



FROM ANTHROPOMETRY TO SPATIAL PATTERN DESIGN: A 3D FRAMEWORK FOR WOMEN’S GARMENT CONSTRUCTION

Professional paper
DOI: 10.5937/CT_ITI26280S

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ABSTRACT: Garment construction is a complex process that integrates body morphology, design principles, and production techniques. Traditional pattern-making methods, based on two-dimensional models and standardized sizing systems, often fail to reflect the variability and three-dimensional nature of the human body. This paper proposes a spatial framework that combines anthropometric data, body shape classification, and pattern construction for women’s garments. It emphasizes the transformation of 2D patterns into 3D forms and highlights the limitations of conventional approaches. The findings indicate that incorporating spatial and volumetric considerations improves garment fit, functionality, and adaptability, contributing to more efficient and personalized clothing design.

Keywords: Anthropometry; garment construction; pattern making; body shape classification; spatial design; sizing systems.

OD ANTROPOMETRIJE DO PROSTORNOG DIZAJNA KROJA: 3D OKVIR ZA KONSTRUKCIJU ŽENSKJE ODEĆE

APSTRAKT: Konstrukcija odeće je složen proces koji integriše morfologiju tela, principe dizajna i tehnike proizvodnje. Tradicionalne metode izrade krojeva, zasnovane na dvodimenzionalnim modelima i standardizovanim sistemima veličina, često ne uspeavaju da odražavaju varijabilnost i trodimenzionalnu prirodu ljudskog tela. Ovaj rad predlaže prostorni okvir koji kombinuje antropometrijske podatke, klasifikaciju oblika tela i konstrukciju krojeva za žensku odeću. Naglašava transformaciju 2D krojeva u 3D oblike i ističe ograničenja konvencionalnih pristupa. Rezultati ukazuju da uključivanje prostornih i volumetrijskih razmatranja poboljšava pristajanje odeće, funkcionalnost i prilagodljivost, doprinoseći efikasnijem i personalizovanijem dizajnu odeće.



Ključne reči: Antropometrija; konstruisanje odeće; izrada krojeva; klasifikacija oblika tela; prostorni dizajn; sistemi veličina.

1. INTRODUCTION

From birth, humans constantly interact with textiles, and the visual language of clothing reflects social needs, cultural identity, and personal expression. Historically, textile production has been intricately linked to tradition, trade, religion, and cultural exchange. The fundamental purpose of clothing is protection, making it one of the oldest industries in human history. Today, clothing also plays a significant role in expressing individuality and psychological well-being. Consumers choose garments not only based on design, materials, and comfort, but also on how well they match their personal preferences and body shape [1-6]. The garment industry is a complex system where design, technology, and human factors interact. Clothing is not only a functional necessity but also a form of social communication and personal expression. Modern challenges such as fast fashion, mass production, and increasing consumer demands for personalization have intensified the need for improved garment fit and design accuracy [7-11]. The fashion industry is a highly globalized and dynamic sector, constantly evolving and influencing various aspects of modern lifestyles. Its value chain extends across multiple countries, reflecting its global impact. The term fashion is associated with style, dress, and clothing, particularly in Western societies [12, 13]. Research shows that fashion is shaped by art, architecture, culture, and social life, leading to the creation of the latest trends [14-17]. It is a form of communication and expression of collective preferences and lifestyles. However, fashion is flexible, as styles evolve and are adopted at different rates depending on age, location, and socio-economic conditions [18].

In response to changing consumer preferences toward functionality and digital lifestyles [19-21], the digital economy has accelerated the transformation of the fashion industry through advanced technologies [22-28]. Digital transformation involves company-wide changes and the emergence of new business models, in which digital fashion integrates fashion with ICT tools [29]. Technologies such as artificial intelligence, robotics, e-commerce, and social media are key drivers of industry growth [30]. The fashion industry has shifted from retailer-driven to consumer-driven (fast fashion) production [31], characterized by short cycles, rapid demand changes, and complex supply chains [32]. Consequently, the value chain has evolved toward faster, more flexible production systems, covering mass production, limited editions, and haute couture segments [33].

Today, consumers are more aware of their clothing choices, seeking information about the origins and conditions [34]. Innovation and technological advancement play a key role in the apparel industry, particularly in production processes and in meeting diverse customer demands [35-37]. The adoption of Industry 4.0 technologies is essential for supporting competitiveness, enabling faster production, greater flexibility, and more efficient resource use [38,39]. These systems support intelligent and adaptable manufacturing, especially important for developing economies reliant on production and export [40]. Successful implementation requires investment in infrastructure, education, and policy support [41],



while European industries show varying levels of adoption [42]. Additionally, modern 2D/3D CAD systems are increasingly used to improve pattern design and overall production efficiency [43-45].

A key issue in garment production is the mismatch between standardized sizing systems and the diversity of human body shapes. Anthropometric measurements provide the foundation for garment construction, but traditional approaches often do not fully address body variability. These developments raise an important question: how can garment design better respond to the variability of the human body? The aim of this paper is to analyze the relationship between anthropometric body dimensions, body shape classification, and pattern construction principles, and to propose a spatial framework for improving garment design.

2. THEORETICAL BACKGROUND

2.1 Anthropometry

Body contours are shaped and defined through silhouettes that visually reflect fashion history. The relationship between the body, textiles, and clothing is complex and interdependent, forming a key consideration for designers. Textile and fashion design are intricately connected disciplines, often inseparable in practice [46]. Therefore, a fundamental requirement for creating high-quality garments is a thorough understanding of human anatomy, body shape, and proportions, supported by fields such as anatomy, anthropology, and morphology. Anthropometry studies the measurement and proportions of the human body and is a fundamental tool in garment construction. Key body measurements include height, bust, waist, and hip circumferences, which are used to define garment dimensions and sizing systems. Standardized systems such as ISO and EN sizing frameworks are developed to classify body dimensions and enable mass production. However, these systems cannot fully capture the variability of human body shapes.

2.2 Anthropometric Body Dimensions in Garment Construction

Human body proportions are found through anatomy, which studies the form and structure of body parts, and they vary depending on gender and age. Historically, efforts have been made to define rules for measuring these proportions. In garment construction, the head length is commonly used as a module to find overall body proportions. The human body consists of the head, neck, torso, arms, and legs, and its vertical proportions are typically divided into three parts: head, torso, and legs. Compared to the male body, the female body is generally more delicate, with narrower shoulders, a smaller chest, wider hips, and a more defined waist. It also contains a higher proportion of adipose tissue, resulting in smoother and more rounded body contours [47]. In relation to this, anthropometry represents a fundamental scientific basis for garment design, as it enables the translation of human body dimensions into functional clothing structures. The most important anthropometric parameters used in garment construction are shown in Table 1 and Figure 1:

Table 1: Body dimensions

Primary dimensions:	Secondary dimensions:
Body height (H)	Shoulder width
Bust circumference (B)	Back length
Waist circumference (W)	Arm length
Hip circumference (Hc)	Neck circumference

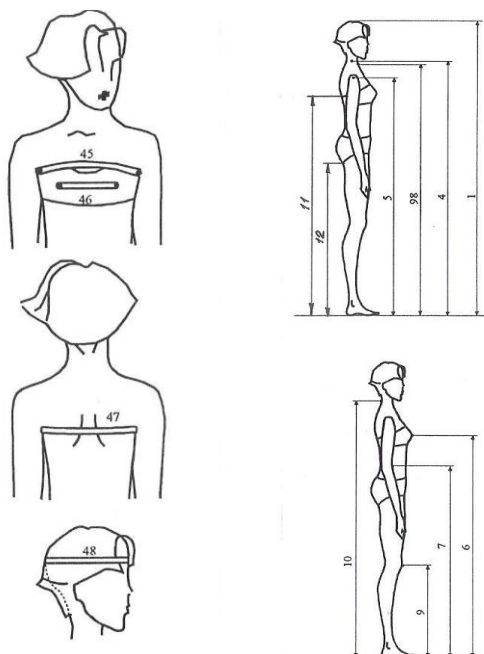


Figure 1: Main anthropometric measurement points used in garment construction

The relationship between primary and secondary anthropometric measurements forms the basis for proportional garment construction and grading systems. These measurements are used to derive construction measurements, which are not directly measured but calculated based on proportional relationships. However, it is important to note that body proportions are not fixed. They vary depending on age, gender, and individual morphology. For this reason, garment construction does not rely only on direct measurements, but also on proportional relationships between them. For example, the relationship between bust, waist, and hip measurements strongly influences garment silhouette, while vertical proportions affect the overall balance of the design. In addition, secondary measurements such as shoulder width and arm length play a significant role in ensuring comfort and mobility. Therefore, a good understanding of human anatomy and proportions is essential for achieving both functional and well-fitted garments.

2.3 Women's Body Shape Classification

In addition to measurements, body shape is another crucial factor in garment design. Several studies have shown women's bodies vary significantly in their proportions and change throughout different life stages [48]. Common body shapes include hourglass, pear (triangle), inverted triangle, rectangle, and round (apple) (Figure 2). Each body type requires specific adjustments in garment construction, particularly in areas such as bust shaping, waist shaping, and hip allowance. Body shape classification is essential in garment design, as it allows adaptation of pattern construction to different morphological characteristics. For instance, pear-shaped bodies often require additional space in the hip area, while inverted triangle shapes may need adjustments in shoulder width. In contrast, rectangular body types usually require added shaping to create visual balance. This suggests that body shape classification is not only descriptive but also highly practical. It allows designers to adapt patterns in a more targeted and effective way.

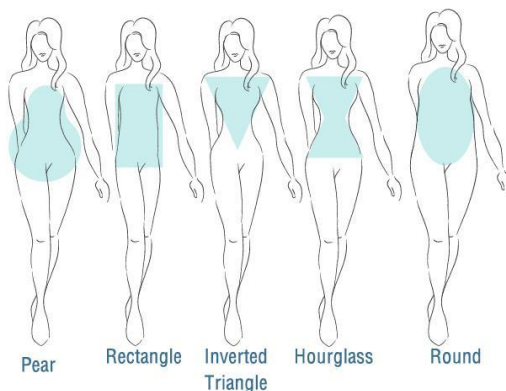


Figure 2: Common women's body shape classifications and their morphological characteristics

2.4 Spatial approach to garment construction

Garment construction can be better understood when viewed from a spatial perspective. The human body is a three-dimensional structure with complex geometry, while garment patterns are typically developed as two-dimensional surfaces. This creates a fundamental design challenge: how to transform flat textile pieces into a form that fits a three-dimensional body. In practice, this transformation involves several steps, including proportional scaling, geometric adaptation, and structural shaping. Anthropometric data provide the necessary input, while pattern-making techniques define how the material is distributed around the body. From this perspective, garment construction can be considered a form of applied spatial engineering. The goal is not only to match dimensions, but also to ensure that the garment follows the natural form and movement of the body.

2.5 Design and Pattern-Making Principles

Fashion design gives identity and value to products and is a fundamental process in the fashion supply chain. In the era of fast fashion, brands must design efficiently due to rapid changes and high pressure on production, delivery, and inventory management [49]. The product development process, led by designers, includes idea generation, fabric selection, sketching, prototyping, fit evaluation, cost calculation, production planning, and grading [50]. Successful product launches depend not only on market knowledge but also on understanding technical and technological aspects of garment production and marketing requirements [51]. This process is generally divided into two stages: design (creative development) and production (implementation of solutions) [52].

Pattern construction represents a key stage in the garment development process. It translates body measurements into a set of technical drawings that define the shape and structure of the garment [53–56]. It includes determination of construction measurements, development of base patterns and modeling and adaptation. Two main approaches are commonly used. The flat pattern method (2D), which is widely applied in industrial production, is valued for its efficiency and consistency. On the other hand, the draping method allows designers to work directly on a mannequin, providing greater flexibility and precision, especially for complex designs. Today, CAD/CAM systems play an increasingly important role in this process. They make it possible to develop patterns more quickly, reduce errors, material waste, and improve overall production efficiency [57–60]. Nevertheless, it is important to emphasize that both traditional and digital methods still depend on the experience and skills of the pattern maker [61].

3. METHODOLOGICAL APPROACH (ANALYTICAL FRAMEWORK)

3.1 Linking Body Shapes and Pattern Construction

In practice, there is a clear relationship between body measurements and pattern construction. For example, bust circumference figures out garment width, while waist measurements influence shaping through darts and seams. Hip measurements affect the volume of lower garments, and body height defines vertical proportions. However, these relationships are not purely mechanical. They must be adjusted depending on body shape. This means that pattern construction involves both measurement-based calculations and interpretative decisions. For instance, more ease may be needed for round body shapes, while more structured shaping is often needed for rectangular forms. This confirms that garment design is not only a technical process, but also an adaptive one. A systematic relationship between body measurements and pattern construction can be defined:

- Bust circumference → decide garment width;
- Waist circumference → defines shaping and darts;
- Hip circumference → affects lower garment volume;
- Body height → influences vertical proportions.

Different body shapes require specific pattern modifications (Table 2).

Table 2: Linking Body Shape Types and Pattern Adjustments

Body Shape Type	Key Characteristics	Pattern Adjustments
Hourglass	Balanced proportions (bust & hips), defined waist	Standard proportional construction; minimal adjustment needed
Pear (Triangle)	Wider hips, narrower shoulders	Increase hip allowance; reduce upper width; adjust waist shaping
Inverted Triangle	Wider shoulders; narrower hips	Reduce shoulder width; add volume in hip area
Rectangle	Similar bust; waist and hip measurements	Add darts and shaping elements to create waist definition
Round (Apple)	Fuller midsection, less defined waist	Increase ease in waist area; reduce tight shaping; ensure comfort fit

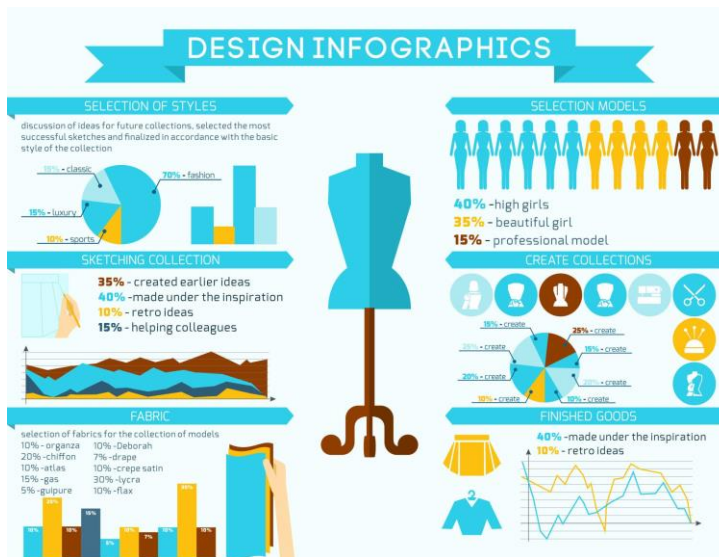


Figure 3: Design development and pattern adjustment workflow in garment construction

Figure 3 presents the workflow of design development and pattern adjustment according to body shape and design requirements. It includes concept creation, sketching, pattern modification, and fit evaluation. The figure demonstrates how technical and creative processes are integrated in garment construction.

These relationships form the basis for constructing different garment types. The transformation of anthropometric measurements into garment patterns requires the application of construction rules such as ease allowance, dart manipulation, and

proportional scaling. These rules ensure that garments not only fit the body but also allow movement and comfort.

3.2 Spatial Perspective in Garment Construction

Fit, comfort, and size are key factors in clothing design and are considered essential for garment quality, influencing customer satisfaction and purchase decisions [62–64]. Proper fit depends on body measurements, shape, and proportions [65]. The development of standardized sizing systems emerged with mass production in the late 19th and early 20th centuries and has been extensively studied since the 1940s [66]. From a spatial perspective, the human body can be understood as a complex three-dimensional structure, while garment patterns are two-dimensional representations. Garment construction therefore involves transforming flat textile surfaces into forms that correspond to body geometry. This process requires geometric adaptation, proportional scaling, and structural adjustment based on anthropometric data and pattern-making principles. In this context, garment construction can be interpreted as a spatial transformation process, where the objective is to achieve a balance between body form, functionality, and comfort. The spatial transformation process in garment construction is illustrated in Figure 4.

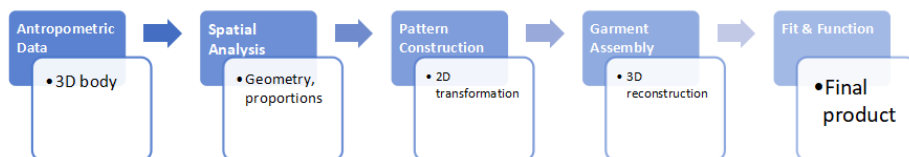


Figure 4: Spatial transformation process in garment construction

3.3 Limitations of 2D Models and Proposed 3D Volumetric Classifications

Traditional 2D modeling is limited by its reliance on the X–Y plane, which flattens the human body and ignores Z-axis depth (front and back volume). As a result, it often produces “flat-pattern distortion,” where garments meet width requirements but fail to accommodate true body depth, leading to tension and poor fit. To address these limitations, a 3D volumetric framework is proposed (Figure 5), focusing on depth and body dynamics. The Projected Keystone accounts for anterior–posterior torso depth, ensuring proper accommodation of body thickness. The Bi-Segmented Helix considers rotational asymmetry between the upper and lower body, reflecting natural movement. The Expanding Arc describes three-dimensional body curvature, particularly in areas with increased volume. This approach enables more accurate and adaptive garment construction by integrating spatial body characteristics.

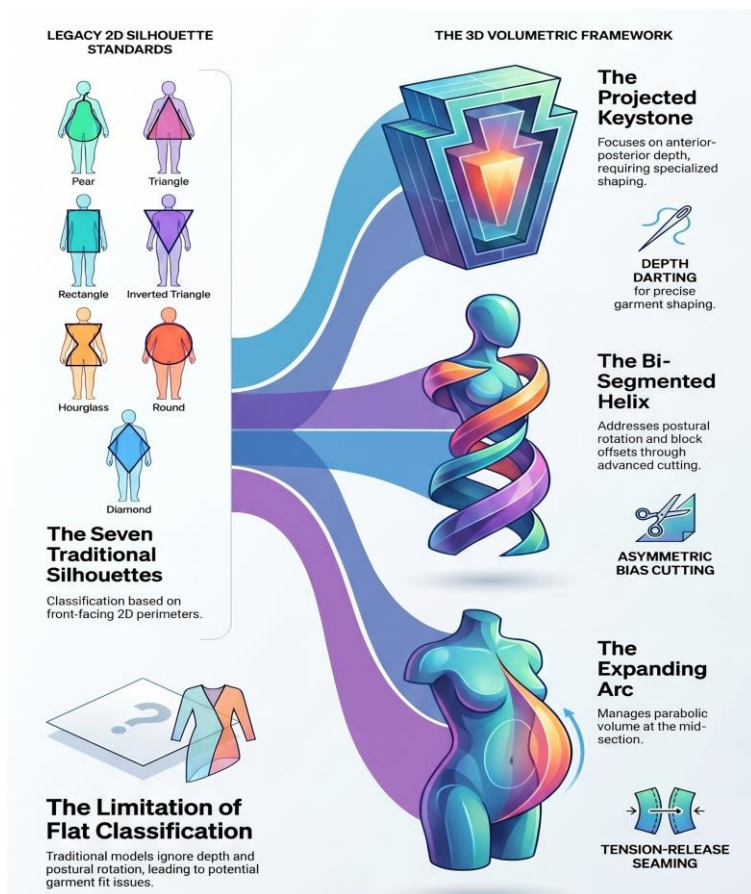


Figure 5: 3D volumetric framework

The transition from 2D pattern models to 3D volumetric approaches is influenced by morphological variations and body mechanics. In this context, garment construction requires moving beyond flat-pattern logic toward more adaptive, multi-dimensional design strategies. In practice, this may include the use of multi-directional darting to accommodate body depth and redistribute fabric according to areas of greater volume, such as the chest or abdomen. Similarly, seam placement can be adjusted to follow natural body movement and structural lines, improving both fit and comfort. These approaches suggest that incorporating three-dimensional body characteristics into pattern design can enhance garment performance and reduce fitting issues. At the same time, more accurate pattern construction may contribute to reduced material waste by minimizing the need for excessive allowances.

4. DISCUSSION

The findings highlight that garment construction is a multidimensional process requiring the integration of anthropometry, body morphology, and spatial design principles. While traditional methods provide standardized procedures, they are often insufficient for addressing the diversity of modern consumers.

Standard sizing systems simplify production but fail to account for variations in body depth, posture, and volume distribution. Body shape classification improves pattern adaptation by providing an intermediate framework between measurements and design. The proposed spatial approach enhances garment construction by incorporating three-dimensional body characteristics.

Traditional Garment Pattern Development			Digital CAD-Based Design Approach		
1. Body Measurement		Manual body measurements using measuring tape.	1. 3D Body Scanning		Accurate 3D body scan captures body shape in seconds.
2. Pattern Drafting		Patterns are drafted manually on paper using rulers.	2. Digital Pattern Creation		Patterns are created digitally using CAD software.
3. Pattern Modification		Manual adjustments require redrawing and recutting.	3. Digital Modification		Modifications are done instantly with precise updates.
4. Sample Making		Physical samples are sewn to check fit and design.	4. Virtual Fitting		Virtual simulation checks fit, drape and movement.
5. Fit Evaluation		Fit is evaluated on the body and marked manually.	5. Fit Analysis		Software analyzes fit and shows problem areas clearly.
6. Production		Patterns are graded manually and sent for production.	6. Production Preparation		Digital files go directly to automated cutting and production.
Time Consuming More Samples Higher Cost More Material Waste			Faster Process Fewer Samples Lower Cost Less Waste		

Figure 6: Comparison between traditional garment pattern development and digital CAD-based design approaches

In addition, digital technologies such as 3D body scanning and virtual fitting systems offer significant potential for improving accuracy and efficiency.

Improved garment fit can also contribute to sustainability by reducing return rates, minimizing material waste, and increasing product longevity.

The Figure 6 compares conventional garment development methods with modern digital approaches. Traditional processes involve manual measurements, flat pattern drafting, and physical prototyping, whereas digital methods use 3D body scanning, CAD/CAM systems, and virtual fitting technologies for faster and more precise garment production.

5. CONCLUSION

This research substantiates the necessity of reconceptualizing garment construction as a spatially oriented, multidisciplinary design process grounded in anthropometric science,



body morphology analysis, and three-dimensional spatial reasoning. Although anthropometric measurements constitute the foundational dataset for pattern development, they are inherently limited when applied in isolation. Their integration with body shape classification and spatial interpretation of the human form is essential for achieving enhanced structural accuracy, ergonomic performance, and functional adaptability in garment design. Furthermore, the incorporation of advanced digital technologies-particularly 3D body scanning, computer-aided design (CAD), and virtual prototyping systems-significantly extends the precision and efficiency of the design process, while simultaneously contributing to greater sustainability and reduced material waste within the apparel industry. In conclusion, garment construction should be understood as an interdisciplinary domain at the intersection of science, engineering, and design. The spatial approach proposed in this study provides a robust analytical framework for the development of individualized and innovative women’s clothing systems. Future research should prioritize empirical validation through 3D scanning methodologies and computational simulation within virtual fitting environments.

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