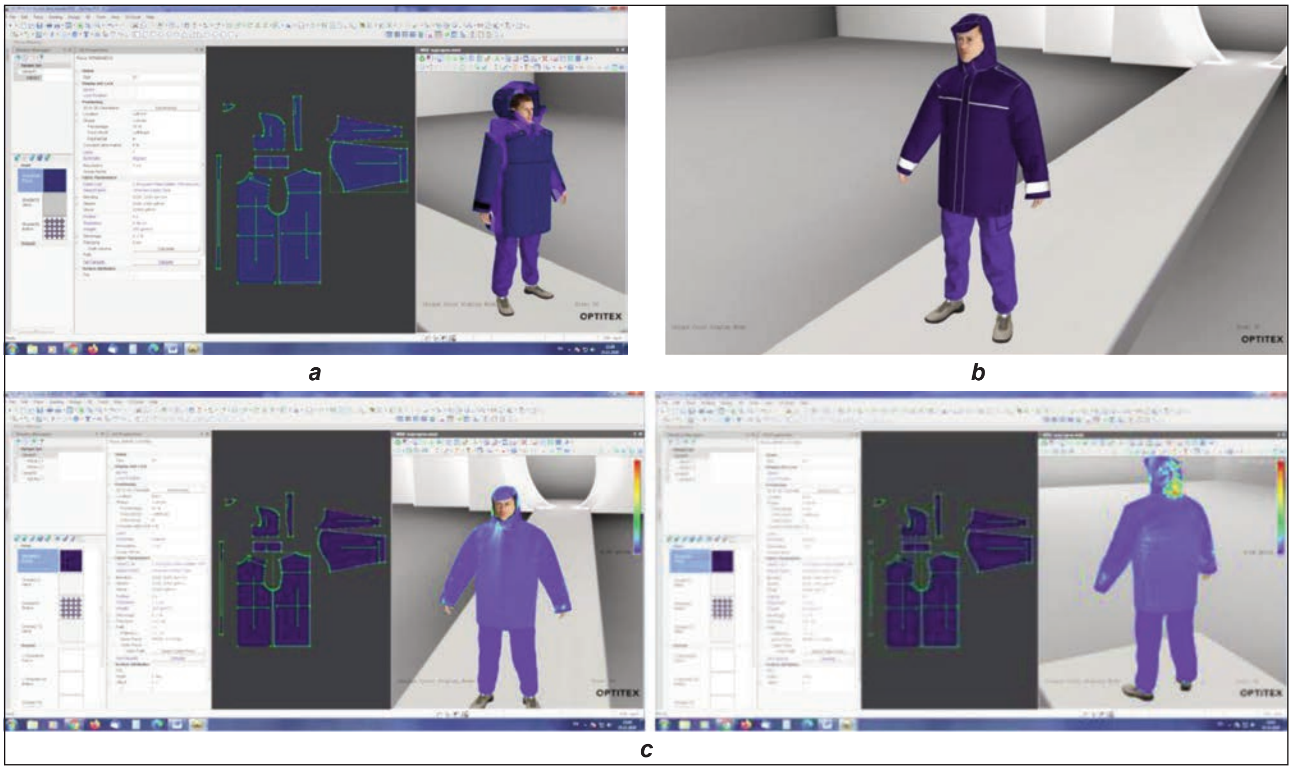

Fig. 4. Modular layer 1 (Underwear PPE) + Modular layer 2 (Duty Uniform) + Modular layer 3.2 (Specialized PPE for interventions in extreme weather conditions): *a* – the 2D patterns with seam lines; *b* – virtual try-on verification; *c* – tension map

• *Modular layer 1* – interior layer (in contact with skin) – Underwear PPE has characteristics according to the specifications of the following standards: a) SR EN ISO 11612:2015: point 6.3 (resistance to limited flame spread) – the mean value of after flame time and afterglow time: 0 s, code letter A1; point 6.4 (dimensional change) within the limits imposed, less than ± 3%, in both directions, longitudinally and transversely; point 6.5.3 (burst strength) above the minimum required value, 200 kPa; point 6.9.2 (pH value) within the required limits, greater than 3.5 and less than 9.5; b) SR EN ISO 13688:2013: point 4.2 (innocuousness – the content of carcinogenic amines) within the imposed limits, undetectable; point 4.3 (design); section 4.4 (comfort);

• *Modular layer 2* – base layer (intermediate) – Duty uniform has characteristics according to the specifications of the following standards: a) SR EN ISO 11612:2015: point 6.3 (resistance to limited flame spread) – the mean value of after flame time and afterglow time: 0 s, code letter A1; point 6.4 (dimensional change) within the limits imposed, less than ± 3%, in both directions, warp and weft; point 6.5.1 (tensile strength) above the minimum value imposed, 300 N in warp and weft; point 6.5.2 (tear strength) above the minimum value imposed, 15 N in warp and weft; point 6.9.2 (pH value) within the required limits, greater than 3.5 and less than 9.5; b) SR EN ISO 13688:2013: point 4.2 (innocuousness – the content of carcinogenic amines) within the imposed limits, undetectable; point 4.3 (design); section 4.4 (comfort);

• *Modular layer 3.1* – outer layer Specialized PPE for firefighters has characteristics according to the specifications of the following standard: SR EN 469:2020: point 6.1 (resistance to limited flame spread) – the mean value of afterflame time and afterglow time: 0 s, code letter A1; point 6.5 (thermal resistance) – dimensional changes after exposure 5 minutes at 180°C, below 5%; point 6.6 (tensile strength) above the minimum value imposed for the outer material of the PPE for firefighters, 450 N in warp and weft; point 6.7 (tear strength) above the minimum value imposed for the outer material of the PPE for fighters, 25 N in warp and weft; point 6.8 (surface wetting), degree of softening above the minimum value imposed for the outer material of the PPE for firefighters, 4 (ISO degree scale); point 6.9 (dimensional change when washing) below the required minimum values, ± 3% (for all materials in the component of the PPE for firefighters); point 6.10 (resistance to penetration of liquid chemicals), rejection rate over 80% for each of the liquid chemicals mentioned in the standard (for the set of materials in the component of the PPE specialized for firefighters); point 6.11 (resistance to water penetration) over 20 kPa, level 2 performance (for the multilayer assembly with a barrier of moisture of the PPE specialized for firefighters); point 6.12 (water vapor resistance), below 30 m^2Pa/W, performance level 2 (for the set of materials in the component of the PPE specialized for firefighters);

• *Modular layer 3.2* – outer layer: Specialized PPE for interventions in extreme weather conditions (Jacket with detachable hood and lining) has characteristics according to the specifications of the following standards: a) SR EN 343:2019: point 4.2 (resistance to water penetration) above the limit values imposed for performance class 4 (20000 Pa); point 4.3 (water vapor resistance) below the maximum value imposed, 40 m^2Pa/W; point 4.4 (tensile strength) above the required value, 450 N in warp and weft; point 4.5 (tear strength) above the imposed value, 20 N in warp and weft; point 4.6 (dimensional changes) below the required minimum values, ± 3% in both directions of the material; b) SR EN 342:2018: point 4.2 (thermal resistance) above the required minimum value, 0.31 m^2K/W; point 4.3 (air permeability, AP) within the limit values imposed for performance class 3 (AP < 5 mm/s); point 4.4 (resistance to water penetration) above the limit values imposed 8000 Pa; point 4.5 (water vapor resistance) below the maximum value imposed, 55 m^2Pa/W; point 4.6.1 (tear strength) above the minimum value imposed, 20 N in warp and weft; d) SR EN ISO 13688:2013: point 4.2 (innocuousness}: (pH value) within the required limits, greater than 3.5 and less than 9.5; point 4.3 (design); section 4.4 (comfort);

The results of the evaluation of the way of fitting the modular layers/integrated systems of modular layers of the EIP for intervention in emergency situations on the parametrized virtual mannequin are the following:

1. Simulation of the inner layer (in contact with the skin) – underwear PPE (figure 1): the appearance of the component products of the model is appropriate; checking and evaluating the body-product fit – highlights the closeness of the products to the body, without exerting a pressure that exceeds the allowed limit;
2. Simulation of the PPE system for emergency intervention that integrates the inner layer (in contact with the skin) – underwear PPE and the intermediate (base) layer – Duty Uniform (figure 2): the appearance of the products that are components of the Duty Uniform, dressed over the underwear PPE, it is appropriate; checking and evaluating the body-product fit – highlights a great lightness of the clothing layer (blue colour on the tension map), thus ensuring good wearing comfort;
3. Simulation of the emergency PPE system that integrates the inner layer (in contact with the skin) – underwear PPE, the intermediate (base) layer – Duty uniform and specialized PPE for firefighters (figure 3): the appearance of the product's components of the specialized PPE for firefighters, worn over the Duty uniform and underwear PPE; visualization of the tension map shows a good body-product correspondence, without pressure exerted on the body;
4. Simulation of the emergency PPE system that integrates the inner layer (in contact with the skin) – underwear PPE, the intermediate (base) layer – Duty uniform and specialized PPE for interventions in extreme weather conditions (figure 4): the appearance of the component product of the specialized PPE for interventions in extreme weather conditions – Short coat with removable hood and lining worn, over the Duty uniform and underwear PPE, is appropriate; viewing the tension map shows a good body-product correspondence, without pressure exerted on the body.

CONCLUSIONS

This research aimed to develop, for emergency workers, a PPE system, in a modular structure, built upon a duty uniform that provides limited protection and physiological benefits in combination with a series of modular, mission-specific layers to provide specialized protection.

Starting from the needs analysis, the key needs of the PPE system were identified, which were the basis for establishing the key performance parameters and the high-performance parameters. The established performance parameters were translated into design requirements, based on which the raw materials, the realization technologies, and the conception (design) of the PPE system were identified

The objective laboratory testing indicates that the fabrics selected for the garment's modular layers included within the PPE system meet or exceed the minimum performance requirements defined in the operational requirements specification.

The solutions and advantages offered by the Optitex software suite were used for the virtual prototyping of the PPE system for emergency intervention, before the physical realization and verification of its compliance through 3D simulation on an avatar.

For 3 variants of the integration of the modular layers in the interventions PPE system, after the completion of the 3D simulation process, the appearance of the product and the way it sits on the surface of the body (its fit or product-body correspondence) were analysed.

The PPE system, in the modular structure, integrates state-of-the-art protective technologies; provides basic protection from most likely threats (for example fire, extremes weather etc.); enhances daily-wear comfort; provides increased localized protection as needed (for example knees, forearms); includes next-to-skin layer and outer layer to provide varying levels of protection as needed; the modular layers easily donned and undonned.

This modular approach: provides some advantages, including preserving comfort and flexibility until the intervention mission requires the use of the next level of protection. This helps ensure that emergency responders are not in the position of choosing between their safety or mission effectiveness.

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