designs

Article

Development of Ballistic Protection Soft Panels According to Regulatory Documents

Dana Barkane [1], Marianna Grecka [1], Dana Almli [1], Viktorija Mecnika [2] and Inese Ziemele [1,*]

[1] Institute of Architecture and Design, Riga Technical University, LV-1048 Riga, Latvia; dana.barkane@rtu.lv (D.B.); marianna.grecka@rtu.lv (M.G.); dana.almli@rtu.lv (D.A.)
[2] ZF LIFETEC, E4/C Seatbelt Textiles, 73553 Alfdorf, Germany; vmecnika@gmail.com
* Correspondence: inese.ziemele@rtu.lv

Abstract: The development of Ballistic Protection Vests (BPVs) has gained significant attention, particularly focusing on the design of Ballistic Protection Soft Panels (BPSPs), which are crucial to the overall size and configuration of these vests. Despite their critical role, there is a noticeable lack of a standardized design method for surface area patterns of BPSPs in the existing literature. The findings indicate that the National Institute of Justice (NIJ) standard 0101.06 Ballistic Test Templates (BTTs) are only partially applicable to the design of BPSP patterns. While the NIJ standard 0101.06 provides a useful framework, it requires adaptation to meet the specific needs of regional body types and the practicalities of BPV manufacturing. This research aims to address this gap by assessing the suitability of NIJ BTTs for the design of BPSPs and BPVs and to develop a standardized pattern design methodology along with a method for calculating the surface area of the soft amour prior to its creation. Results have to be achieved ready for the production of BPSP patterns tailored to the body types of regional soldiers while adhering to relevant standards and soldier's physical comfort, thereby saving time and resources for manufacturers and researchers. In this study, we evaluated the applicability of the NIJ standard 0101.06 BTT for configuring these templates into the cutting patterns of BPSPs. To achieve this, patterns for BPSPs were designed and the feasibility of using NIJ BTTs for their configuration was analyzed. The research process involved a comprehensive literature review, an analysis of the dimensions of existing BPV soft panels, and a comparison with NIJ standard 0101.06 BTT. The design and scaling of the panel patterns were executed using computer-aided design (CAD) systems and evaluated through both physical fitting on mannequins and virtual fitting using the Clo3D program. The developed pattern-making methodology includes size specifications tailored to regional covers, incorporating a coefficient K identified to calculate the BPSP surface area prior to design. This approach not only ensures better fitting for the physical comfort and protection of soldiers but also saves time and resources in the manufacturing process of BPSPs. The proposed design methodology offers a significant step forward in standardizing BPSP patterns, promising enhanced protection and efficiency in BPV manufacturing.

Keywords: ballistic protection vests; body armor; soft panels patterns; pattern making; design; NIJ standards

check for updates

Citation: Barkane, D.; Grecka, M.; Almli, D.; Mecnika, V.; Ziemele, I. Development of Ballistic Protection Soft Panels According to Regulatory Documents. *Designs* **2024**, *8*, 76. https://doi.org/10.3390/designs8040076

Academic Editor: Yuping He

Received: 20 June 2024
Revised: 22 July 2024
Accepted: 29 July 2024
Published: 31 July 2024

1. Introduction

The development of individual BPVs is critical globally due to the high demand in both civil and military defense sectors [1,2]. To ensure optimal protection and comfort and to meet the stringent requirements of modern personal protective Equipment (PPE) [3], modern BPVs must comply with NIJ standard 0101.07 [4], widely used among NATO member states. Enhancing the physical comfort and mobility of the wearer can be achieved through flexible BPV construction and design, task-specific compliance, weight reduction, and the creation of BPVs tailored to specific sizes, accommodating various body types within the target audience.

The primary functional components of a BPV are the soft panels and the hard plates, both of which provide critical protection against ballistic impacts. The size and features of a BPV are predominantly determined by its BPSP. According to the National Institute of Justice Selection and Application Guide 0101.06 [5] to Ballistic-Resistant Body Armor, "The standard does not dictate how armor must be designed; rather, it prescribes what it must be able to do. This ensures that body armor meets officers' needs, yet leaves manufacturers free to innovate". Furthermore, the guide [5] states, "To provide for uniformity in testing, the standards [4,6] provide five Ballistic Test Template (BTT) sizes for soft armor panel samples (C1, C2, C3, C4, and C5). These templates are designed to represent 95% of officers, although they are not indicative of service armor design and are required for testing purposes only" [5]. This implies that the only design parameter of NIJ standard [4,6] BTTs that is relevant to manufacturers is the surface area of the soft panel.

Given that the surface area of the panel is significantly influenced by the primary dimensions of the soft panel—length and width—and that the guide [5] claims the BTTs are intended to cover a wide range of officers' bodies, this study aims to determine the feasibility of using NIJ standard [6] test templates, adapted to human body proportions, as the basis for the dimensions of BPV soft panels. Additionally, it seeks to investigate whether other manufacturers have utilized these BTTs in their design solutions.

The primary objective of this research is to develop methodology for the design of BTT patterns suitable for the body types of regional soldiers across all necessary sizes, ensuring compliance with NIJ standards [4,6] and STANAG 2335 ("Interchangeability of Combat Clothing Sizes") [7]. The goal is to achieve an optimal balance between ballistic protection and physical comfort. This study explores the possibility of using standardized BTTs [4,6] for BPV design in total and specially to develop a pattern design methodology that could be employed by manufacturing and research companies for BPSP pattern production.

Currently, no comprehensive methodology exists for the design of the soft panel patterns that adhere to the guide [5] and standard STANAG 2335 [7], potentially saving companies considerable time in locating relevant information and ensuring compliance with minimum requirements without extensive research. Often, companies may bypass the research phase to expedite the design, relying on existing market panels without fully understanding the correlation between parameters and human body proportions, thereby compromising both the physical comfort and ballistic protection of the BPV.

This methodology can also be valuable for researchers focusing on improving soft panels dimensions and BPVs in aspects beyond size fitting. The study involves analyzing regulatory documents and technical information on globally produced soft panels dimensions, designing soft panel patterns for specific regions, fitting them on appropriate figures, and assessing their compliance with standards [4,6,7] requirements. The proposed methodology's broad applicability was tested on 16 different BPSP and BPV sizes in two variations: as an outer garment and as an undergarment.

The development of a standardized methodology for the design of patterns for soft panels not only facilitates compliance with regulatory standards but also enhances the efficiency and effectiveness of BPSP manufacturing. By ensuring that soft panels are tailored to the specific body types of regional soldiers, this research contributes to the creation of more comfortable and protective BPVs, ultimately improving the safety and performance of military personnel.

2. Materials and Methods

This research was initially based on the NIJ standard 0101.06 [6] and later evaluated against the updated NIJ standard 0101.07 [4]. The methodology comprises several key steps:

- *Literature Review*: Conducting an extensive review of existing standards and BPV soft panel configuration's designs.
- *BPSP Pattern Design*: Developing and scaling soft panels patterns using CAD systems, based on the typical measurements of regional soldiers.

- *Fitting Evaluation*: Assessing the patterns through physical fitting on mannequins and virtual fitting using the Clo3D program.
- *Algorithm Development*: Formulating an algorithm for design of patterns for soft panels, incorporating necessary improvements and adjustments identified during the fitting process.
- *Comparative Analysis*: Comparing the surface areas of NIJ BTTs [4,6] with the designed patterns of soft panels to evaluate their applicability.

The study aims to assess the suitability of NIJ test templates [4,6] for BPSP an BPV design and to develop a standardized pattern design methodology for the manufacturing of soft panels, thereby saving time and resources for producers and researchers.

This research was conducted based on NIJ standard 0101.06 [6] and its updated version, NIJ 0101.07 [4], released in October 2023. Consequently, the designed BPSP patterns and development methodology were reassessed to ensure compatibility with the updated standard. Despite supplementations in NIJ 0101.07, such as improved test methods for designing women's BPVs, more rigorous testing of soft panels and references to standardized test methods, and laboratory practices, it was determined that there were no significant changes affecting BPSP patterns design. Although NIJ standard 0101.07 [4] does not specify the surface area for the production of soft panels, it retains the same test template sizes and configurations. The standard states, "...the supplier selects the templates to be used based on the range of sizes over which the armor model will be produced". This necessitates comparisons between production soft panels and NIJ test templates, particularly in terms of surface area. For this research, test templates from NIJ standard 0101.06 [6] were utilized due to their convenient metric measurements, which are not included in NIJ standard 0101.07 [4].

2.1. BPV Types and Design Recommendations

According to the NIJ standard [4], two types of BPVs can be distinguished based on their usage: undergarment BPVs, designed to be concealed and typically consisting only of soft panels, and outer garment BPVs, which may include hard plates for additional protection depending on the required protection level. Outer garment BPVs can also incorporate various elements and accessories necessary for specific work duties. Unlike the NIJ standard, which primarily focuses on requirements and performance, more specific recommendations for BPV design and body interaction points are found in the guide [5] and are summarized in Table 2. For instance, the frontal panel shall start at the nape of the neck and extend to 2–3 finger widths above the waistline. The guide [5] also explains the use of the proposed C1-C5 Ballistic Test Templates (BTTs) [4,6]. The width and length gradation step were defined using the STANAG 2335 standard [7], adopting the unified size designation—an 8-digit code for more precise size comparison between member states.

2.2. Analysis of Existing BPV Soft Panels

The study included an analysis of BPV soft panels currently used by the national army, involving a pattern comparison of sample parameters with NIJ standard [6] test templates in both printed and CAD formats. The surface area corresponding to each test template was used to determine the characteristics of the soft panels and to assess whether the proposed NIJ standard test templates and requirements were considered in their design [5,6].

2.3. Data Collection and Adaptation

Due to the absence of up-to-date information on regional soldiers' body measurements, the national literature from previous periods was reviewed [8,9] and measurement tables from global BAV companies [8,10–18] were surveyed. In collaboration with a local military clothing manufacturing company, these measurement tables were re-worked to reflect the current situation in the region.

2.4. Determining Ease Allowances

Seven different layers of military clothing were placed on a size-appropriate mannequin to measure the differences between an uncoated and a clothed mannequin in chest and waist circumferences. This helped to determine the required pattern's making ease allowances for the outer garment and undergarment BPVs and for those BPSPs [19].

2.5. Design and Fitting Evaluation

The soft panel patterns were designed and scaled using a CAD system based on typical regional soldier measurements. Fitting evaluations were conducted on an adjusted mannequin and virtually using the Clo3D CAD system's fitting module. The suitability of the patterns for different sizes within the target audience was assessed. All improvements and changes identified during the fitting process were analyzed and digitally incorporated into the soft panel patterns in the CAD system.

2.6. Development of Design Methodology

The design methodology was developed as an algorithm, incorporating all necessary improvements, analyzing them, and summarizing the development progress of the soft panels. This comprehensive methodology aims to assist companies in saving time and ensuring compliance with minimum standards without extensive research. It also serves as a valuable resource for researchers focusing on aspects of soft panel and BPV improvement beyond size fitting.

3. Discussion

The research reveals that although NIJ standard [4,6] test templates provide a useful starting point; they are only partially applicable to the design of patterns for soft panels surface area. By identifying a coefficient K for calculating the soft panel surface at the pattern development stage, the study offers a practical tool for optimizing the design process, thus enhancing efficiency and resource management.

3.1. Determination of Research Data

BPV design criteria can be divided into three groups: ballistic energy absorption, wearer comfort and mobility, and product accessibility. When designing BPVs, including their soft panels, demanding tasks such as: maximum absorption of ballistic energy, comfort of the wearer, usability, compliance with regulatory documents, reduction in the total weight of the product, flexibility of the design, and reduction in product costs must be solved (see Figure 1) [5–7,20,21].

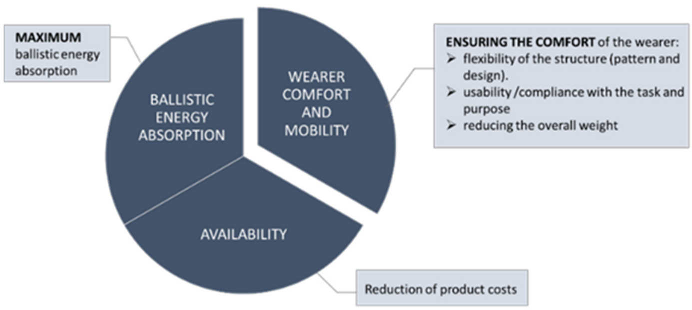

Figure 1. BPV design criteria and tasks (author's image).

Each BPV is designed for a specific level of protection [22] according to the speed of the bullet which can reach 398–990 m/s and impacts the body with different forces. The NIJ standard 0101.06 [6] distinguishes five levels of protection from IIA to IV levels, where IIA is the least ballistic energy absorption. Each subsequent level can also protect against the threat of the previous levels. Since October 2023, there has been a separate NIJ standard, 0123.00, for the ballistic protection levels and associated test threats [22]. To improve the physical comfort and mobility of soldiers in the designed BPV, the level of protection must be first determined. The BPSP developed within this research was designed for level IIIA (NIJ 0101.06) of a BPV, which according to the new standard, NIJ standard 0123.00. [22], is NIJ HG2 (9 mm Luger FMJ RN 124 grain 0.44 Mag JHP 240 grain), as this is the highest level for which the necessary protection can be achieved only with soft panels.

Depending on the protection level, size, and type, an assembled BPV can weigh between 3 and 25 kg [10–18]. A higher level of protection can be achieved by increasing the number of layers of soft panels and adding hard plates, as well as other additional protective parts (shoulder, neck, upper arm, throat, groin, etc.). These measures result in a heavier and less flexible BPV assembly, interfering with the soldier's daily tasks [6,21].

3.2. Physical Comfort of the BPV

The product's functionality is critical for the soldier's efficiency and is closely related to the number of layers of clothing worn underneath and the amount of equipment that can be attached to the BPV. Functionality is determined by the work tasks to be performed by the wearer and the actions required for their completion. For example, this could be the ability to quickly change the layers of clothing worn underneath, run, bend, and squat freely, stand in battle positions, and so on [23]. When designing the soft panel configuration, it is necessary to pay attention to physical comfort, which is directly related to freedom of movement and coherence with the body surface.

In order to choose suitable anthropometric data for the specific product, it is essential to identify which parts of the body will be covered by the BPV and to what extent, what physical activities need to be performed, and how long they need to be performed by the wearer [21].

Freedom of movement can be evaluated in field experiments, for example with a worn prototype trying to walk, sit, climb, run, pick up an object from the floor, or simulating the movements that are necessary for a soldier's everyday life, such as placing a weapon on the shoulder and throwing a grenade.

For example, the important body measurements for the design of shoulder garments is the width of the shoulders, because when raising the arms up, the shoulder width of a soldier decreases by 4.6–5.8 cm, while the width of the armpits when extending the arms forward increases by 9.3 cm [23]. This example clearly demonstrates that changes in body measurements during movement must be considered in the pattern making of soft panels.

3.3. Dimensions of the BPSP

According to the NIJ standard 0101.06 [6], the basic characteristic of soft panels is their surface area. The NIJ standard [6] defines three different area limits for each panel size:

- The first is a ballistic test template surface area with a very accurate configuration, according to which soft panels are prepared for ballistic protection tests;
- The second and third are the maximum and minimum surface areas for production soft panels to be placed in protective vests, specifying only their configuration with specific indications about panel overlapping in the side parts and indications ensuring the ergonomic comfort of the BPV wearer in the neck, waist, and arm areas.

Table 1 presents the main characteristics of the soft panel test templates under the NIJ standard. According to these characteristics, the proposed test templates were verified to determine whether they can be adapted to the human body and used in panel production. As well, other manufacturers' soft panels were compared to determine whether they adhered to them in their designs.

Table 1. Summary of the main characteristics of NIJ standard test templates [6].

	Surface Area, mm^2		Width (A), mm		Height (B), mm		Upper Part Width (C), mm	
	Min	Max	A_{min}	A_{max}	B_{min} (Front/Back)	B_{max}	C_{min}	C_{max}
NIJ-C1	<98,000	98,000	292.2	317.5	262.9/292.1	317.5	228.6	254
NIJ-C2	98,000	139,900	406.4	431.8	313.7/342.9	368.3	254	279.4
NIJ-C3	139,900	189,000	520.7	546.1	364.5/393.7	419.1	279.4	304.8
NIJ-C4	189,000	245,500	635	660.4	415.3/444.5	469.9	304.8	330.2
NIJ-C5	245,500	>245,500	749.3	774.7	466.1/495.3	520.7	330.2	355.6

The guide [5] contains suggestions for the selection of BPVs and indicates exact points where the soft panels need to start and end on the soldier's body, which also helps in the designing of the soft panel patterns. For example, the front panel must start directly from the jugular notch and end 4.45–6.67 cm above the working belt. All of the requirements specified in the document supplementing the NIJ standard [6] regarding the side cover of the panels and the indications ensuring the physical comfort of the BPV wearer in the neck, waist, and arm areas are summarized in Table 2.

Table 2. Guide [5] requirements regarding the design and use of soft panels in BPVs.

No.	Requirement	Front Panel	Back Panel	Instructions for Outer Garment BPVs
1.	Side coverage	Front and back panels overlap at least 5.08 cm on each side.		-
2.	Height	It should extend from just below the jugular notch to two to three finger-widths above the top of the belt when the individual is in the standing position.	Should extend from approximately 5.08 cm below the collar to approximately 2.54 cm above the belt.	They can be slightly longer without impeding movement or comfort.
3.	Armpit area coverage	Ballistic coverage under the arms should be as high as possible without compromising the ability to reach a shooting position.		They may afford slightly greater protection in this area.
4.	Surface area	The minimum and maximum specified in the NIJ standard must be maintained.		A larger area of the body should be covered, and more protection should be provided.
5.	Fit	It should fit snugly but not so tightly that it may affect breathing (including deep breathing, such as that which may occur during an on-foot chase). The armor should slide slightly on the body as the torso is rotated back and forth.		Less tight/looser
6.	BPV and soft panel's physical comfort check	When trying on the soft panels and the BPV itself, soldiers must conduct various daily movements, such as rotating their upper bodies or sitting down, to ensure that the soft panels are not "sitting" on the belt and the upper edge is not pressing against their neck.		

Considering the above summary, the soft panels were configured using the dimensions C and D of the relevant size BTT from Figure 1. of this article, covering the entire minimum border area of the upper part of the test template. Dimension A changes depending on the chest and waist circumferences of the human body, which are supplemented with the constructive allowances (undergarment BPV: 1–4 cm, outer garment BPV: 3–7 cm) and the side coverage width, while dimension B changes according to the human body's height.

These dimensions also serve as features of the soft panels that are going to be created, allowing us to analyze their compatibility with the proportions of the human body. Figure 2 illustrates the locations of all dimensions on the soft panel.

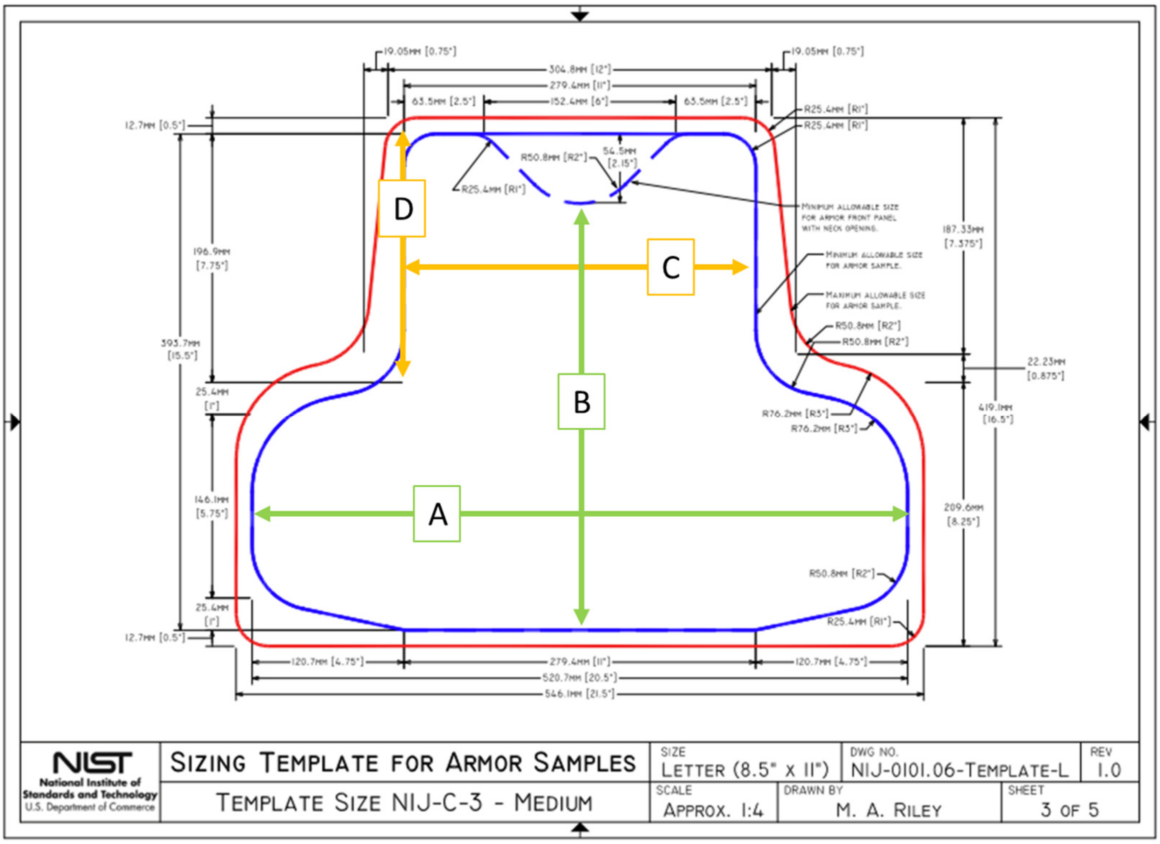

Figure 2. NIJ C3 test template [6] for soft panels with the main dimensions marked, where A is the panel's width, B is the panel's height, C is the panel's upper part width, and D is the panel's upper part height. The blue line indicates the test template's minimal parameters, while the red line indicates the maximum.

3.4. Configuration Analysis of Ballistic Protection Soft Panel Samples Used in the Military

In order to improve the BPVs and BPSPs used in a certain region, it is necessary to understand the product range and configurations that are already in use; therefore, an analysis of available soft panel samples was carried out.

Soft panel patterns from two manufacturers, "Company A" and "Company B", were studied and analyzed to determine their conformity with the requirements of NIJ standard 0101.06 [6] and the indications of accompanying documents [5], presented in Tables 1 and 2 and Figure 2.

3.5. The First Requirement: Surface Area of BPSPs

Table 3 shows the dimensions of the analyzed BPSPs according to their surface area which adheres to a specific NIJ standard [6] test template. The study determined that the analyzed BPSP samples did not cover all test templates; only soft panels of NIJ-C3 and NIJ-C4 sizes were available for the sample assessment.

In total, 15 samples of soft panels were examined—five outer garment BPV soft panel sets, two undergarment BPV soft panel sets, and one undergarment BPV back panel.

In comparison, the areas of the outer garment BPV size S2 soft panels of both manufacturers showed minimal differences: 0.0095 m^2 for the front panel and 0.0016 m^2 for the back panel.

Table 3. Adherence of the analyzed samples of the BPSP to test templates NIJ-C3 and NIJ-C4 [6].

Title 1	Allowable Surface Areas for Production BPV, Min–Max, m^2	Manufacturer, Name of the Analyzed Soft Panel	Size	Type of Wear	Surface Area, m^2		Height B, cm		Width A, cm	
					Front Panel	Back Panel	Front Panel	Back Panel	Front Panel	Back Panel
NIJ-C3	0.1399–0.1890	"Company A", S1	S1	Outer garment	0.1710	0.1436	34.3	36.6	64.6	52.2
		"Company A", S2	S2		0.1770	0.1635	36.6	39	64.8	59.4
		"Company A", S3	S3		0.1832	0.1838	39.2	41.9	64.6	66.8
		"Company A", paper	S1/S2		0.1635	0.1505	36	38.5	61	56.8
		"Company B", No. 39/57, No. 37	S2		0.1675	0.1651	35.7	38.7	61.5	62
		"Company B", No. 15/16, No. 13/14	LL	Undergarment	0.1523	0.1639	37	44	54.5	56.8
NIJ-C4	0.1890–0.2455	"Company B", No. 27	2XLL	Undergarment	-	0.1999	-	49	-	64.5

3.6. The Second Requirement: Configuration of BPSPs

To determine whether these companies used the dimensions from the relevant test templates specified by the NIJ standard, all three dimensions, A, B, and C (see Figure 2), were estimated for the soft panel samples and compared to the NIJ-C3 and NIJ-C4 test template [6].

First, the width, or dimension A, of the soft panels were compared. Since the test templates specified in the standard do not include side overlap, but the manufactured samples do, to ensure that both sizes are graphically comparable, it is assumed that the minimum expected side overlap of 5.08 cm was used and distributed symmetrically on the front and back soft panels (see Figure 3).

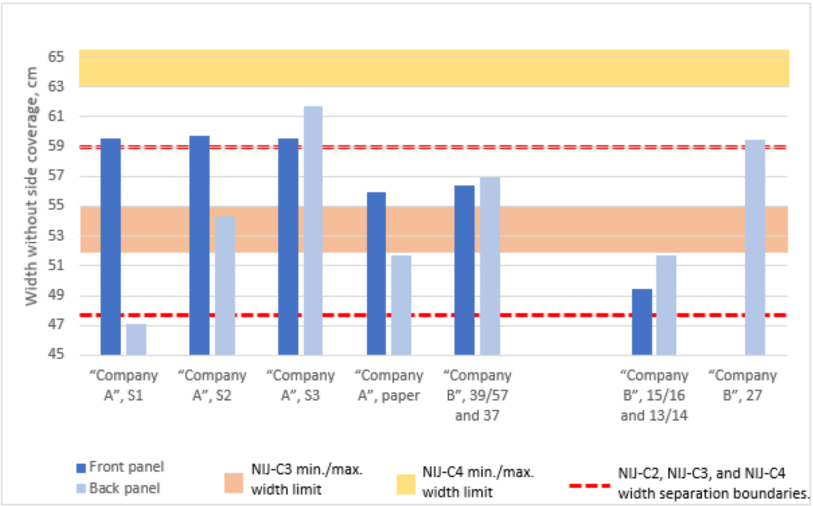

Figure 3. Comparison of the width (A) of the BPSP samples with the corresponding NIJ standard [6] test templates.

The vertical axis indicates (Figure 3) the widths of the soft panel pairs (front and back) without side coverage. The minimal and maximal limits of the NIJ-C3 and NIJ-C4 test template [6] widths are marked in orange.

The graphic in Figure 3 clearly illustrates that the majority of the soft panels in width A correspond to the relevant test template. The widths of the outer garment BPV soft panels on the left slightly exceed the maximum width limit of the NIJ-C3 test template, the front panel by 0.3 to 0.7 cm and the back panel by 2.35 cm for the S3 size (Company A), yet the back panel of S1 size (Company A) does not exceed NIJ-C3 by 0.7 cm.

3.7. Determination of the Height B of BPSPs

The NIJ guide [5] specifies the required position of soft panels in relation to specified anthropometric points on the body (see Table 3). This demonstrates that the height B of the soft panel is proportionate to the length of the soldier's torso. For panels of the same size designed for users of different heights, the height B will differ.

Document [5] specifies that the front panel should extend from below the jugular notch to two to three finger-widths (4.45–6.67 cm) above the top of the belt when the individual is in standing position. The back panel should extend approximately 5.08 cm below the collar and 2.54 cm above the belt.

Figure 4 illustrates the height B dimensions of all investigated soft panels. It was determined that the studied undergarment BPV soft panels were designed for tall users with torso lengths above 50 cm; therefore, the height B of the back panels exceeds the maximum height B restrictions of the NIJ-C3 and NIJ-C4 test templates [6]. On the other hand, the height of the front panel B is less than the minimum height restriction of the NIJ-C3 test template [6], which can be explained by the allowable neckline recess of up to 5.54 cm.

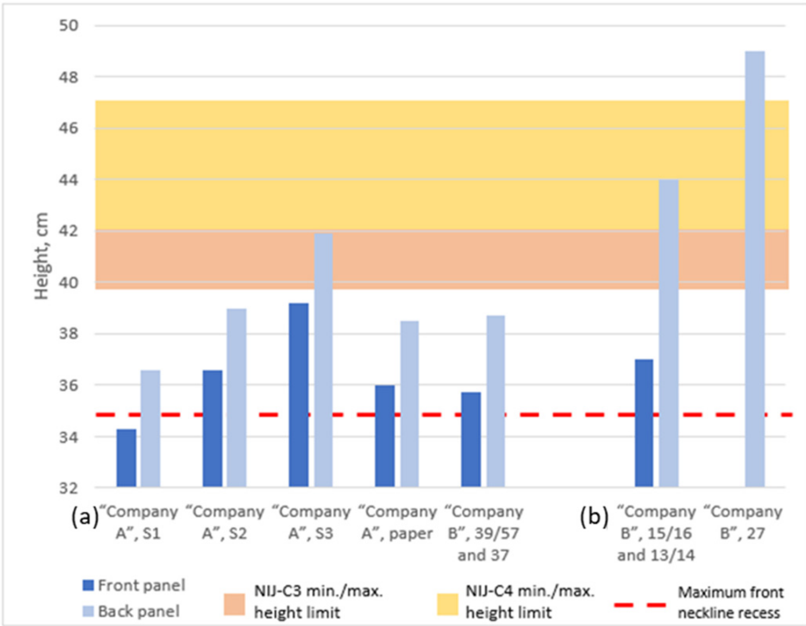

Figure 4. Comparison of the height B for BPSP samples with the NIJ-C3 and NIJ-C4 test templates [6]: (**a**) outer garment and (**b**) undergarment.

The comparison of the outer garment BPV soft panel dimensions of both manufacturers showed that their height B measurements did not reach the minimum specification limit of the corresponding NIJ-C3 test template [6] height B. This could be because the BPV can be accompanied with shoulder and neck protectors to cover the sections of the body not protected by the BPV soft panels. Protectors overlap with the front and back soft panels. However, it should be noted that shoulder and neck protectors are not always used.

3.8. Determination of the Top Width C of BPSPs

The top width C (Figure 2) of the analyzed outer garment BPV front soft panels mostly exceeds the maximum limit value of the NIJ-C3 test template [6], while the back panels are below the minimum limit value (see Figure 5) by 0.7 to 2.1 cm. Undergarment back panel No. 27 is 4.3 cm shorter than the NIJ-C4 test template's [6] minimum top width requirement.

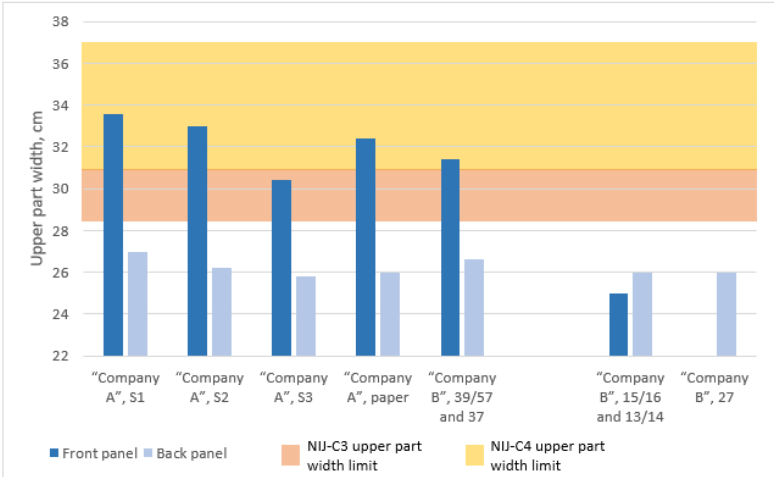

Figure 5. Comparison of the upper part width (C) of BPSP samples with the NIJ-C3 and NIJ-C4 test template [6] limits.

The upper part width of the examined soft panel front parts has an obliquity (E) of 4.2 to 6.3 cm, which significantly exceeds the maximum of 1.9 cm allowed by the NIJ standard test templates [6] (see Figure 6). However, given that the C parameter of the studied soft panel samples mostly exceeds the maximum limit of the NIJ-C3 test template [6], the larger obliquity helps to bring the mid-width of the top ($C_{average}$) closer to the standard. This can be explained by the intention to reduce the area of the soft panels and thus increase the protection in the armpit area.

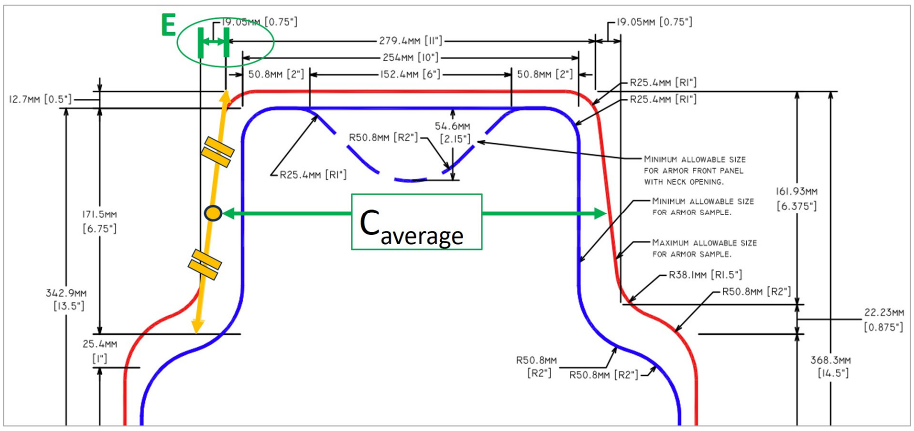

Figure 6. Allowed obliquity (E) of the BPSP upper part width (C) of NIJ standard test templates [6].

Even though measurement C of analyzed panel No. 27 should be within the NIJ-C4 test template's [6] limits, the upper part width of the undergarment BPV soft panels does not even satisfy the NIJ-C3 test template's [6] minimal limit. The upper part width of this panel is narrowed by 1.5–4.2 cm compared to dimension C of the NIJ-C3 test template [6].

3.9. Determining the Configuration of BPSPs

By matching the contours of the front and back undergarment BPV soft panels of "Company B" with the corresponding NIJ-C3 test template [6] (see Figure 7 with the blue contour), the overall dimensions and configuration of the soft panels are compared to the NIJ standard test template [6].

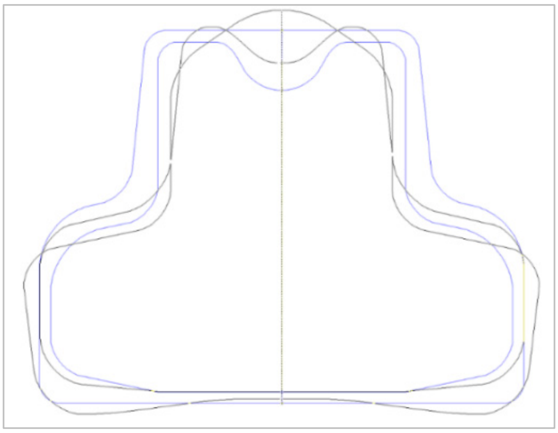

Figure 7. Comparison of "Company B" LL-size undergarment BPV soft panels' configuration (black line) with the NIJ-C3 test template [6] configuration (blue lines).

As the soft panel height B is increased to fit tall users with torso length > 50 cm [19], this causes an increase in the total surface area. In order to keep the soft panel fit in the specific area of the NIJ-C3 test template [6], the upper corners of the back panel have obliquity.

Looking at the configuration of the undergarment BPV soft panels relative to the configuration of the corresponding NIJ standard test template [6], it can be seen that the bottom edge of the soft panels is curved to provide a snug fit. The size of the curve depends on the difference between the chest and waist circumferences of the soldier's figure, as well as the tolerances in those circumferences.

3.10. Output Parameters for Designing BPSP Patterns

The NATO standard STANAG 2335 [7] mandates that each member state produce a minimal range of sizes sufficient to meet national demand. At the local military clothing production facility, company analysis revealed that the regional body type varies significantly, with heights ranging from 160 to 200 cm and chest circumferences spanning from 80 to 140 cm. This variation presents challenges in standardizing BPVs while ensuring adequate fit and protection for all soldiers. Consequently, the production strategy must accommodate this diverse range of body dimensions while adhering to the NATO directive for a limited size range.

To ensure modularity and comparability of ballistic protection vests (BPVs) across all NATO member states, the STANAG 2335 [7] prescribes a graduation step by length and circumference group sizes of 5, 10, and 15 cm, with each step being divisible by 5. Additionally, the standard specifies a size marking code consisting of eight symbols: the first four digits indicate length graduation, while the subsequent four digits represent chest circumference graduation. This standardized approach facilitates uniformity and interoperability of BPVs within NATO forces, ensuring that the protective equipment meets the diverse sizing requirements of military personnel across different nations.

The designed BPSP patterns were graded for three distinct body heights: short (168 cm), regular (182 cm), and long (196 cm). Figure 8 illustrates the comprehensive coverage of these full-size patterns. The numerical size designations adhere to the codes established in the STANAG 2335 standard [7], whereas the letter designations facilitate easier comparison at the national level. This dual labeling system ensures both international standardization and local usability, enhancing the effectiveness and adaptability of ballistic protection vests.

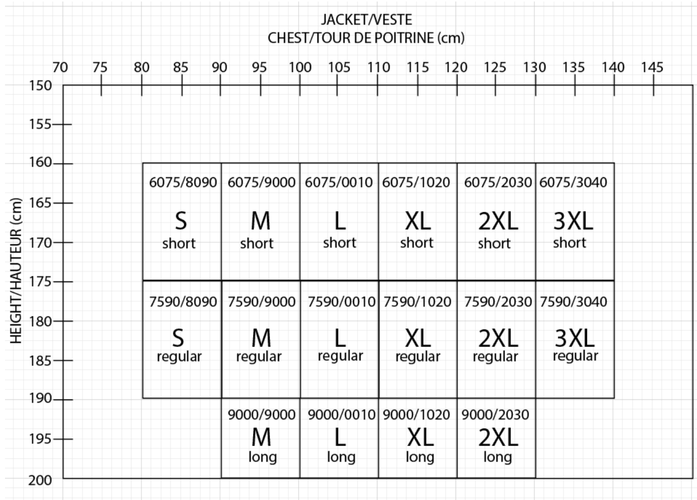

Figure 8. National sizes coverage for BPVs.

Obtaining current body measurements for the specific region posed significant challenges, as the available measurements were outdated, and companies were reluctant to share their accumulated measurement systems. Developing a comprehensive table of measurements for the target audience, through direct measurement and compilation, is a time-consuming process necessitating separate research. To address this issue, all previously published literature sources of measurements [8,9,19] were consolidated into a single chart and provided to Company A for updates based on the current situation. This process resulted in updated measurements required for all 16 sizes, with gradation specified according to the STANAG 2335 standard [7].

To estimate the required tolerances for chest and waist circumferences, a mannequin was fitted with multiple layers of army clothing, and the resultant increases in circumferences at the chest and waist levels were observed. As illustrated in Figure 9, the outer garment BPV is worn over these layers of garments. The thickness of six layers worn under the BPV increased the chest circumference by 10 cm and the waist circumference by 7 cm. Consequently, the average tolerances for the outer garment BPV were determined to be 5.8 cm at the chest and 3.7 cm at the waist. These measurements are critical for ensuring that the BPV provides adequate protection while accommodating the bulk of additional clothing layers.

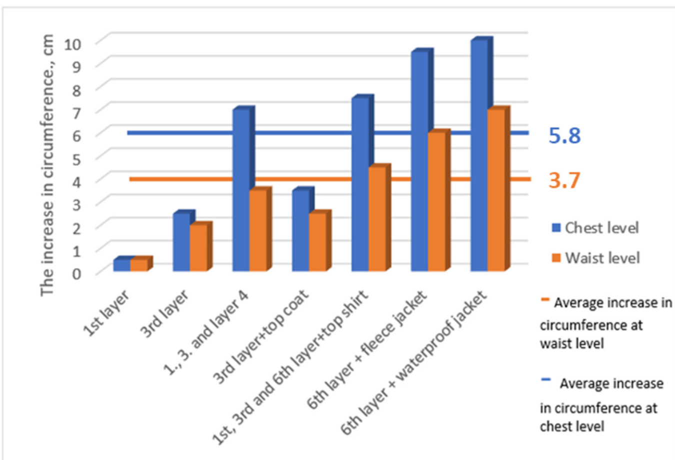

Figure 9. An increase in the circumference of layers of clothing worn under the outer garment BPV at chest and waist level.

The undergarment ballistic protection vest (BPV) is typically worn over the first layer of clothes, consisting of one or two undershirts. This positioning allows the BPV to be designed with smaller tolerances, as illustrated in Table 4. Conversely, the presence of multiple layers of clothing worn beneath the outer garment BPV, and potentially even beneath the undergarment BPV, necessitates larger tolerances. These increased tolerances directly impact the surface area and configuration of the soft panels, ensuring that the BPV provides adequate protection while accommodating the additional bulk of the clothing layers.

Table 4. Values of pattern design tolerances for undergarment and outer garment BPV.

Designation	Name	Tolerance Value for Undergarment BPV, cm	Tolerance Value for Outer Garment BPV, cm
V_{kra}	Tolerance in chest circumference	4	7
V_{va}	Tolerance in waist circumference	2	4
V_{mgpl}	Tolerance for back width	1	1.75
V_{krpl}	Tolerance for front width	0.5	8.8
V_{rocei}	Tolerance in armpit area	2.5	4.37

3.11. Designing Patterns for BPSPs

During the design of the patterns for BPSPs, the first challenges arose and contradictions in the standards were revealed. For example, the NIJ standard states that the soft panel should cover the largest possible body area to obtain the maximum absorption of ballistic energy. When designing the first version exactly according to the maximum characteristics of each size of the proposed NIJ standard test templates [6] and determining the area of each designed soft panel, it was discovered that the area of the M regular size for the back panel, used for comparison, was bigger (0.1841 m^2) than the investigated “Company B” No. 13 and No. 14 BPSP samples of comparable size (0.1639 m^2). Furthermore, the upper part width C of the panel is at its maximum limit (indicated with a red circle in Figure 10) according to the standard LVS EN 13921:2007 ergonomics criteria [20]. This causes the soldier in discomfort to stretch their arms forward. The contradictions that emerged during the creation of Version 1 indicate that an unreasonable increase in the surface area of soft panels reduces physical comfort and interferes with mobility, as the increased surface area limits movement. Additionally, this approach requires more fabric, making the soft panels and BPV heavier. The green circle line in Figure 10 illustrates a corner that can be rounded to a bigger diameter to minimize the area, as the front panel overlaps the back panel at this location.

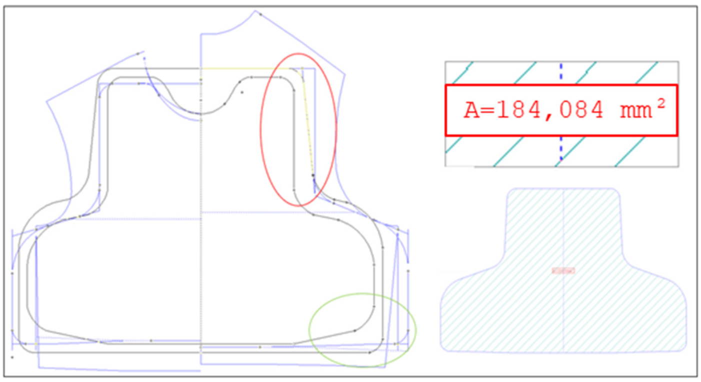

Figure 10. Version 1 of the back panel pattern of M regular size (developed in CAD Grafis).

All of the issues mentioned above were solved in the next version of patterns for BPSP configuration development. To ensure that the back panel was not noticeably larger than the front panel in the second version within the BPV of the same size, the top corner obliquity was designed for the back panel (Figure 11 with the red circle line), and the front panel was given 90% of the side overlay size. In this version, the area of the back soft panel for M regular size was 0.1498 m^2, which is less than the 0.1639 m^2 of the studied sample no. 14 and significantly less than the area of the pattern in Version 1.

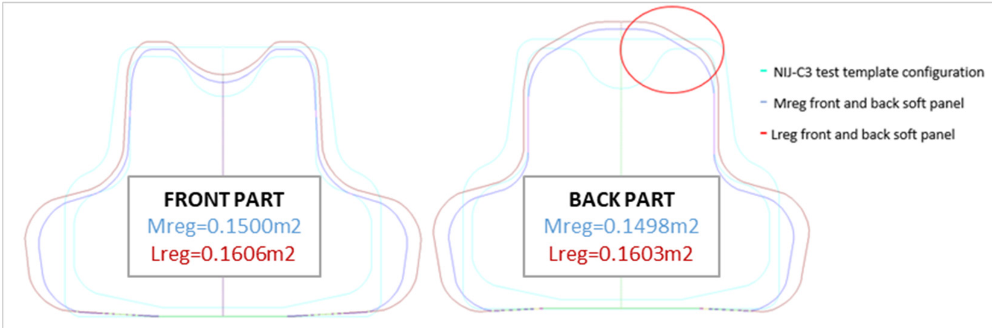

Figure 11. Version 2 comparison between the M and L regular size BPSP configuration with the corresponding NIJ-C3 test template [6] (developed in CAD Grafis).

However, when sizing Version 2, it was challenging to meet the national demand for the height range of 160–200 cm and chest circumference of 80–140 cm. Specifically, when grading the back panels for shorter soldier figures and comparing them to the NIJ standard test templates, the obliquity of the corners significantly reduced shoulder coverage by 5–7 cm. This reduction in shoulder coverage consequently diminishes the overall ballistic protection provided by the vest.

The first two versions of the BPSP configurations were designed to fit seven sizes, ranging from XS to XXXL, ignoring soldier height differences within one size. This option satisfies the STANAG standard requirement [7] to cover the demand for the smallest sizes only at the national demand, making the BPV more convenient for manufacturing and assembly between NATO alliance countries. However, when grading and measuring against the specific soldier figure, it was determined that this type of gradation does not completely cover all demands, reduces ballistic protection for taller soldiers due to shortened BPV and BPSP torso proportions, and unnecessarily increases surface area and weight for shorter users, reducing their comfort, mobility, and overall ballistic protection.

Next, the third version of the soft panel configuration design was created on the 16 sizes shown in Figure 8, with six short sizes from S-3XL, designed for shorter soldiers from 160–175 cm in height, with the next six regular sizes for heights between 175 and 190 cm, and four additional sizes for tall users—over 190 cm in body height. Figure 12 illustrates the configuration of version 3 and the M regular size surface areas for the front and back panels.

Figure 12. Comparison of Version 3 M regular-sized soft panel configuration with the equivalent NIJ-C3 test template [6] (developed in CAD Grafis).

The third version's M regular size BPSP patterns was measured on a mannequin that matched the soldier figure's chest circumference of 100 cm and waist circumference of

86 cm. The fitting indicated that the side overlay should be designed symmetrically for the front and back panels. When adding 90% of the overlay to the front panel, the BPV closure moves to the back, making it more difficult to close, open, and adjust. However, in general, the soft panel pattern's design was adequate for the corresponding NIJ test template [6] (see Figure 13), and fitting in the CAD program Clo3D virtual environment for sizes S–XL in short, regular, and long height variations could be performed.

Figure 13. Fitting of the size M regular BPSP mock-up on an appropriately sized mannequin.

When preparing the soft panels of different sizes for virtual fitting, the sideline displacement of the front and back panels that did not appear in the actual fitting was discovered (see Figure 14 with the yellow and orange circle line). The analysis showed that this displacement had occurred due to the different starting points of the soft panels above the work belt (see Figure 14 red circle), which ranged from 4.45 to 6.77 cm in the front to only 2.54 cm in the back and were not aligned in the side seam. The same displacement of the sideline was also obvious in the Clo3D fitting (see Figure 15), and it was fixed in the final version, which is illustrated in Figure 14 with dashed lines: red for the back and green for the front.

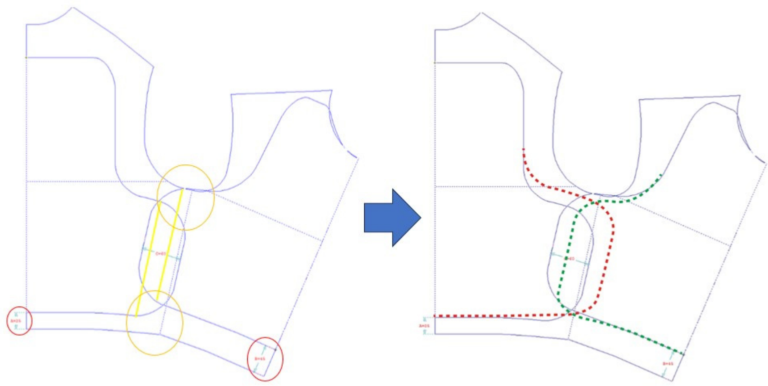

Figure 14. Displacement of the front and back BPSP patterns in the sideline for the M regular size (developed in CAD Grafis).

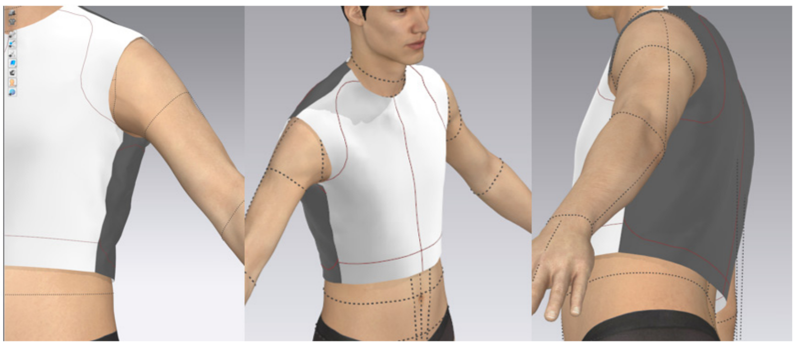

Figure 15. Virtual fitting of the BPSP patterns for M regular size in the Clo3D program.

The outer garment BPV soft panels were designed based on the undergarment BPV soft panel patterns, with changed tolerances. The top of the front panel straightened toward the junglar notch and coverage increased in the armpit and chest areas. However, when sewing and placing the BPV with inserted soft panels and hard plates on the appropriately size mannequin, a new defect was revealed. Because of the hard plate that did not match the body curves identically and gave free space between the BPV and waist, the BPV was too small for the relevant size, unable to form the minimum 5.08 cm side overlay [5] (see Figure 16). Detailed analysis indicated that the hard plate and the layers of clothes worn underneath significantly increase the volume at the waist level. Therefore, when designing the patterns for outer garment BPV soft panels, the chest circumference needs to be equal to the waist circumference.

Figure 16. Outer garment BPV's first fitting for size M regular.

4. Results

In the results, the development methodology for the design of BPSP patterns for the undergarment and outer garment BPV were designed, and the values of the BPSP's surface area's coefficient K were determined by addressing the previously mentioned issues, adhering to the NIJ standards [4,6], the guide [5], and a thorough literature analysis [19–21,23]. The studied dimensions and configurations of existing BPV soft panel examples were considered, ensuring that the BPV meets national requirements while remaining adaptable to the individual body types of soldiers, thus fulfilling the research's purpose.

Using the developed methodology, the soft panel patterns were designed for three different body heights—short, regular, and long—providing optimal ballistic protection coverage without adding unnecessary weight to users of the same size but with different body heights. Figure 17 illustrates the complications that arise when height size gradation is not performed. The figure indicates, in green, that an average body height of approximately 180 cm is suitable, but shorter and taller users will encounter issues.

The research concluded that the guide [5] provided more detailed instructions for designing soft panels in relation to the proportions and specific points of the human body, particularly regarding the A and B dimensions. However, the NIJ standard [4,6] test templates serve as a useful starting point for manufacturers and researchers who are new to this field. These templates help in verifying whether, for example, a designed soft panel provides adequate ballistic coverage in the chest area for a specific size (dimensions C and D).

Although the configuration analysis of the available BPSP samples indicated differences from the NIJ standard [4,6] test templates, it was evident that manufacturers attempted to comply with the standards by modifying them to fit the intended size and body shape. While NIJ standard 0101.06 [4] strictly defines the surface area limits for BPSPs of various sizes and the exact configuration of the corresponding test templates, it does not specify which specific standardized soft panel test template surface area corresponds to each BPV type (outer garment or undergarment) and size.

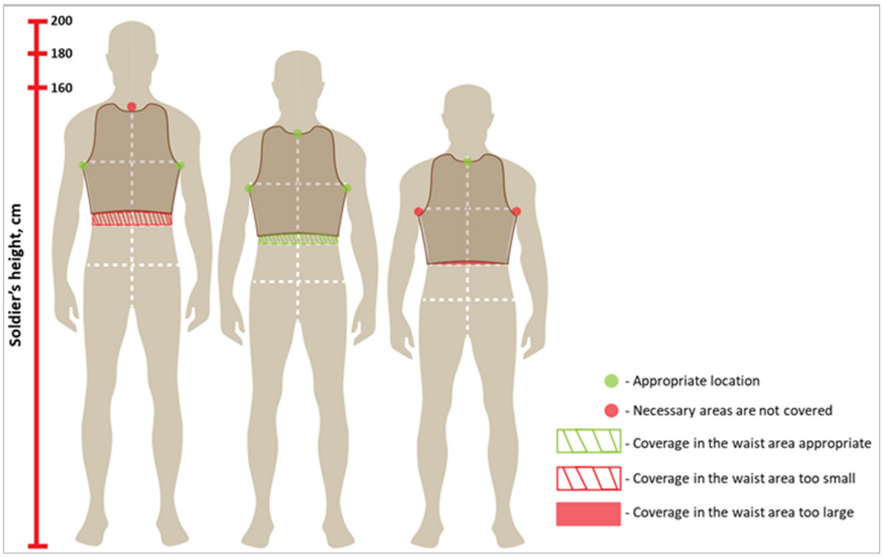

Figure 17. The issues created with the soft panel's dimensions (marked red) if body height gradation is not performed.

This raised questions and confusion about how to match a designed BPV size to a specific NIJ test template [4] for testing and usage dimensions. Constructing one version, measuring the surface area, then making modifications and constructing additional versions is a time-consuming and unpredictable process, as modifying the parameters affects the surface area of the new soft panel, necessitating a restart of the process.

Since the dimensions A (panel height) and B (panel width) are closely related to the height and chest circumference of the body, and the minimum side overlay of 5.08 cm is known, the research discovered a method for calculating the surface area of the designated soft panel before it is created. By multiplying the known parameters, A and B, the surface area for a rectangle is obtained but not for the soft panel itself. To obtain the needed surface area, these dimensions, A and B, should be multiplied by the coefficient K, which accounts for all curves of the soft panel (see Figure 18). As the back and front panels have different curves, the coefficient K values differ for these panels, depending on the type of BPV.

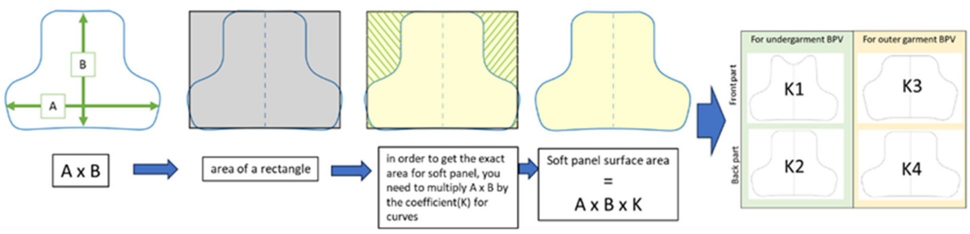

Figure 18. Obtaining the coefficient K for the calculation of the surface area for the designed BPSP patterns.

The coefficient K magnitude was determined based on the overall dimensions of NIJ standard 0101.06 test templates [6], with the minimum and maximum coefficients being within the range of 0.7–0.84. Figure 19 illustrates an example of calculating coefficient K limits for the NIJ-C3 test template.

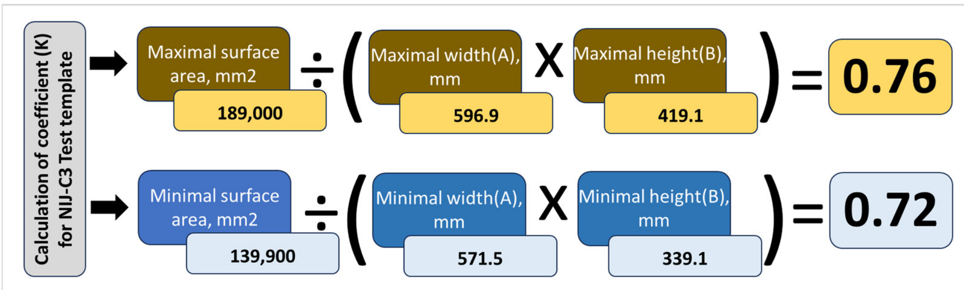

Figure 19. Calculation of the coefficient K for the NIJ-C3 [6] test template's surface area.

These coefficients K were then verified on the soft panels' surface area created for the research. By using a coefficient of 0.78 for the front panels and 0.7 for the back panels, a comparison of the calculated and actual surface areas for the undergarment BPV soft panels revealed a potential error of 4.7%, 3.9% for the outer garment, with an average error of 4.3%. This suggests that the calculated coefficients and surface area calculation formula for soft panels are sufficiently accurate for research purposes.

Knowing the affiliation of each planned size to a specific NIJ standard [4,6] test template allows us to verify that we are proceeding in the correct direction and to understand the origins of the C and D dimensions (see Figure 2) for BPSP patterns. The design process for the patterns of soft panels started with the creation of the basic block pattern, developed in the CAD GRAFIS program using the SEPP unified construction approach. A regular size M, corresponding to a chest circumference of 96 cm, was used as the basic size for the construction. The tolerance sizes used for the undergarment and outer garment BPV are indicated in Table 4. The dimensions, A—width and B—height (see Figure 2), for the BPSP patterns are obtained from the guide [5] and are closely related to the soldier's body height and chest circumference, while the upper part width (C) and upper part height (D) measures are calculated from the corresponding NIJ standard [4,6] test templates, providing optimal protection in the chest and armpit area. There are several soft panel sizes to be designed within one NIJ standard [4,6] test template. To ensure equal gradation, the maximum number of sizes from the same length for one test template (n_{max}) should be determined, which in this case is four ($n_{max} = 4$). The measurement range is obtained by subtracting the test template's maximum ($T_{nmax}C_{max}$) from its minimum ($T_{nmax}C_{min}$) (see Table 5), which, when divided by $n_{max} - 1$, yields the size gradation step. Below is an example (2) and the entire Formula (1) for calculating the upper part width (C) for sizes M–2XL regular that belong to the NIJ-C3 test template:

$$(T_{nmax}C_{max} - T_{nmax}C_{min})/(n_{max} - 1) \quad (1)$$

$$(304.8 - 279.4)/(4 - 1) = 8.47 \text{ mm (step for upper part width (C))} \quad (2)$$

Table 5. Summary for the NIJ standard [4,6] test template [6] dimensions.

	Main Characteristics of the NIJ Standard [4,6] Test Templates							
	Width (A), mm		Height (B), mm		Upper Part Width (C), mm		Back Upper Part Height (D), mm	Front Upper Part Height (D), mm
Template	A_{min}	A_{max}	B_{min}	B_{max}	C_{min}	C_{max}	D_{back}	D_{front}
NIJ-C1	292.2	317.5	292.1	317.5	228.6	254	146.1	136.5
NIJ-C2	406.4	431.8	342.9	368.3	254	279.4	171.5	161.9
NIJ-C3	520.7	546.1	393.7	419.1	279.4	304.8	196.9	187.3
NIJ-C4	635	660.4	444.5	469.9	304.8	330.2	222.3	212.7
NIJ-C5	749.3	774.7	495.3	520.7	330.2	355.6	247.7	238.1

For the smallest of the sizes—M regular, the width of the top C = 279.4 mm, L regular, and for each subsequent size, a step of 8.47 mm is added.

In this study, the process of pattern design for undergarment and outer garment BPVs' soft panels was transferred to the algorithm, illustrated in Figure 20.

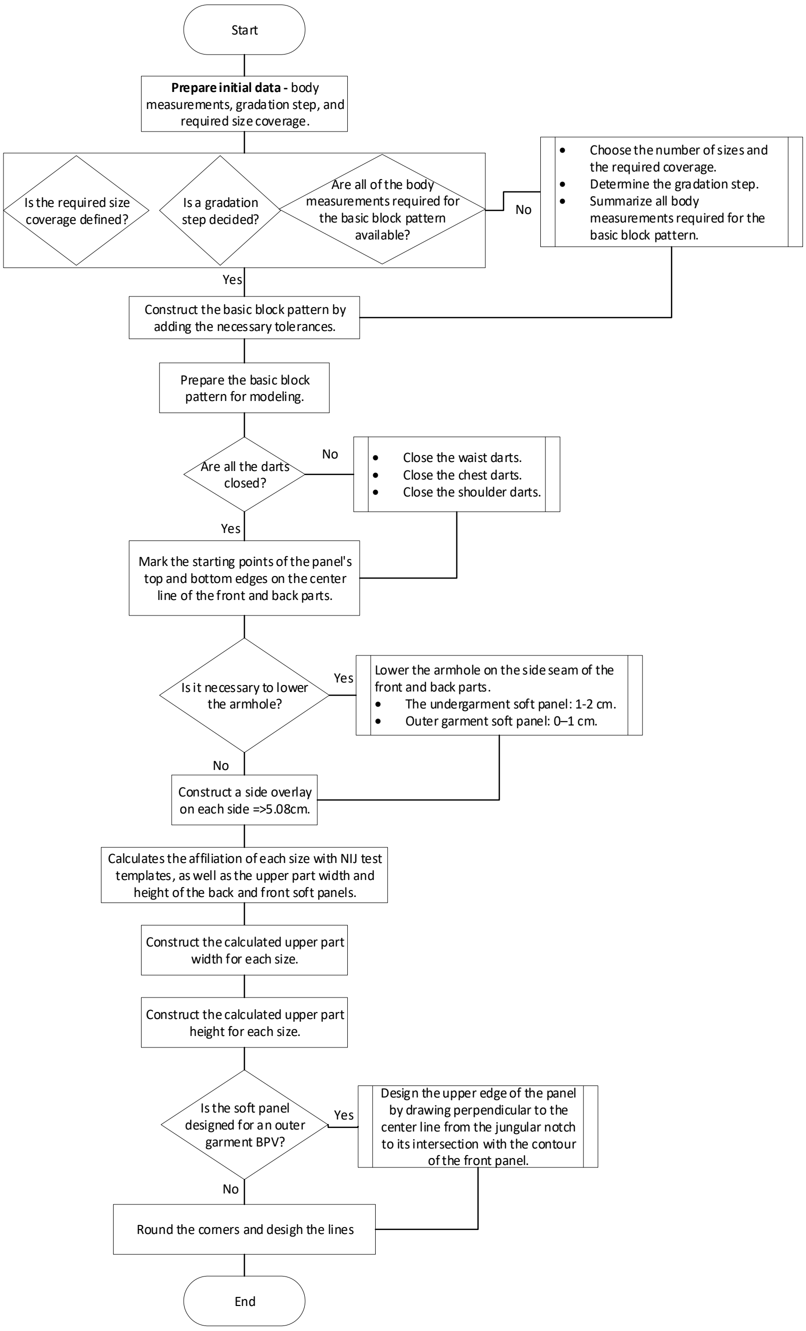

Figure 20. Design algorithm of BPSP patterns.

The algorithm of pattern design for BPSPs begins with the preparation of initial data, which include the necessary size coverage, graduation steps, and accurate body measurements for constructing the basic block pattern.

The basic block pattern is then created and prepared for soft panel modeling by closing the chest, waist, and shoulder darts for both the front and back parts. This completes the preparation process and enables the establishment of the main characteristics of the soft panels.

The first step is to mark the starting points of the upper and lower edges of the soft panel along the center line of the front and back. These distances, defined in Table 1, form parameter B.

The next step is to determine if armhole lowering is necessary, which depends on the type of BPV (undergarment or outer garment) and the desired level of armpit coverage. According to the NIJ standard [6] and related documents [5], the soft panel should be as close to the armpit as possible. Based on measurements obtained during the research, the recommended distance for undergarment BPVs is 1–2 cm, while for outer garment BPVs, it is 0–1 cm.

The width of the soft panel (A) is then determined by the width of the basic block pattern, to which a minimum of 5.08 cm of side overlay is added on each side. The size of the overlay can be divided equally between the back and front panels or adjusted as needed.

The height—D and width—C of the upper part are adjusted based on the calculated sizes from the NIJ test template (see Table 5).

The final steps involve connecting points with lines and designing the corners to complete the soft panel shape.

5. Conclusions

This research contributes to the field of ballistic protection by offering a standardized approach to designing BPSP patterns for ballistic protective vests (BPVs). By addressing the specific body type requirements of regional soldiers and adhering to relevant standards, the study enhances the modularity and adaptability of BPVs.

In this research, we developed a methodology for designing soft panel patterns for both undergarment and outer garment BPVs. This methodology facilitates the creation of patterns that ensure the comfort and adaptability of BPVs to the body types of the target audience. The soft panels developed using our methodology aim to improve the modularity of BPVs in accordance with modern personal protective equipment (PPE) requirements, while ensuring maximum comfort and size adaptability for various body types. Additionally, the methodology developed in this research can assist other regions in designing BPVs tailored to their specific body types.

The critical aspect of this research is the determined coefficient's (K) value as it allows for the calculation of the surface area of the designed soft panel before pattern making. This saves time by eliminating the need to construct the panel, measure the surface area, adjust, and restart the process. This coefficient K enables easy comparison with NIJ test templates [4,6] and facilitates further calculations for material consumption or the total weight of the soft panel.

Author Contributions: Conceptualization, D.B., I.Z., and V.M.; methodology, D.B. and D.A.; validation, D.B., M.G., and I.Z.; formal analysis, D.B. and I.Z.; investigation, D.B. and M.G.; resources, D.B. and M.G.; data curation, D.B., M.G., I.Z., and D.A.; writing—original draft preparation, D.B.; writing—review and editing, D.A., I.Z., M.G., and V.M.; visualization, D.B. and M.G.; supervision, I.Z. and D.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Defence of the Republic of Latvia project "Graphene-and-silica-aerogel-enhanced lightweight ballistic protection vest prototype with integrated pressure-sensitive layer for multi-zone impact detection", project No. VPP-AIPP-2021/1-0009" and Riga Technical University funding for the project "Modular ballistic protection vest", project No. 0400-1.3-e/23 | ZM-2023/22 | 4823.

Data Availability Statement: The reported research and results can be found in Master thesis: Dana Barkane, *Modular smart ballistic protection vest*, Riga Technical University, 2024; available online: https://ndr.rtu.lv/lv/view/39410.

Acknowledgments: Riga Technical University gratefully acknowledges the U.S. Department of Justice, Office of Justice Programs for allowing us to reproduce, in part, the publication by Mukasey, B.M.; Sedgwick, J.L.; Hagy, D.W. National Institute of Justice. Ballistic Resistance of Body Armor NIJ

Standard-0101.06. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily represent the official position or policies of the U.S. Department of Justice.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Precedence Research. Available online: https://www.precedenceresearch.com/body-armor-market (accessed on 20 January 2023).
2. MarkWide Research Inspiring Growth. Available online: https://markwideresearch.com/ballistic-protection-market/ (accessed on 20 January 2023).
3. Hu, Q.; Shen, X.; Qian, X.; Huang, G.; Yuan, M. The personal protective equipment (PPE) based on individual combat: A systematic review and trend analysis. *Def. Technol.* **2023**, *28*, 195–221. [CrossRef]
4. Vigne, N.L. *Ballistic Resistance of Body Armor NIJ Standard 0101.07*; National Institute of Justice: Washington, DC, USA, 2023. Available online: https://nij.ojp.gov/ballistic-resistance-body-armor-nij-standard-010107 (accessed on 12 December 2023).
5. Holder, E.H.; Mason, K.V.; Sabol, V.J. National Institute of Justice Guide—Body Armor. In *Selection & Application Guide 0101.06 to Ballistic-Resistant Body Armor*; National Institute of Justice: Washington, DC, USA, 2014. Available online: https://www.ojp.gov/pdffiles1/nij/247281.pdf (accessed on 30 January 2023).
6. Mukasey, B.M.; Sedgwick, J.L.; Hagy, D.W. *Ballistic Resistance of Body Armor NIJ Standard-0101.06*; National Institute of Justice: Washington, DC, USA, 2008. Available online: https://www.nist.gov/system/files/documents/oles/ballistic.pdf (accessed on 30 January 2023).
7. *STANAG 2335 (Edtion 3)*; Interchangeability Combat Clothing Sizes. NATO Standartization Agency: Sydney, NSW, Australia, 2012. Available online: https://www.intertekinform.com/en-gb/standards/stanag-2335-2012-736803_saig_nato_nato_1789762/ (accessed on 30 January 2023).
8. Hard Shell. Available online: https://www.hardshell.ae/size-chart/ (accessed on 25 January 2023).
9. Alvanon. Available online: https://alvanon.com/wp-content/uploads/2018/06/AF-SPECS_ASD-EU-Men_v4.0__06MAR2015.pdf (accessed on 20 January 2023).
10. Safeguard Armor. Available online: https://www.safeguardarmor.com/pages/size-chart (accessed on 20 January 2023).
11. Bullet Safe. Available online: https://bulletsafe.com/pages/bulletproof-vest-size-chart (accessed on 20 January 2023).
12. BAO, Body Armor Outlet. Available online: https://www.bodyarmoroutlet.com/pages/sizing-charts (accessed on 22 January 2023).
13. BAO, Body Armor Outlet. Available online: https://www.bodyarmoroutlet.com/products/baot-cxiiia-xseries-w-iiia-ballistics (accessed on 21 January 2023).
14. Protection Group Danmark Wholesale ApS. Available online: https://protectiongroupdenmark.com/shop/4-bulletproof-vest/ (accessed on 25 January 2023).
15. GH Armor. Available online: https://www.gharmor.com/sizing (accessed on 21 January 2023).
16. National Body Armor, Concealed Experts. Available online: https://nationalbodyarmor.com/pages/sizing-chart-1 (accessed on 29 January 2023).
17. The Tactical Boutique. Available online: https://www.thetacticalboutique.com/product/bulletsafe-bulletproof-vest (accessed on 3 February 2023).
18. Safe Life Defence. Available online: https://safelifedefense.com/concealable-multi-threat-vest-level-iiia-hg2 (accessed on 25 January 2023).
19. Šitvjenkins, I. Karavīra individuālās aizsardzības sistēma. In *Lietošanas Rokasgrāmata*. 2008; Volume 1, 160p. Available online: https://www.mod.gov.lv/sites/mod/files/document/karavira_ias_0.pdf (accessed on 5 December 2022).
20. *NATO Standard AEP-2333*; Combat Clothing Performance and Protective Properties and Trial Guidance. NATO: Brussels, Belgium, 2021. Available online: https://standards.globalspec.com/std/14486495/aep-2333 (accessed on 8 June 2023).
21. *EN 13921:2007*; Personal Protective Equipment—Ergonomic Principles. European Committee for Standardization: Brussels, Belgium, 2007. Available online: https://www.lvs.lv/lv/products/index?ProductsSearch[product_number]=EN+13921:2007&yt0=&Products[status_code][]=11&page=0 (accessed on 10 June 2023).
22. Vigne, N.L. *Specification for NIJ Ballistic Protection Levels and Associated Test Threats—NIJ Standard 0123.00*; National Institute of Justice: Washington, DC, USA, 2023. Available online: https://nij.ojp.gov/specification-nij-ballistic-protection-levels-and-associated-test-threats-nij-standard-012300 (accessed on 19 January 2024).
23. Dabolina, I.; Lapkovska, E.; Vilumosone, A. Dynamic Anthropometry for Investigation of Body Movement Comfort in Protective Jackets. In *Functional Textiles and Technology*; Majumdar, A., Gupta, D., Gupta, S., Eds.; Springer: Singapore, 2019; pp. 241–259. ISBN 9789811377204.