Evaluating women's jacket sleeves designs for sustainable fashion and textile waste reduction

DOI: 10.35530/IT.075.05.2023120

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ABSTRACT – REZUMAT

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Finding the most efficient marker planning method is crucial to reduce cut-and-sew waste. Small adjustments to the design and pattern can help reduce the amount of fabric waste, since marking loss happens during the cutting process because of spaces and unusable sections between pattern pieces and the curved pattern edges.

Existing research mainly concentrates on optimising the consumption of textile material without taking into account the design, aesthetics and functionality of the final product. On the other hand, they are mainly focused on optimizing the sleeves' construction and in search of new design solutions, with gaps in quantitative and comparative analysis to reduce waste while producing women's jackets.

This article aims to propose and explore constructive changes in women's jacket designs with 5 different types of sleeves, to assess the possibility of reducing cut-and-sew waste levels in the cutting process. There have been created 4 different marker plans for each type of sleeve to achieve the high-efficiency markers. It was found that the semi-raglan sleeve showed the marker efficiency with the best results (76.04%), followed by the raglan sleeve with 72.03% and 72.34% for the drop shoulder sleeve. Interestingly, for the raglan and semi-raglan sleeve variants, the marker efficiency is not affected by the specific geometric characteristics.

The Principal Component Analysis (PCA) method was used to determine which pattern arrangement variant was most appropriate for the different sleeve types.

Keywords: *women's jacket, sleeve design, reduction* of *textile waste, pattern pieces, nesting*

Evaluarea designului mânecilor jachetelor de damă pentru o modă durabilă și reducerea deşeurilor textile

Identificarea celei mai eficiente variante de încadrare este esențială pentru a diminua risipa de material în procesul de croire și asamblare. Ajustări minore ale designului și tiparului pot contribui la reducerea cantității de deșeuri, deoarece pierderile apar în timpul procesului de croire din cauza spațiilor și secțiunilor neutilizate dintre piesele tiparului, precum și din cauza marginilor curbe ale acestuia.

Cercetările existente se concentrează în principal pe optimizarea consumului de material textil, fără a lua în considerare estetica, designul și funcționalitatea produsului finit. Pe de altă parte, aceste cercetări vizează optimizarea construcției mânecilor și căutarea de noi soluții de design, având lacune în analiza cantitativă și comparativă în vederea reducerii deșeurilor în producția jachetelor de damă.

Scopul acestui articol este de a propune și explora modificări constructive în designul jachetelor de damă, cu 5 tipuri diferite de mâneci, pentru a evalua posibilitatea reducerii nivelului de deșeuri în procesul de croire și asamblare. Au fost realizate 4 încadrări diferite pentru fiecare tip de mânecă, pentru a obține cea mai eficientă utilizare a materialului în încadrarea tiparului. S-a constatat că mâneca semi-raglan a prezentat cea mai eficientă încadrare (76,04%), urmată de mâneca raglan cu 72,03% și mâneca căzută cu 72,34%. Interesant este că, pentru variantele de mânecă raglan și semi-raglan, eficiența încadrării nu este afectată de caracteristicile geometrice ale acestor tipuri de mâneci.

A fost utilizată metoda analizei componentelor principale (PCA) pentru a determina care variantă de încadrare a fost cea mai potrivită pentru diferitele tipuri de mâneci.

Cuvinte-cheie: *jachetă de damă, design de mâneci, reducerea deșeurilor textile, tipare, încadrare*

INTRODUCTION

The mass production of low-cost clothing is associated with significant environmental costs, including the depletion of natural resources, the pollution of water sources, and the release of significant greenhouse gas emissions. In response to these pressing environmental issues, the European Commission adopted a new initiative in March 2022 through the "Strategy for Sustainable Textile Products". It advocates sustainable approaches to both the production and consumption of clothing while prioritizing the reduction of textile waste. This strategy encourages changes in consumer behaviour towards more sustainable clothing models whose designs are the result of efficient design developments that minimize the use of textile materials and reduce the generation of waste in the production of clothing.

Enforcing this strategy in practice involves rethinking the traditional designs of women's jacket sleeves and replacing them with alternative models that seamlessly integrate with existing basic design elements. These design changes, although minimal, represent a significant leap towards a more sustainable and environmentally friendly future for the textile industry.

Optimizing the arrangement of pattern pieces in textile cutting is extensively studied and represents a critical challenge within textile manufacturing [1, 2]. This task is mainly aimed at minimizing textile waste, which is usually unusable and discarded, thereby significantly affecting the production cost. By increasing the precision of material use, this process aims to reduce waste and increase cost efficiency in production [3].

Reasons for obtaining different amounts of waste when cutting textiles include differences in design, type of material used, production technology, ensuring comfort when wearing the garment [4], matching individual parts of the garment, individual consumer tastes, total cost of production, sustainability, and environmental protection [5]. These parameters can significantly affect the measured parameters, including aesthetics, functionality, cost-effectiveness, and environmental impact.

Since fabric is the primary expense in the garment production process, Rissanen [6] claims that one of the biggest issues facing the fashion industry is the marker plan's efficiency.

During the marker planning phase, cut waste minimization might be encouraged. Before going into mass production, the processes of creating patterns and planning markers are crucial for reducing waste. According to Rissanen [6], a marker is a cutting arrangement that includes every pattern piece required for a garment's manufacture. The cutting table length, fabric width, type of fabric, and fabric feature are all taken into consideration while placing the garment pattern pieces on the marker plan. The efficiency of the marker plan is mostly determined by the unpredictable pattern pieces, which are determined by their shapes and how closely they fit into the plan [7].

Effective pattern arrangement for the sleeves of a jacket for women is a challenging task due to the irregular and unique shapes of the individual details of the pattern. Finding an optimal solution is often impossible due to the specificity of each design and the large number of potential solutions [8]. Software products and computational algorithms have been developed to address this matter. These tools provide relatively satisfactory solutions to a wide range of textile cut layout problems, streamlining the process and improving efficiency in the arrangement of cut details.

Qiang [9] analysed the relationship between the raglan sleeve design and the human body from static and dynamic aspects, the construction characteristics of the raglan sleeve, and the factors affecting the design of the raglan sleeve from the perspective of the pattern component characteristics. The kimono sleeve design shows increased complexity and visual richness, customization for body movement, improved flexibility, adaptation to different body shapes, and the ability to make pattern adjustments. Challenges with the sleeve are related to the complexity of the design, compromises in personalization, potential defects during production, limitations arising from the type and structure of the textile material, societal and cultural considerations, the need for specialized skills, and difficulties in adapting the sleeve to the individual characteristics of the body.

Jing An [10] introduced proportional relationships to improve precision and adaptability in clothing pattern design. Although it simplifies the design process and makes models more flexible, it may require specialized tools and validation for different garments. Human expertise remains critical to effective implementation, and this approach holds potential for future computer-based intelligent systems in fashion design.

In their study, Islam et al. [11] point out that in textile manufacturing, flexibility is key to meeting diverse customer demands. The pursuit of quality and cost-effectiveness is essential, but finding the right method of consuming the textile material can be challenging. An experiment compared methods for different types of sleeves (semi-raglan, raglan, and kimono) in six garments. While marker planning is the most accurate method, it is not always practical for pre-production. This study aims to provide clarity on which formula to use for each type of garment, potentially saving textile fabrics and financial resources. Challenges include the lack of industry standards, resource constraints, and resistance to change.

The study by Marjanović et al. [12] highlighted the benefits of using 2D/3D CAD systems and digital printing in apparel design, including increased precision, efficiency, material visualization, reduced waste, rapid response to market demands, and environmental practices. The challenges are the need for technical expertise, the initial investment of resources, potential inconsistencies in material behaviour, and the continued need for real-world design validation. The approach is also technology-dependent and requires quality control.

According to Indrie et al. [13], the benefits of using 3D technology in apparel manufacturing include cost reduction, time efficiency, improved accuracy, sustainability, improved collaboration, and customization. However, there are limitations such as initial investment, learning curve, accuracy challenges, data and material requirements, software limitations, and lack of feedback. 3D technology offers significant advantages but also presents a challenge that different garment sizes must take into account when implementing it in their manufacturing processes.

Upon reviewing the existing literature, it is evident that there exists a requirement for additional research in the realm of optimizing fabric efficiency in production. Furthermore, employing data analysis techniques for sustainable fashion designs emerges as a promising avenue for exploration. The fashion industry can benefit from research into sustainable practices, while resource management and conservation strategies need cross-disciplinary research.

Understanding, developing, and applying performance metrics, green design principles, and environmental impact assessment methods are essential to sustainability. Moreover, circular economy research, policy development, and interdisciplinary approaches can pave the way for a more environmentally responsible future in industries and sectors, contributing to the protection of our planet.

Research in the available literature is focused on the design of different types of sleeves [14] and their efficient production methods with a reduction of waste materials. Individual posts only look at one type of sleeve. The research is mainly focused on the optimization and improvement of sleeve construction. It is necessary to offer tools for quantitative analysis of the efficiency of arranging sleeve patterns in their cutting, which will reduce the possibility of human error. Not enough research was found to summarize and analyse methods for reducing waste material in the production of the different types of women's jacket sleeves. No literary sources were found presenting data for the analysis of the constructive and design features of the types of sleeves in women's jackets studied to reduce the consumption of textile material and its minimal residue during cutting.

The purpose of this article is to propose and explore constructive changes in women's jacket designs with different types of sleeves, to assess the possibility of reducing the amount of textile waste or fabric remnants during cutting from the point of view of sustainability and environmental protection.

WOMEN'S JACKET DESIGN WITH DIFFERENT TYPES OF SLEEVES

In the depiction, a range of women's jacket designs is presented in figure 1, showcasing five distinctive sleeve variations: regular, kimono, raglan, semi-raglan, and those with a dropped shoulder.

Set against a predominantly white background and delicately presented in harmonious shades of green, powder pink, turquoise, purple and orange, the jackets show a fusion of fashion and functionality. The ensemble of two pieces – the jacket and skirt – demonstrates an elegant look and timelessness.

The sleeves, while undergoing minor structural adjustments, remain true to the basic essence of the model, ensuring that the garment retains its original look. These small changes in the sleeve design are not only decorative but also constructive; they show efforts to reduce the consumption of textile materials and minimize waste in the cutting stage, embodying a sustainable and ecological approach to design.

INVESTIGATION OF INDICATIVE CHARACTERISTICS

In this study, the models are the same size (M) and are different from each other in terms of sleeve shapes and numbers of patterns. The patterns are drawn in CAD software. AutoCAD 2023 (Autodesk, Inc., California, USA).

While the research primarily focused on other aspects, such as textile pattern arrangement, it is indeed crucial to acknowledge that sleeve construction plays a significant role in various industries. Sleeves are integral components in many products and systems, and optimizing their design and construction can lead to improvements in performance, durability, efficiency, and sustainability.

One of the most crucial factors affecting marker plan efficiency is fabric width. The width of the fabric is

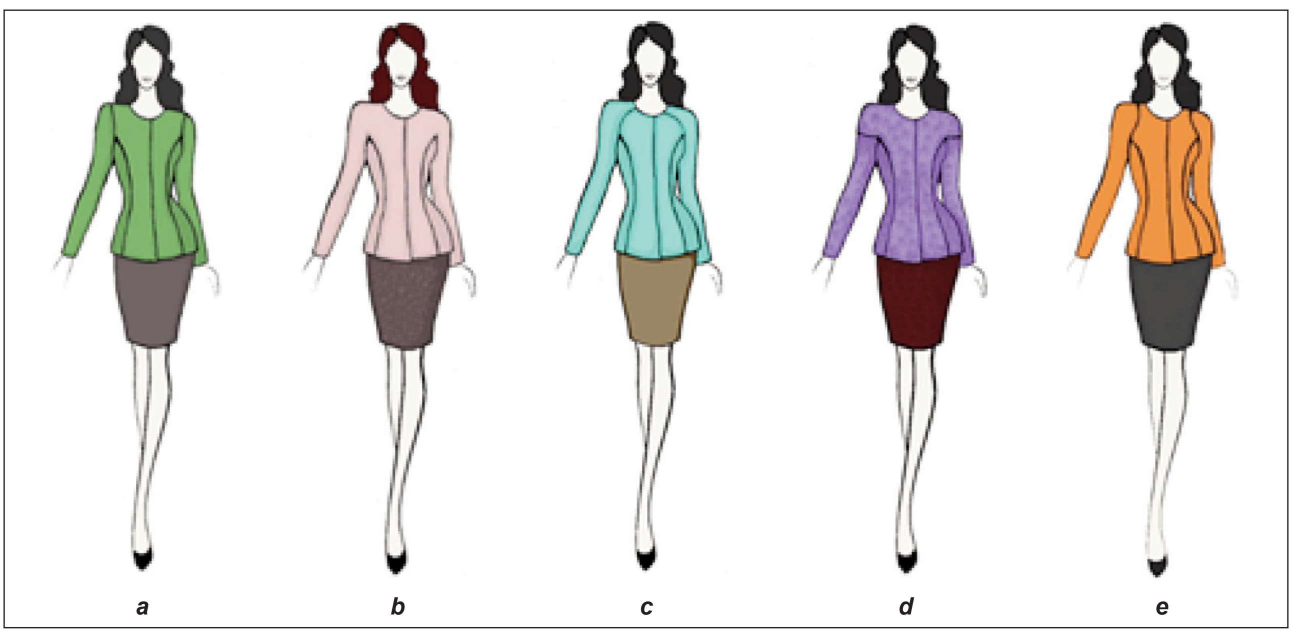

Fig. 1. Designs of women's jackets with different types of sleeves:
a – regular; *b* – Kimono; *c* – raglan; *d* – dropped shoulder; *e* – semi raglan

also the width of the marker plan. The fabric width employed in this study is 150 cm. Four different variants of marker plans have been created for each type of sleeve to achieve the most efficient usage of fabric on the marker plan.

The fill function is a crucial concept that accurately defines the spatial intervals between patterns. It integrates parameters associated with both the area occupied by patterns and the vacant spaces that divide them, employing a weighted sum methodology. The calculation of the Fill function is outlined as follows:

$$A_F = L \cdot W \tag{1}$$

$$F = a \cdot \frac{\sum_{i=1}^{N} A_{e(i)}}{A_F} + b \cdot \left(1 - \frac{A_s}{A_F}\right) \tag{2}$$

where A_s represents the area of the unoccupied space enclosed by the patterns; A_F denotes the area occupied by the patterns; L and W stand for the length and width, respectively, of the rectangle encompassing the patterns; A_e represents the area of an individual element. The constants a and b are assigned values of 0.7 and 0.3, respectively, based on the findings of Hopper [15].

The fabric utilization rate is a vital measure of quantifying the efficient use of the fabric. This metric is determined by the area selected by the operator for arranging patterns about the disparity between the areas of the patterns and the unoccupied space among them. The formula encapsulating the extent of effective material utilization is expressed as follows:

$$D_F = \frac{(A_e - A_s)}{A_T} \cdot 100, \% \tag{3}$$

where A_e refers to the area occupied by patterns, A_s denotes the area between the patterns, and A_T represents the total area defined by the operator.

The total filling efficiency is the sum ratio of the element's areas to the total area they occupy, expressed as a percentage. The mathematical dependence of this relationship has the form:

$$E_T = \frac{\sum_{i=1}^{n} A_{e(i)}}{A_F} \cdot 100, \% \tag{4}$$

where A_e represents the area of an individual piece of pattern, n stands for the number of patterns, and A_F denotes the area filled with these patterns.

Following the analyses and computations, visual representations illustrating the presentation of different approaches to arranging patterns for women's jackets are provided. The results of evaluating the effectiveness of these options are presented and discussed.

In all variants of the pattern piece's arrangement of the women's jackets, the principle of the arrangement according to the main thread of the textile material is observed. Details have added seam allowances. Out of these, one detail (counter sample) is divided into two elements to reduce the amount of occupied area and more efficiently fill the fabric with patterns. The constructive solution does not change the design of the clothing.

Arranging patterns for a women's jacket with regular sleeves, figure 2 illustrates eight distinct patterns and presents four deployment alternatives, showcasing the fabric-filling efficiency specific to each proposed option.

Displaying the outcomes of organizing patterns for a women's jacket featuring a kimono sleeve, figure 3 presents six segments, each showcasing the fabric filling efficiency, and highlights four distinct pattern arrangements.

Presenting a visual representation of the element arrangement for a women's jacket with a raglan sleeve, figure 4 depicts the filling efficiency of the fabric across eight segments, elucidating the specific proposed variant for each.

Illustrating the outcomes of organizing patterns for a dropped shoulder women's jacket, figure 5 presents seven segments. The visual depiction showcases the fabric filling efficiency, highlighting the specific proposed option associated with each arrangement.

Depicting the outcomes of arranging patterns for a women's jacket with a semi-raglan sleeve, figure 6 is divided into four arrangement options, presenting eight jacket pattern pieces. The visual representation showcases the fabric filling efficiency, indicating the specific proposed option for arranging the pattern pieces closer to each other.

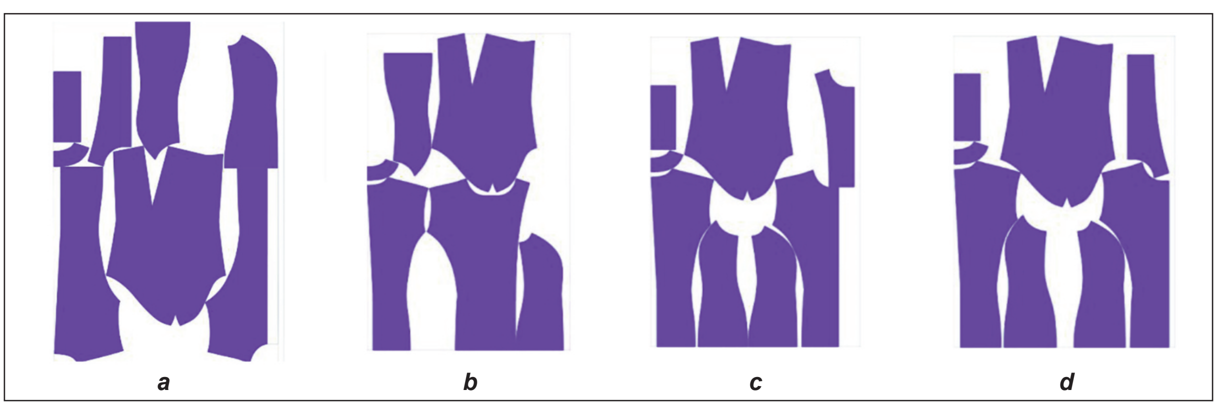

Fig. 2. Comparative analysis of pattern arrangement options for a women's jacket with regular sleeve: *a* – V1; *b* – V2; *c* – V3; *d* – V4

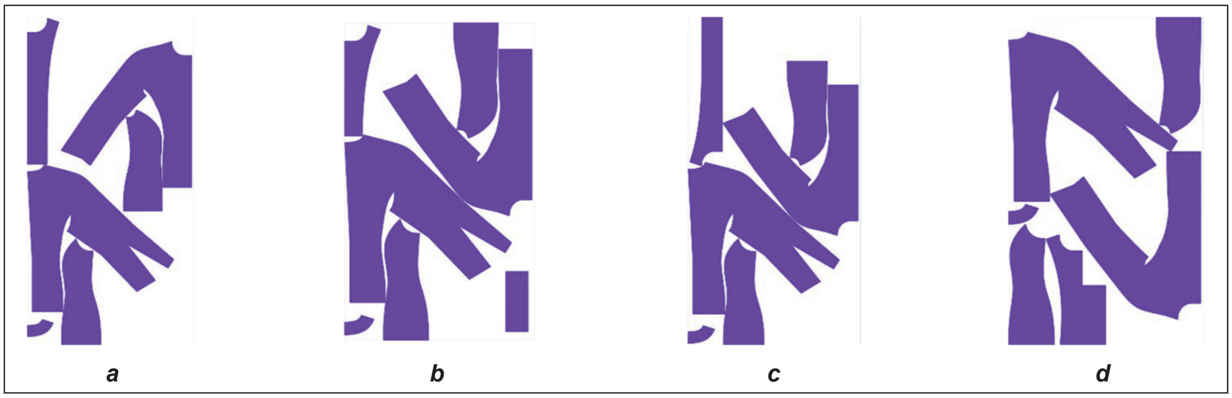

Fig. 3. Comparative analysis of options for arranging patterns of a women's jacket with a kimono sleeve:
a – V1; *b* – V2; *c* – V3; *d* – V4

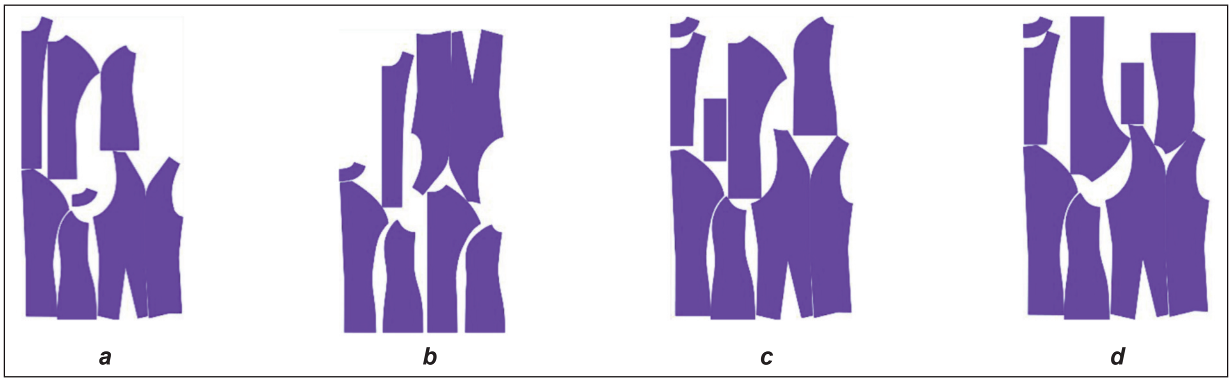

Fig. 4. Comparative analysis of item arrangement options for a women's raglan sleeve jacket:
a – V1; *b* – V2; *c* – V3; *d* – V4

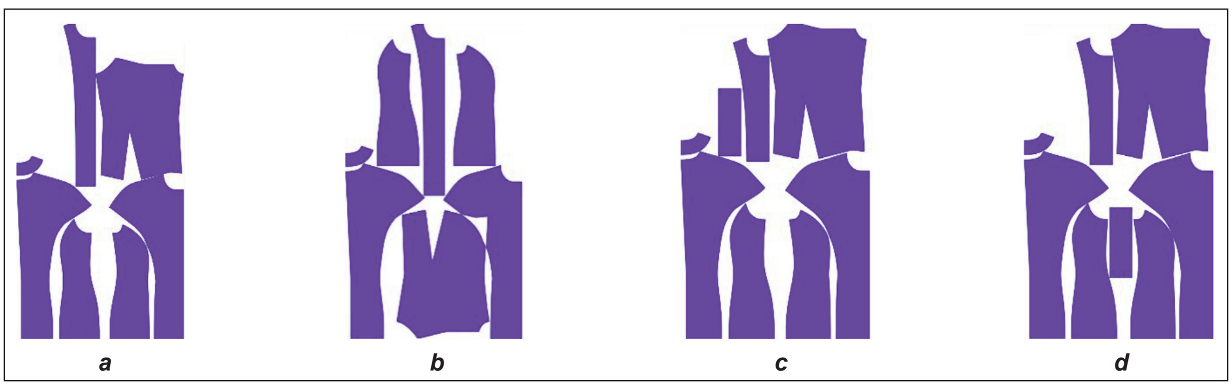

Fig. 5. A comparative analysis of item arrangement options for a women's jacket with dropped shoulder sleeve:
a – V1; *b* – V2; *c* – V3; *d* – V4

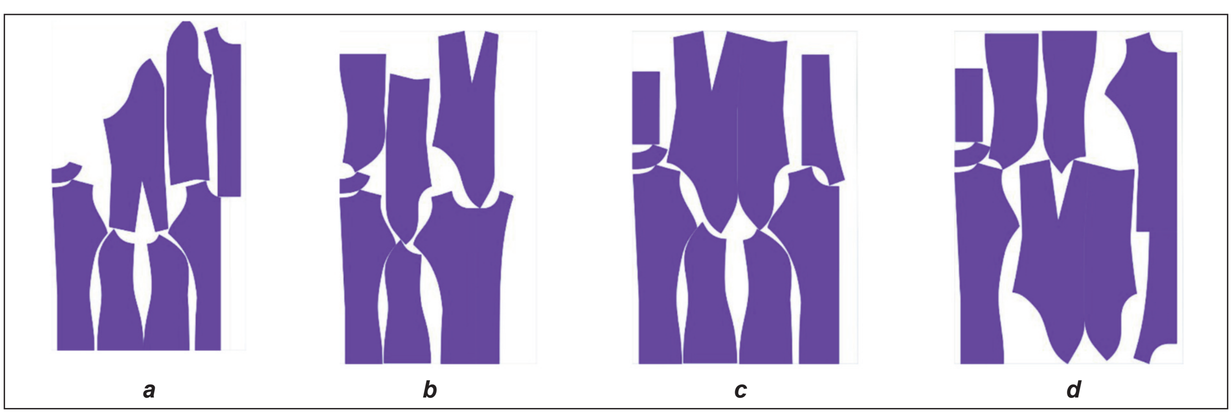

Fig. 6. Comparative analysis of options for arranging patterns of a women's jacket with a semi-raglan sleeve:
a – V1; *b* – V2; *c* – V3; *d* – V4

In table 1, the results of a comprehensive analysis focusing on the pattern arrangement in a women's jacket with a semi-raglan sleeve are presented.
The table is organized to show various key parameters, including fill function (F), material utilization rate, and corresponding percentages of total element area (Df) and void area (Et) for each of the four distinct configurations, denoted by V1, V2, V3, and V4. These results show marker efficiency in terms of arranging pattern pieces closer to each other how much space is used for items and how they compare in terms of their design and fit.
These results show how the characteristics of the various patterns of women's jackets are made up.

Table 1

OUTCOMES FROM AN EVALUATION OF THE EFFICIENCY OF VARIOUS ARRANGEMENT OPTIONS

Sleeve	**Parameter / Variant**	**F**	**D_f (%)**	**E_t (%)**
Regular	V1	0.62	80.25	66.78
	V2	0.63	75.48	69.7
	V3	0.63	70.79	72.51
	V4	0.62	78.42	67.4
Kimono	V1	0.52	96.5	53.67
	V2	0.59	84.6	63.75
	V3	0.54	95.89	54.25
	V4	0.52	88.92	60.05
Raglan	V1	0.58	87.05	62.13
	V2	0.58	84.94	63.73
	V3	0.63	75.31	70.53
	V4	0.64	72.99	72.03
Dropped shoulder	V1	0.57	86.74	61.96
	V2	0.61	82.77	64.76
	V3	0.62	75.07	69.95
	V4	0.63	74.85	70.15
Semi raglan	V1	0.59	87.96	60.83
	V2	0.64	78.48	71.04
	V3	0.68	67.44	76.04
	V4	0.65	68.11	74.4

The PCA method was used to determine which pattern arrangement variant was most appropriate for the different sleeve types.
Principal component analysis (PCA) [16] is a tool for reducing the dimensionality of data while preserving as much information as possible. It is used for data visualization and feature extraction in various fields such as data analysis, image processing, and machine learning. PCA makes no independence assumptions; it focuses on statistical dependencies (correlations) between variables in the data.
Before processing with the PCA method, the data were normalized to the interval [0, 1]. Table 2 shows the normalized data for overall material filling efficiency for the different types of women's jacket sleeves studied.

Table 2

THE OVERALL ARRANGING EFFICIENCY OF THE MATERIAL FOR DIFFERENT TYPES OF WOMEN'S JACKET SLEEVES

Variant / Sleeve	V1	V2	V3	V4
Regular	0.00	0.00	0.00	0.00
Kimono	0.04	0.16	0.02	0.04
Raglan	0.08	0.01	0.12	0.11
Dropped shoulder	0.01	0.10	0.14	0.12
Semi raglan	0.00	0.00	0.00	0.00

Since the number of rows is 5 and the number of columns is 4, the data can be reduced to 4 principal components in rows and 3 in columns. The number of components required was determined under the condition that the sum of the principal components should describe more than 95% of the variance in the data.
In figure 7, the outcomes of a PCA analysis examining the connection between sleeve type and arranging pattern pieces' variants are presented using three principal components. The graph illustrates that these components collectively account for over 95% of the variance in the data. Notably, for regular and semi-raglan sleeves, the 4th arrangement option proves to be the most effective. In the case of a kimono sleeve, option 1 is notable, followed by option 2. For a dropped shoulder and raglan sleeve, option 3 emerges as the suitable choice.
The insights from analysing pattern arrangements, guided by PCA, were crucial in creating markers in the CAD system. The aim was to optimize efficiency and material usage while preserving the sleeve's original shape. Drawing upon the insights gained from PCA, the pattern pieces were manually arranged within the CAD environment to achieve layouts best suited for each sleeve type.
Upon comparison with markers generated using the CAD system's automatic layout options, the manually optimized markers exhibited significant advantages. They showcased enhanced material efficiency and reduced waste, illustrating the effectiveness of the proposed tailored pattern placement strategies. Although CAD's automatic layout options offer convenience and speed, they may not always produce the most optimized results for specific design requirements. PCA analysis guided the approach, leading to markers that are better aligned with the goals of reducing waste and maximizing efficiency through thoughtful pattern arrangement.

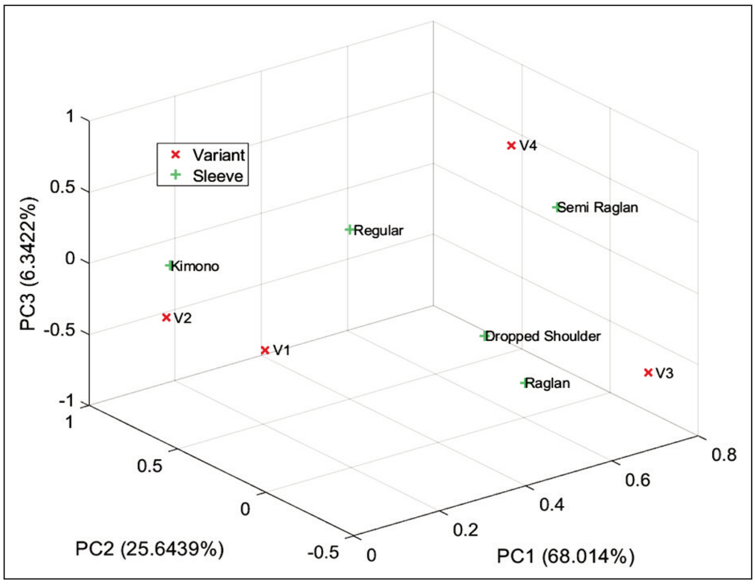

Fig. 7. PCA results for the relationship between sleeve type and pattern arrangement variant

DISCUSSION

The efficient use of resources by applying the concepts of "marker efficiency" and "filling function" can be applied in various industries, including fashion to maximize fabric utilization for enhancing cost efficiency and minimize waste. This has clear benefits for sustainability by conserving natural resources and reducing the impact of production on the environment. This complements the results of Spahiu et al. [3], according to which, by increasing the precision of fabric used, the amount of waste can be significantly reduced and the cost efficiency of production can be increased.

The designs presented are model developments based on a women's jacket construction with regular sleeves. Replacing this type of sleeves with others resulting from small design changes, while maintaining the main patterns design, leads to a reduction in the amount of material used and minimizes the cutting residue. The analysis of the patterns in a women's jacket and the choice of the type and placement of the pattern's pieces of the sleeves in the marker plan can reduce the fabric waste during the cutting process while increasing the production and use of resources efficiently. By choosing more resource-efficient designs, the fashion industry can reduce its environmental footprint, complementing the research of Secan et al. [8].

The provided results offer specific recommendations for different scenarios, such as which sleeve type and placement are best. In areas such as the fashion industry, this can encourage designers and manufacturers to make more sustainable choices, potentially reducing the environmental impact of their products, and fulfilling the recommendation of Islam et al. [11].

Leveraging data analysis, particularly through techniques like PCA, and implementing the insights derived from these analyses, has the potential to enhance resource management and formulate more effective environmental protection policies. The application of data-driven methodologies proves beneficial across diverse fields, offering valuable tools to address challenges related to sustainability.

CONCLUSION

This article examines changes in women's jacket designs with different sleeve types to reduce textile waste during cutting, promoting sustainability and environmental protection.

From the proposed options, the highest efficiency of the marker plan was observed for the following: semi-raglan sleeves (76.04%); raglan sleeves (72.03%); and dropped shoulder sleeves (72.34%).

For the raglan and semi-raglan sleeve variants, it can be seen that the filling is largely independent of the geometry of the raglan and semi-raglan shape.

In almost all marker plan variants, drop shoulder sleeves showed the most efficient usage of fabric on the marker plan.

The data showed that the lowest material consumption and reduced waste cut have been found in semi-raglan, raglan, and dropped shoulder jacket variants. Design reasons: In the drop-shoulder sleeve, the dropped shoulders shorten the length of the sleeve. The raglan and semi-raglan shape of the sleeves also shorten the length of the front and back of the jacket.

The results presented in this research have the potential to influence decision-making in textile manufacturing, leading to more sustainable practices, reduced waste and improved resource management. These results are consistent with the broader objective of sustainability and conservation, reducing negative environmental impact, and promoting responsible use of resources.

While the research at hand does not directly address constructive changes to reduce waste, the broader landscape of sustainability efforts involves multifaceted approaches that aim to mitigate waste generation and promote more efficient resource utilization.

ACKNOWLEDGEMENTS

This work was administrative and technically supported by the Bulgarian national program "Development of scientific research and innovation at Trakia University in the service of health and sustainable well-being" – BG-RRP-2.004-006-C02.

Also, the authors would like to express appreciation for the co-funding of the Erasmus+ Programme of the European Union [Project Fashion DIET "Sustainable fashion curriculum at textile Universities in Europe – Development, Implementation and Evaluation of a Teaching Module for Educators" / Erasmus+ Programme 2020-1-DE01-KA203-005657] by the NA DAAD.

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