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Adaptive method of designing a swimsuit bra

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Abstract. The relevance of the research lies in the need to develop accurate and effective methods for designing swimwear bras, considering the elastic properties of modern knitted fabrics, which will enhance the comfort and quality of the products. The purpose of the study was to develop a method of adjusting the size of the bra cup to the amount of stretching using the method of geodetic parallels. The study employed methods of mathematical modelling for the development and optimisation of swimsuit bra cups design and analysed the mechanical properties of knitted materials. The study identified representative groups of elastic knitted fabrics based on the analysis of their tensile characteristics. Two primary groups of fabrics were identified based on their fibrous composition: the first group consisted of polyamide threads blended with elastane, while the second group comprised polyester threads combined with elastane. Anthropomorphic factors affecting the inaccuracies in the unfolding of the hard surface of the cup have been identified. Recommendations have been developed for transforming the rigid unfolding into a soft shell of moulded cup parts, considering discrete elongations of knitted materials. The soft-shell construction method was based on recalculating the main dimensions of the cup, taking into account the deformation coefficients of the materials. The effectiveness of the proposed method was confirmed by comparing the deviation

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areas of the moulded cup sweeps of the basic design. The deviation of the area of 3.56% indicated the compliance of the rigid sweep with the breast surface. Mathematical models of modification methods for four types of bra cup separation have been developed. The practical value lies in the use of an effective method of designing swimwear bras that ensures precise fit and comfort by considering the elastic properties of knitted materials

Keywords: knitted fabric; bathing suit; fibrous composition; tensile characteristics; cup articulation; modification methods

Introduction

Modern trends in consumer behaviour and the high competition in the swimwear market require new approaches to traditional design technologies that consider the relationship between the consumer's body shape and the corresponding bra model. The development of swimwear bras is a challenging task due to the wide variety of materials used and the structural requirements for the parts, which must provide comfort, support, and enhance the aesthetic appearance of the body. The trend of using object dimensional control methods discussed in the study by Y. Tian & R. Ball (2020) expanded the possibilities for accurately reproducing the top part of the bra based on a moulded cup proposed by Z. Zhong *et al*. (2023). A strong correlation between the dimensional features of the cup and the product size, according to Y. Zhao (2024), allowed the use of a measuring bra to create a three-dimensional geometric model and simulate the material properties.

A promising area for creating a rigid shell of a moulded cup was the use of adaptive 3D printing technology, which was based on the principle of layer-by-layer growth of a solid object (Polishchuk *et al*., 2023). The study by M. Riabchykov *et al*. (2023) proved that the use of 3D body scanning allowed creating accurate digital copies of the body, which significantly improved the process of developing clothing, ensuring accurate consideration of anatomical features.

The widespread use of three-dimensional scanning to build three-dimensional clothing was analysed in the study by H. Xie & Y. Zhong (2019). Replacing the contact measurement with scanning simplified the technology of virtual reproduction of the body surface by introducing it into the mesh frame. A plausible model for predicting and controlling the levels of clothing fit based on neural networks with the definition of tolerances in clothing for pressure parameters and mechanical properties of fabrics measured in a 3D-virtual environment were considered in the study Z. Wang *et al*. (2021). The model predicted the quality of free and tight fit from the position of the silhouette. However, the comparison with classical models of linear regression and reference vectors was not persuasive.

3D models of women's swimsuits were used as a database to illustrate the effectiveness of a clothing design system based on the interactive genetic algorithm (IGA) and the fuzzy clustering method (FCM) in the study by T. Zarezade & P. Payvandy (2019). The application of the FCM method simplified the sorting of the model range by comparing the similarity of compositional features according to style decisions, however, the modelling effect of shaping body parts significantly depends on both the design and the materials, as proven by A. Slavinska *et al*. (2020).

The comfort of a swimsuit required specific materials due to being in both the water environment and outdoors. The social determination of the attributes of using a swimsuit also affected gender differences in women's attitudes towards the uniqueness of swimsuit items both in material and design. The purpose of this study was to develop a method for adjusting the size of a bra cup to the amount of stretch using the geodesic parallel method.

Materials and Methods

For experimental studies of the fibrous composition of knitted fabrics for bathing suits, 300 samples from well-known manufacturers have been analysed. Two groups of ratios of fibrous composition of cloth were revealed: Group 1 was the combination of polyamide threads of RA with elastane EA (86%); Group 2 was the combination of PE polyester yarns with EA elastane (14%). Fibrous composition of RA 80 ± 5; EA 20 ± 5 occupied 36.4% of the sample. Type of weave and surface density in the ratio groups were given in Table 1.

Table 1. *Structural characteristics of knitted fabrics for bathing suits*

Type of weave		Surface density, g/m^2						Total frequency of occurrence of weaves	
		155 ± 5	165 ± 5	175 ± 5	185 ± 5	195 ± 5	205 ± 5	pcs.	%
rib knit fabric		0	0	0	8	47	43	98	32.7
interlock stitch structure		8	33	90	49	8	0	188	62.6
others		2	3	6	3	0	0	4	4.7
total surface density	pc.	10	36	96	60	55	43	300	-
	%	3.3	12	32	20	18.4	14.3	-	100

Source: *developed by the authors*

The weight distribution of different weave types within the fabric groups, categorised by surface density, was illustrated in Figure 1. This graph highlighted the predominance of the interlock stitch structure across the tested samples, which constituted 62.6% of the total fabrics. Rib knit fabrics made up 32.7%, while other less common weaves account for only 4.7%. The figure clearly demonstrated that fabrics with interlock stitch structure dominate in surface densities ranging from 165 g/m² to 185 g/m², indicating their prevalence in materials designed for swimwear applications. In contrast, rib knit fabrics were primarily concentrated in the higher density range of 195 g/m² to 205 g/m², which may be attributed to their increased durability and structural stability.

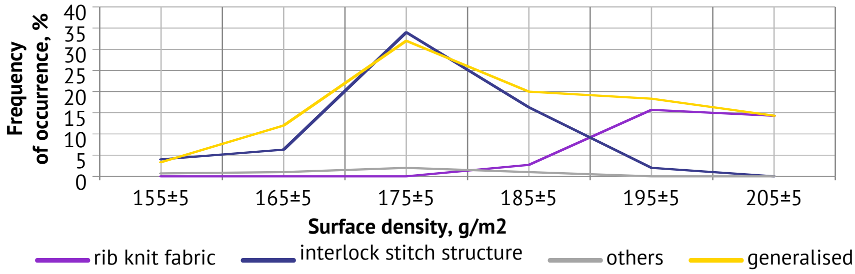


Figure 1. *Graph of the distribution of the type of weave in the structural characteristics of a knitted fabric*
Source: *developed by the authors*

Statistical characteristics of the distribution curve: arithmetic value = 175.5 g/m^2; standard deviation S = 8.81; Pearson coefficient $\chi^2 = 3.78$; the asymmetry coefficient $\gamma_1 = 1.13$, and the coefficient of variation $\gamma_2 = 1.43$ determined the choice of the base fabric for standard studies of the physiological properties of the swimsuit bra (DSTU 2319-93, 1995). This is a knitted fabric with a weave of interlock stitch structure and a surface density of 175.5 g/m^2; fibrous composition – PA 80 EA 20; number of looped columns – 230 (horizontally), 270 (vertically); height looped step – 0.43, height looped row – 0.43; thread length in the loop – 1.93 mm. The classification features of a bathing suit are the completeness of the items, the established names of the swimsuits, the construction of the bra, the presence of divisions in the details (Fig. 2).

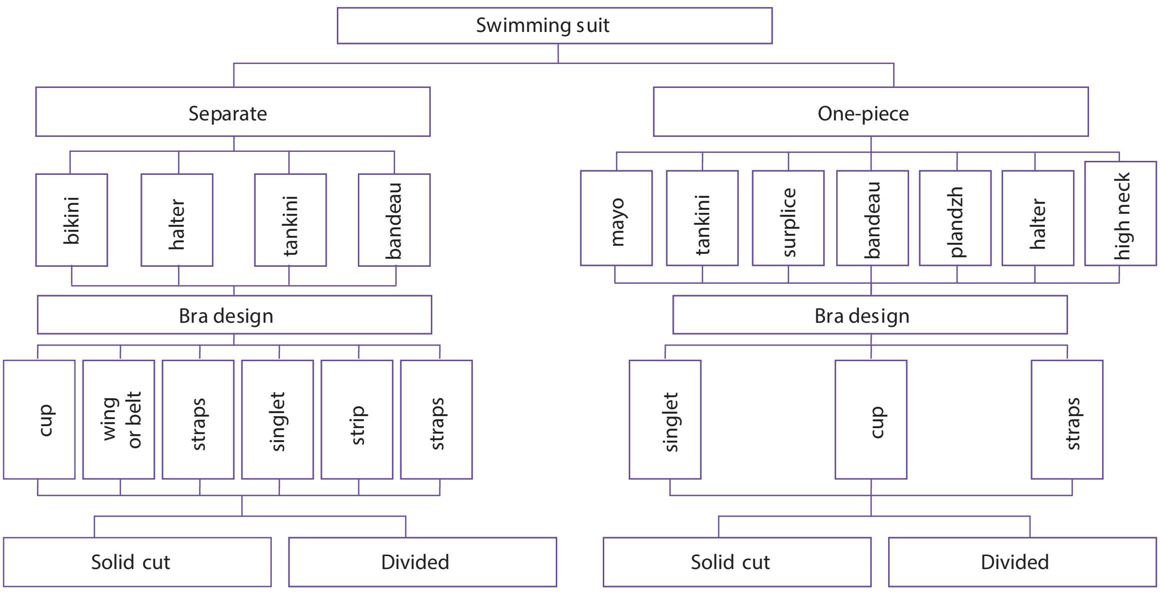


Figure 2. *Classification of bathing suits by bra construction*
Source: *developed by the authors*

According to the standard method of research on the explosive machine RT-250 used samples of 100 x 50 mm with a different surface thickness (DSTU 3045-95, 1996). The recommended duration of the ripping of the strips was 45-75 s, depending on the structural characteristics of the materials and their fibrous composition. The results presented in Table 2 summarised the statistical characteristics of discontinuous elongation along the looped columns and rows. Specifically, the table provided data on the magnitude of elongation, standard deviation (S), coefficient of variation (Cv), and margin of error (ME) for each tested fabric group.

***Table 2.** Statistical characteristics of the discontinuous elongation of knitted fabrics*

No. fabric group	Fibrous composition, %, ±5	Weave type	Surface density, g/m², ±5	Magnitude of the discontinuous elongation							
				Along the looped columns				Along the looped rows			
				$\overline{X}$, mm	S, mm	Cv	ME, %	$\overline{X}$, mm	S, mm	Cv	ME, %
1	PA 70 EA 30	interlock stitch structure	155	95.5	2.47	2.58	1.74	161.25	2.86	1.77	2.02
2	PA 70 EA 30	interlock stitch structure	165	112.47	3.48	3.1	2.20	177.87	3.24	1.82	2.05
3	PA 80 EA 20	interlock stitch structure	175	156.58	2.64	1.69	1.87	155.08	3.24	2.09	2.29
4	PA 80 EA 20	interlock stitch structure	185	182.07	2.54	1.39	1.61	152.87	2.94	1.92	1.86
5	PA 80 EA 20	rib knit fabric	195	152.17	2.06	1.35	1.46	138.0	2.01	1.46	1.42
6	PA 90 EA 10	rib knit fabric	205	110.47	3.27	2.96	2.07	178.07	3.33	1.87	2.11

Source: *developed by the authors*

Analysis of the graph of variation of the coefficient of variation Cv (Fig. 3) showed that the largest deviations of the discontinuous elongation from $\overline{X}$ base density have 1, 2, and 6 groups of surface density. This indicated the heterogeneity in the elongation properties of these fabric groups, likely due to differences in their fibrous composition and structural characteristics.

Figure 3 illustrated the relationship between the coefficient of variation Cv and the surface density groups of knitted fabrics. The data pointed on the graph represent the values of Cv for each tested group, highlighting the variability within the samples. Groups 1 and 6 exhibited higher Cv values, which corresponded to a broader dispersion of elongation data, indicating less uniform behaviour under tensile stress. In contrast, Group 3 demonstrated a nearly normal distribution, as evidenced by the low Cv, making it the most stable group in terms of elongation characteristics.

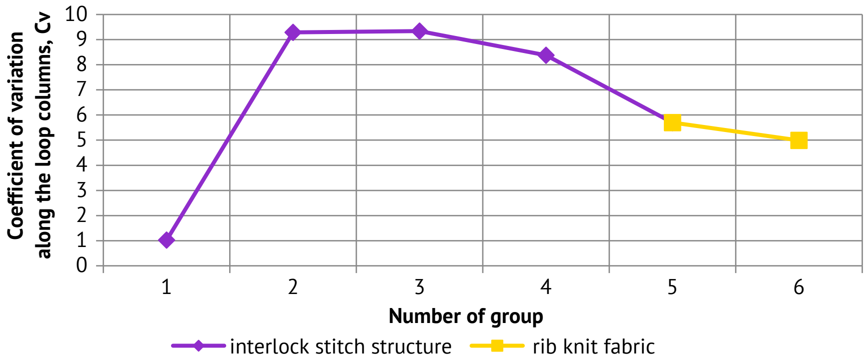


***Figure 3.** Dependence of the coefficient of variation Cv on the group of knitted fabrics under study*
Source: *developed by the authors*

To determine the change in the size of the parts on the threads of the loop columns and rows was used the coefficient of proportional elongation *Cp.el*:

$$\text{Cp.el}=\frac{L_{\text{ellgr}}}{L_{\text{elb}}}, \qquad (1)$$

where L_{ellgr} – index of strength elongation for the first group of fabric; L_{elb} – indicator of strength elongation for the base group of the fabric. The coefficient of change of the sizes of a pattern considering the structural characteristics of a knitted fabric was given in Table 3.

***Table 3.** Coefficient of change in the size of the pattern depending on the structural characteristics of the knitted fabric*

Value of the coefficient, *Cp.el*	Number of fabric group					
	1	2	3	4	5	6
by looped columns	0.61	0.72	1.0	1.16	0.97	0.71
by looped rows	1.04	1.15	1.0	0.99	0.89	1.15

Source: *developed by the authors*

Evaluation of strength characteristics for compliance with the requirements of elasticity in ensuring the physiological and hygienic properties of the swimsuit (Table 2) was performed using the triangle method, built on three axes located at an angle of 120^0 (Fig. 4). The plotted points represent the values of the elasticity parameters for each fabric group, and their positioning within the triangular field indicates the balance of tensile deformation in these directions. Fabrics that exhibit balanced elasticity properties fall closer to the centre of the triangle, while those with pronounced anisotropy (higher elasticity in one direction compared to others) deviate towards the triangle's edges.

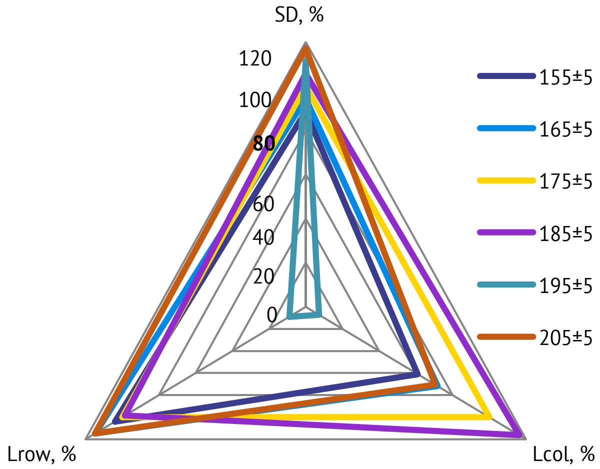


Figure 4. *Determination of complex elasticity of six groups of knitted fabrics by the triangle method*
Source: *developed by the authors*

A comprehensive study of the elasticity of knitted fabrics from Groups 2, 3, 5, 6 confirmed their belonging to the fabrics with a deviation of elastic deformation within 2... 5% in relation to Group 3. The state of skew before the appearance of folds in the fabric is called critical, and the angle between the loop rows and columns is called critical angle ϕ. The smaller the angle ϕ, the higher the ability of the fabric to shape.

Engineering methods based on the approximation of unfolded surfaces with a sufficiently high degree of accuracy in the shell, which was strictly coordinated on the surface, take into consideration two principles (Kämmerer, 2024):

- methods of Chebyshev scans from mesh materials for the formation of the surface lining;
- replacement of the unfolded surface with unfolding sections.

Since the shape of the cup surface was set by a rigid model of the shape of the breast, the equilibrium state of the lining provided a method of geodetic parallels (Fig. 5), which preserved the changed network angle during the transition to the state of UV-grids (Fan *et al.*, 2024).

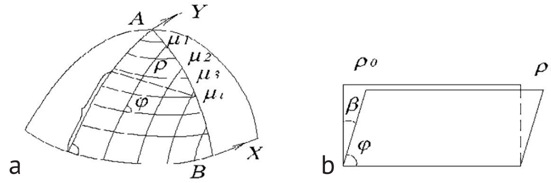


Figure 5. *Reproduction of the shape of the breast by the method of geodetic parallels*
Note: *a – geodetic coordinates of points in the shell of a spherical surface; b – change in the area of the scan during the skew of the fabric threads*
Source: *developed by the authors*

The property of changing the network angles when converting flat knitwear into a lining state was called moulding. It was accepted to estimate formation not by a networking angle ϕ, and an additional angle βmax: $\beta max = 90° - \phi$. βmax depended on the structure of the material and the type of equipment. The non-uniformity of the change of ϕ_{crit} as the tensile deformation increases both along the loop rows and along the loop columns was illustrated in Figure 6.

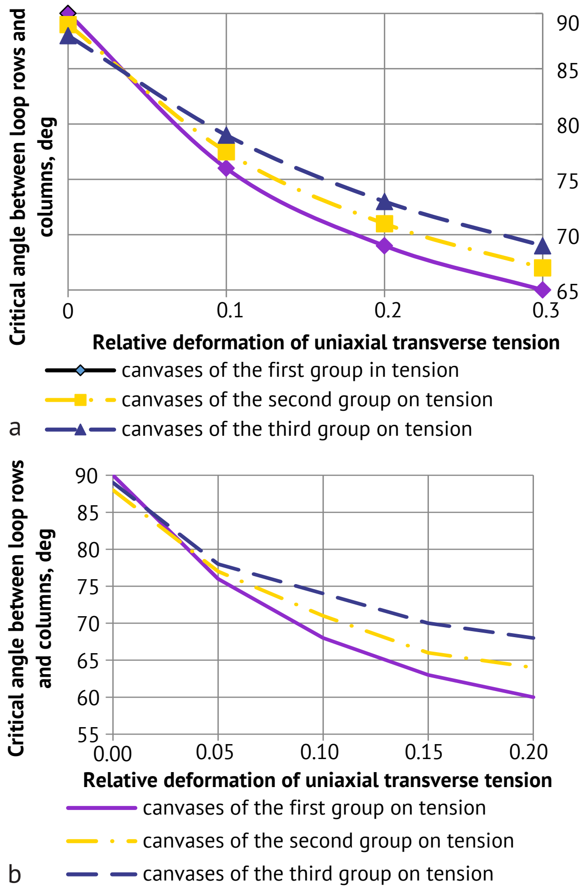


Figure 6. *Change in the ability of the canvas to skew*
Note: *a – in a transverse; b – in a longitudinal tension*
Source: *developed by the authors*

The process of warping the fabric was described by equation (Bobrova *et al.*, 2018):

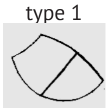
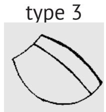
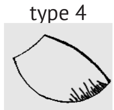
$$\cos\phi = \frac{1}{2}\left[\frac{1}{(1\pm E_x)^2} + \frac{1}{(1\pm E_y)^2}\right](1+E_g)^2 - 1, \quad (2)$$

where ϕ – angle between the loop rows and columns, deg; *Ex* – relative deformation of the fabric along the loop rows that accompanies the skew; *Ey* – relative deformation of the fabric along the looped columns, which accompanied the skew; *Eg* – relative deformation of the web in the diagonal direction, when the fabric was skewed. Consideration of the pressure on the body and changes in the wear resistance of the web to assess the moulding properties of practical importance were tensile deformations *Ex* from 0 to 0.3, *Ey* from 0 to 0.15.

If the error of the corners in the shells of knitwear was assumed to be permissible ± 1.5°, based on the accuracy of the calculations, the intervals of indifference of the forming indicators will be equal to: $\Delta\beta_0$ = ± 1.5%, ΔC = ± 6.0°, $\Delta\mu x$ = $\Delta\mu$ = ± 0.07. These average values of the formed indicators were used to characterise all the fabrics of the group. Therefore, when designing knitted products by the method of shells, it was advisable to obtain a shape skewed in combination with uniaxial transverse tension of the fabric.

Since the bathing suit was made on the basis of underwear, the initial data for the construction were similar to corsetry. The construction of the swimsuit bra was based on the construction of the general-purpose bra, which ensured the formation of the breasts. As the bra determines the shape and location of the breasts, its construction was closely related. Classification features of the construction formation of the moulded cup as a prototype of the breast were the indentation and internal divisions, which determined the model decisions of the cup relative to the neckline. The results of the analysis of structural types of the top of the moulded cup were presented in Table 4.

Table 4. *Analysis of the construction features of the moulded cup top*

Quantitative indicator		**Sketch of a model of the moulded cup top**				
		type 1 	type 2 	type 3 	type 4 	∑
Total value	pcs.	38	72	71	65	246
	%	15	30	29	26	100

Note: *type 1 – vertical relief; type 2 – vertical or horizontal indentation; type 3 – horizontal relief; type 4 – drapery*
Source: *developed by the authors*

The most common types of cup divisions were vertical relief and indentation – 45%, horizontal relief – 29%, drapery at the bottom of the bra – 26%. Model of moulded bra cup, size 75B corresponded to size 158-88-96 according to DSTU ISO/TR 10652:2006 (2009) and hemispherical shape of the breast. In the direction of division, the original deployment lines, in order to reduce the values of skew angles, should be allocated in the form of geodetic lines: the *X* axis passed through the point O (convex point of the nipple) parallel to the neckline, the *Y* axis – through the point O perpendicular to the *X* axis. Thus, the bra cup was divided into four structural zones within a Cartesian coordinate system, which characterised the anthropometric correspondence to the shape of the breast: the upper part of the cup – I and III zone, the lower part of the cup – II and IV zone, the front part of the cup – III and IV zone, the side part of the cup – I and II zone (Fig. 7).

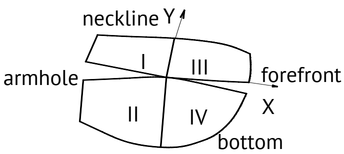


Figure 7. *Constructive zones of the bra cup in the Cartesian coordinate system*
Source: *developed by the authors*

The accuracy class of deployment was determined by the step of the location of geodetic lines relative to the original axes of deployment, which in study was equal to 10 mm. To build a scan with a vertical relief (type 1), it should connect the cells in the form of transverse stripes relative to the axis B, starting from the armhole of the cup in zone II – with the transition to zone IV and respectively in zone III – with the transition to zone I (Fig. 8, a). For vertical indentation (type 2), the construction of the scan can be started from the vertical geodetic line (*Y* axis) in the directions of the cup edges (armhole, front), connecting the cells in transverse strips (Fig. 8, b).

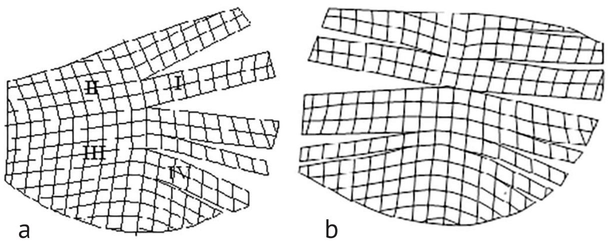


Figure 8. *Drawing of a cup scan with a vertical articulation of the top*
Source: *developed by the authors*

For horizontal division, the construction of the scan started from the horizontal geodetic line (*X*-axis), connecting the cells in the form of longitudinal strips. To scan the horizontal relief (type 3) longitudinal strips of zones were formed by connecting cells from the neckline to the geodetic line of the *X* axis, longitudinal stripes of zones II and IV were obtained by connecting cells from the *X* axis to the edge lines relative to the *Y* axis (Fig. 9). The option of forming a geodetic indentation (type 2) considered the minimum deviation of the contours of the zone from the geodetic lines of the *X*, *Y* axes.

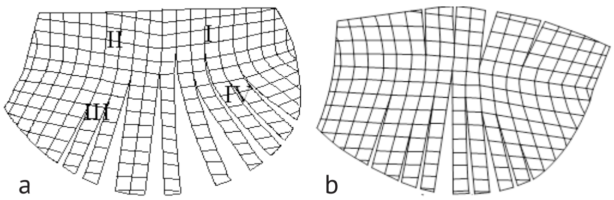


Figure 9. *Drawing of the cup sweep with a horizontal division of a bra top (type 3)*
Source: *developed by the authors*

To form draperies in a certain area, the construction should be started on the opposite side of the cup from the location of the drapery, using techniques for constructing a scan with vertical relief for draperies from the armhole (Fig. 10, a), techniques for modelling horizontal relief – for draping from the bottom (Fig. 10, b). Figure 10 illustrated two approaches to constructing draperies on the cup top. On Figure 10 (a), the method for creating draperies starting from the armhole was demonstrated. The scan was formed by connecting cells in vertical stripes, ensuring a smooth transition of relief folds across the cup surface. This approach was particularly suitable for designs emphasising vertical symmetry and structural stability. Figure 10 (b) showed a technique of forming the horizontal drapery, where cells were connected longitudinally, starting from the lower edge of the cup. This method created a softer visual effect and was commonly used for aesthetic enhancement in the lower section of the cup.

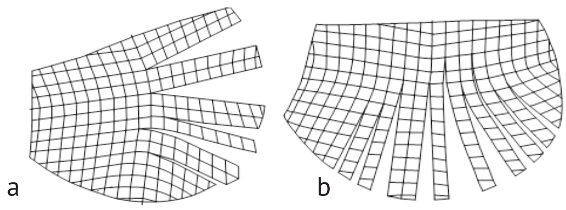


Figure 10. *Drawing of the sweep of the cup top with drapery (type 4)*
Note: *a – from the armhole; b – from the bottom*
Source: *developed by the authors*

The presented data and graphical illustrations comprehensively highlight the structural and mechanical characteristics of the tested fabrics, emphasising the relationship between surface density, weave type, and elasticity parameters. The developed drawings of the bra cup design with different types of division (vertical, horizontal, drapery) provide flexibility in choosing design solutions, in particular, considering the characteristics of the fabric and anthropometric parameters.

Results and Discussion

The results focused on identifying optimal fabric characteristics, analysing deformation properties, and creating mathematical models to ensure precise fit and comfort. The interlock stitch structure fabric was selected for approbation of the engineering method of the construction in the sample, which belongs to the third group of elasticity (L ⩾ 100 mm). According to the set of combinations *Ex*, *Ey* using the graph of skew lines (Fig. 8) determined the relative deformation of uniaxial transverse *Ex* and longitudinal tension Ey. The coordinates of new points were found using the equation:

$$X_i = X_{0i}(1 \pm E_x), Y_1 = Y_{0i}(1 \pm E_y), \qquad (3)$$

where X_i, Y_i – new coordinates of points; X_{0i}, Y_{0i} – initial coordinates of the points.

The results of calculations Ex, Ey, Xi, *Yi* were given in Table 5.

Table 4. *Results of calculations Ex, Ey, Xi, Yi*

Zone number	Ex_i	X_i, mm	Ey_i	Y_i, mm	$\overline{\varphi_i}$
I	-0.016	$O_2 = 0; X_1 = 9.5; X_7 = 9.8$ $X_4 = 0$	0.05	$O_2 = 0; Y_1 = 0$ $Y_7 = 4.1; Y_4 = 8.9$	79.2⁰
II	-0.009	$O_1 = 0; X_1 = 9.5; X_5 = 8.8$ $X_3 = 0$	0.03	$O_1 = 0; Y_1 = 0$ $Y_5 = 3.3; Y_3 = 5.3$	97.2⁰
III	-0.012	$O_3 = 0; X_2 = 9.3; X_6 = 8.5;$ $X_3 = 0$	0.04	$O_3 = 0; Y_2 = 0;$ $Y_6 = 3.5; Y_3 = 5$	80.0⁰
IV	-0.043	$O_4 = 0; X_2 = 9.3; X_4 = 0$	0.14	$O_4 = 0; Y_2 = 0; Y_4 = 8.1$	109.1⁰

Source: *developed by the authors*

The resulting points, calculated based on the relative deformations *Ex* and *Ey*, were connected by smooth lines to form the contours of the top details of the moulded cup. These contours accurately reflect the deformation characteristics of the fabric under transverse and longitudinal tension, ensuring a precise fit of the moulded cup to the body. The data presented in Table 6 summarised the calculated coordinates X_i and Y_i for each zone of the cup, derived from the base measurements and adjusted for the material's deformation properties. The drawing of the soft scan, illustrated Figure 11, highlighted the adjusted contours, which ensure the cup maintains its intended shape and fits comfortably. By incorporating deformation coefficients into the design process, the resulting scan achieves a balance between aesthetic appeal and functional performance, particularly in terms of elasticity and comfort. This approach enhanced the overall quality and precision of the moulded cup construction, making it suitable for applications in swimwear and other garments requiring complex 3D shapes.To test the resulting construction in the sample seam allowances were added to the templates, the details were cut out, the parts were sewn together and placed on the moulded cup, checking the conformity of the contours and the shape of the top of the moulded cup surface. To determine the limit values of the parameters of the forming elements, namely the indentations, the obtained scans of the elementary sections were oriented in the basic grid of drawings of the basic structure relative to the lines passing through the nipple point. Slice lengths were measured along these lines in the base structure and rigid scan structures (Table 6) to within ± 1 mm.

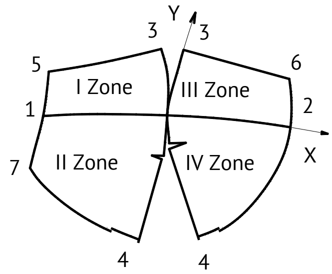


Figure 11. *Drawing of the modified cup construction*
Source: *developed by the authors*

Table 6. *Determination of the sections' lengths of the of the divisions of the cup in the base construction (BC) and the matrix construction (MC) of the rigid scan of the moulded cup*

Name of the scan option	Cut length, cm				Deviation of the length of sections of RSS BS, %	
	BC		MC			
	x	y	x	y	x	y
Scan of the cup top with vertical relief	18.8	14.7	18.8	14.7	0	0
Scan of the cup top with horizontal relief	18.8	14.7	18.4	13.8	2.1	6.1
Scan of the cup top with a dart	18.8	14.7	18.5	14.5	1.6	1.2
Scan of the cup top with drapery	18.8	14.7	19.2	14.5	2.1	1.2

Source: *developed by the authors*

The error in determining the length of the curve, when replacing it with a broken relative to the original horizontal was determined by the equation:

$$\delta_e = \frac{l_{BC} - \Sigma l_{MC}}{l_{MC}} \times 100\% \ , \quad (4)$$

where l_{BC} – horizontal length of the BC at the level of the nipple point, cm; l_{MC} – length of the matrix construction at the level of the nipple point, cm. The error δ_e for rigid scans of the matrix structure was respectively 0.75%, which does not exceed 2%. The rationality of the construction was investigated by comparing the areas of deviation of the darts formed on the surface and shown in Table 7. The deviation of the sum of the areas of deviation of the darts was determined by the equation:

$$\delta_S = \frac{S_{BC} - \Sigma S_{MC}}{S_{BC}} \times 100\%, \quad (5)$$

where S_{BC} – area of the base structure, cm^2; S_{MC} – area of the matrix structure, cm^2.

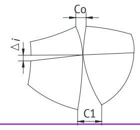
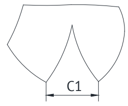
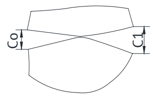
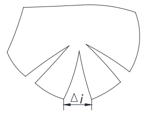
Table 7. *Determination of the divergence areas of the cup darts in the matrix construction of the scan*

Basic construction (BC) of knitted fabric, sm^2	Matrix construction (MC) of the scan, sm^2	Deviation of areas, %
16.85	16.27	3.56

Source: *developed by the authors*

The sum of the areas of darts in the MC was less than the area in the BC within 5%, which does not exceed the value of the error established for light industry. Therefore, MC was more rational for transformation into a model construction The results of the study using a rigid shell to build a matrix structure of the moulded cup of the breast confirmed the conformity of the original surface, and the soft shell was built by recalculating the control measurements by the values of tensile strain coefficients. According to the results of the analysis of modified rigid scans in the corresponding type of model construction of the cup top, the corresponding mathematical models of MM were obtained, which described the analytical dependences of a general look on the values of design parameters. Examples of mathematical models describing the modification functions of 4 types of construction were given in Table 8.

Table 8. *Mathematical models for modifying (MM) the types of design solutions on the top of the moulded bra cup*

Modifying function	Conversion scheme	Mathematical model
Type 1 F16 – design of vertical division		$P_{ud} = C_o + \Delta$ $P_{ld} = C1 + \Delta$ $\Delta = \sum \Delta_i$ P_{ud} – the slope of an upper dart P_{ld} – the slope of a lower dart
Type 2 F13 – distribution of the slope of the darts in a typical place of formation		$C1 = C1 + \Delta$
Type 3 F16 – design of horizontal division		$P_{fd} = C_o + \Delta$ $P_{ltd} = C1 + \Delta$ $\Delta = \sum \Delta_i$ P_{fd} – the slope of a forefront dart P_{ltd} – the slope of a lateral dart
Type 4 F14 – conical extension of the part for draping		$C1 = l_{ltd} = C_0 + \Delta$ $\Delta = \sum \Delta_i$ l_{ltd} – the slope of a lateral dart

Note: *C1 – the value of the i-th section of the structure obtained by transforming the BC; Co – initial length of the contour of the i-th section of the BC; Δ – the slope of the dart*
Source: *developed by the authors*

The use of modern digital tools for developing computer-based 3D models of moulded bra cups according to gradation parameters significantly reduces the preparation time for 3D printing of inserts, ensuring an aesthetic breast shape. Additionally, digital technologies enable the creation of a graphical representation of the modification process for four types of moulded bra cup designs, followed by simulation fitting on a 3D model, which facilitated the optimisation of structural solutions. This process provided a comprehensive understanding, of how different materials and design features interact, allowing designers to achieve superior results, while minimising errors and material waste.

In the study by H. Han *et al.* (2020), a method for designing swimwear patterns based on the anthropometric characteristics of the consumer was proposed. However, the material properties, which were crucial for ensuring proper fit and comfort, were not considered in their approach. The study by E.D. Kocak *et al.* (2024) focused on analysing the properties of fabrics used for swimwear, highlighting their mechanical and elastic characteristics. Nevertheless, the design and construction aspects of swimwear products, such as bra cups, were left unaddressed, limiting the practical application of their findings in comprehensive garment development.

The authors Y. Sun *et al.* (2019) proposed a personalised modelling system for bra cups and the human body using the finite element method. While their research offered valuable insights into the geometric and structural aspects of bra cup design, it does not take into account the material properties, which significantly influence the deformation and wearability of the final product. X. Wen *et al.* (2022) analysed the visual perception of bras based on their main structural elements, focusing on aesthetic and perceptual characteristics without addressing technical and functional properties. In contrast, this study focused on adapting the design of swimsuit cups to the elastic properties of knitted materials to ensure fit accuracy and comfort.

B. Baidak *et al.* (2023) discussed the use of 3D body scanning to create customised bras, focusing on the use of digital technology to improve design accuracy. In contrast, this study focused on adapting the design of swimwear cups to the elastic properties of knitwear materials, which ensured comfort and precise fit. The study by J. Zhou *et al.* (2023) explored the relationship between the design attributes of sports bras and the perception of their comfort among elderly women, focusing on social and anatomical aspects without addressing the technical aspects of design. In contrast, this study emphasised the adaptation of swimsuit cup constructions to the elastic properties of knitwear materials to ensure precise fit and comfort.

In the study by J.C.L. López *et al.* (2024), a method for classifying swimsuit fit on the body was presented, with a focus on utilising artificial intelligence to analyse fit parameters. In contrast, this study emphasised the adaptation of swimsuit cup designs to the elastic properties of knitted materials to ensure precise fit. Both papers aimed to optimise garment design; however, the researchers focused on AI tools, while this study highlighted the physical and mechanical properties of materials. C. Malbon *et al.* (2020) investigated the impact of breast size and bra type on the comfort of female police officers in the UK, while wearing body armour, focusing on ergonomics and comfort in specific operational conditions. This study focused on adapting the design of swimsuit cups to the elastic properties of knitted materials to ensure a precise fit and comfort without addressing the broader technical aspects of design.

The study by A. Yu *et al.* (2022) considered the development of a bra cups made of three-dimensional knitted material based on full fashioned knitting technology, which allows the cups to be manufactured seamlessly in one step, starting with yarn. The main focus was on optimising the production process and using innovative materials to create a structured and comfortable cup shape. Both papers were aimed at optimising the cup design, but A. Yu *et al.* (2022) focused on improving production methods and technologies, while this paper emphasised on the physical and mechanical properties of materials and their impact on the final fit of the garment.

This study stood out because it focused on adapting swimwear cup design to the elastic properties of knitwear materials to ensure a precise fit and comfort, unlike other papers that emphasised different aspects of garment design. By placing a strong emphasis on the interaction between material science and garment construction, the study provided valuable insights into the role of fabric stretchability and deformation in achieving an ideal fit. It highlighted the importance of integrating materials science into practical design processes to achieve optimal fit, comfort, and functionality, particularly for swimwear, which requires a delicate balance between support, durability, and flexibility. Furthermore, the research underscored the significance of precision in the design of moulded bra cups to meet diverse consumer needs, setting a new benchmark for the innovative application of engineering principles in textile design. This approach not only enhanced user satisfaction, but also introduced a methodology that can be extended to other categories of functional apparel, demonstrating the potential for interdisciplinary collaboration in advancing garment design technologies.

Conclusions

Classification features of knitted fabrics for bathing suits are fibrous composition, surface density of loop rows and loop columns, type of weave. Evaluation of the complex indicator of elasticity to ensure the physiological and hygienic characteristics of the swimsuit confirmed the feasibility of using as a base fabric canvas of the third group with a fibrous composition of PA 80.5%, EA 20.5% (36.4%) weave interlock stitch structure with a surface density 175.5% g/m^2, with the coefficient of elongation on the loop row and column Quid = 1. The results of the study adequately characterised the elastic deformation of 4 from 6 groups of fabric samples.

Construction of details' scans of the top of a formed bra cup by an engineering method of geodetic parallels considered types of divisions of bra models on a sign of reflection of fashion tendencies and observance of the conditions of preserving the aesthetic functionality formulated by leading manufacturers. To verify the morphological features of the shape of the breast in the configuration of the divisions of the top of the moulded cup, an experimental test of mathematical models describing four types of internal divisions of the cup construction by a rational route of modification of a rigid scan constructed by a grid of geodetic parallels. The swerving of the deviation areas of the darts of the matrix construction of the moulded cup and the base structure for the knitted fabric was 3.56%. The soft shell was built by recalculating the main dimensions of the cup according to the values of the coefficients of tensile strain.

Prospects for further research include the development of integrated digital platforms for automating design processes and optimising designs based on individual anthropometric data and fabric characteristics.

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Conflict of Interest

None.

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Адаптивний метод конструювання бюстгальтера для купальника

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Анотація. Актуальність дослідження зумовлена необхідністю розробки точних і ефективних методів проєктування бюстгальтерів для купальників з урахуванням еластичних властивостей сучасних трикотажних тканин, що сприятиме підвищенню комфорту та якості виробів. Метою дослідження була розробка методу коригування розміру чашки бюстгальтера відповідно до ступеня розтягування за допомогою методу геодезичних паралелей. У дослідженні використовувалися методи математичного моделювання для розробки та оптимізації конструкції чашок бюстгальтера купальника, а також аналізувалися механічні властивості трикотажних матеріалів. Визначено репрезентативні групи еластичних трикотажних тканин на основі аналізу їхніх розтяжних характеристик. Виділено дві основні групи тканин за їхнім волокнистим складом: перша група складалася з поліамідних ниток у поєднанні з еластаном, друга – з поліестерових ниток у поєднанні з еластаном. Виявлено антропоморфні чинники, що впливають на неточності у розгортанні жорсткої поверхні чашки. Розроблено рекомендації щодо трансформації жорсткого розгортання у м'яку оболонку формованих деталей чашки з урахуванням дискретних подовжень трикотажних матеріалів. Метод побудови м'якої оболонки ґрунтувався на перерахунку основних розмірів чашки з урахуванням коефіцієнтів деформації матеріалів. Ефективність запропонованого методу підтверджено шляхом порівняння площ відхилення формованих розгорток чашки базової конструкції. Відхилення площі на 3,56 % свідчило про відповідність жорсткого розгортання поверхні грудей. Розроблено математичні моделі методів модифікації для чотирьох типів поділу чашки бюстгальтера. Практична цінність роботи полягає у застосуванні ефективного методу проєктування бюстгальтерів для купальників, що забезпечує точну посадку та комфорт, враховуючи еластичні властивості трикотажних матеріалів

Ключові слова: трикотажна тканина; купальний костюм; волокнистий склад; розтяжні характеристики; членування чашки; методи модифікації