



Faculty of Applied and Creative Arts

**A 3D Body Shape Classification Approach for Personalized Menswear
Pattern Development: A Case Study**

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A 3D Body Shape Classification Approach for Personalized Menswear
Pattern Development: A Case Study

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Determining correct garment fit remains a significant challenge for manufacturers, particularly in e-commerce, due to variability in human body shapes and technological constraints. Although advancements in 3D technology allow for fit customization, implementing it effectively is complex. This study proposes a 3D body model-based parametric pattern generation method to achieve personalized fit in menswear for mass customization. The research objectives were: (1) To investigate the garment fit factors and the integration of advanced technologies in menswear production processes; (2) To develop a CAD parametric method for generating menswear block and personalized patterns based on 3D body model and body shape classification; and (3) To validate the effectiveness of the proposed pattern generation method in producing accurate personalized fits from 3D body data. A mixed-methods approach was employed: qualitative case studies and interviews showed the integration of 3D technology remains in the experimental phase and has not yet been widely implemented for most apparel firms. Key fit factors included pattern (size system, ease allowance, aesthetics) and technologies (anthropometrics, patternmaking, fitting). Quantitatively, a multi-level male body shape classification method was developed by factor analysis. A parameterized menswear pattern generation method was proposed which employs a pattern-oriented landmark of human feature points to integrate the 3D body model into patternmaking. Finally, virtual fitting comparisons demonstrated that the proposed method improved fit accuracy compared to

conventional techniques. This research promotes the formulation of a "body-pattern-fit" theory which interprets the relationship between human body size, body type, pattern, and fit, and establishes a methodological framework integrating body data into pattern design and fit evaluation. It provides the industry with a scalable solution for mass customization, reducing returns and improving CAD integration. Future work should explore intelligent and automated 3D pattern-making systems for customization.

Keywords: Mass customization, body shape classification, 3D body model, menswear parametric pattern blocks, fit evaluation, virtual fitting

***Pendekatan Pengelasan Bentuk Badan 3D untuk Pembangunan Corak Pakaian Lelaki
Peribadi: Satu Kajian Kes***

ABSTRAK

Penentuan padanan pakaian (garment fit) yang tepat kekal menjadi cabaran kritikal buat pengilang, terutamanya dalam sektor e-dagang, ekoran kepelbagaian morfologi tubuh manusia dan kekangan teknologi sedia ada. Walaupun kemajuan teknologi 3D menawarkan potensi penyesuaian padanan (fit customization), pelaksanaannya secara berkesan masih bersifat kompleks. Kajian ini mencadangkan satu kaedah penghasilan pola parametrik berasaskan model badan 3D bagi mencapai padanan peribadi dalam pakaian lelaki untuk pengeluaran massa tersuai (mass customization). Objektif penyelidikan ini merangkumi tiga aspek utama; (1) menyiasat faktor padanan pakaian serta integrasi teknologi termaju dalam proses pengeluaran pakaian lelaki, (2) membangunkan kaedah parametrik CAD bagi menghasilkan blok pakaian lelaki dan pola peribadi berasaskan model badan 3D serta klasifikasi bentuk badan, dan (3) mengesahkan keberkesanan kaedah penghasilan pola yang dicadangkan dalam menghasilkan padanan peribadi yang jitu daripada data badan 3D. Melalui pendekatan kaedah campuran (mixed-methods), kajian kes kualitatif dan temu bual mendedahkan bahawa integrasi teknologi 3D masih berada di fasa eksperimental dan belum dilaksanakan secara meluas oleh kebanyakan firma pakaian. Faktor utama padanan yang dikenal pasti merangkumi aspek pola (sistem saiz, kelonggaran basi atau ease allowance, dan estetika) serta teknologi (antropometri,

pembuatan pola, dan pepadanan). Secara kuantitatif, kaedah klasifikasi bentuk badan lelaki pelbagai tahap telah dibangunkan melalui analisis faktor. Kajian ini turut mencadangkan kaedah penghasilan pola pakaian lelaki berparameter yang menggunakan tanda rujukan (landmark) berorientasikan pola pada titik ciri manusia untuk mengintegrasikan model badan 3D ke dalam proses pembuatan pola. Hasil perbandingan pepadanan maya (virtual fitting) membuktikan bahawa kaedah yang dicadangkan berupaya meningkatkan kejituan padanan berbanding teknik konvensional. Penyelidikan ini menyumbang kepada formulasi teori "badan-pola-padanan" (body-pattern-fit) yang mentafsirkan hubungan antara saiz badan, jenis badan, pola, dan padanan, seterusnya membina kerangka metodologi yang mengintegrasikan data badan ke dalam reka bentuk pola dan penilaian padanan. Penemuan ini menawarkan penyelesaian berskala bagi industri pengeluaran massa tersuai, sekali gus mengurangkan kadar pemulangan produk dan menambah baik integrasi CAD. Kerja-kerja masa hadapan wajar meneroka sistem pembuatan pola 3D yang pintar dan automatik untuk tujuan penyesuaian.

Kata kunci: *Pengeluaran massa tersuai, klasifikasi bentuk badan, model badan 3D, blok pola parametrik pakaian lelaki, penilaian padanan, pepadanan maya.*

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

This research aims to discover, develop and validate a 3D body shape-based parametric pattern generation model for mass customization to address fit problems. The research combines anthropometric and patternmaking technologies to reduce production costs and enhance fit accuracy in mass customization to satisfy the consumer individual demand.

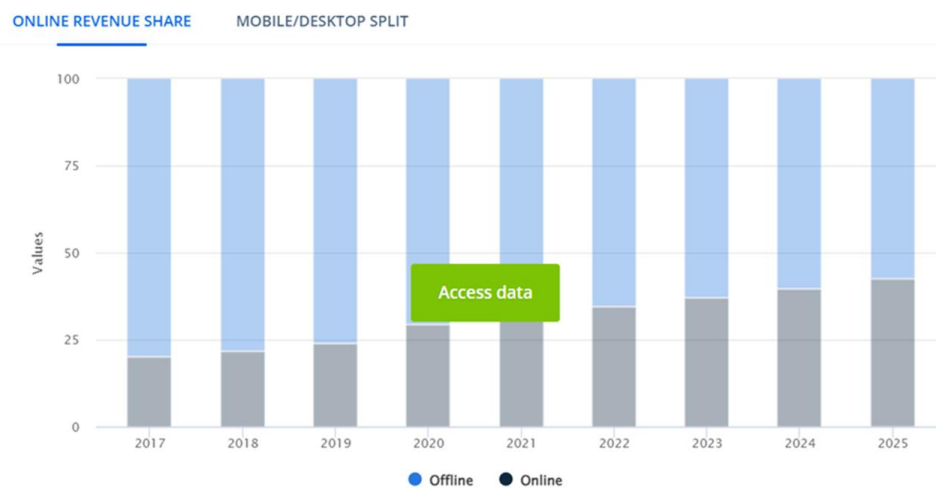
This chapter, as an introduction, provides an overview of the research background and outlines the problem statement, research questions, research purpose, and objectives of the study. It also discusses other aspects of the research, such as the research scope, its significance, limitations, and key terms referred to in this research.

1.2 Research Background

1.2.1 Changes in Market Demand

The recent pandemic has accelerated the ongoing trend of online consumer purchasing. Many individuals have become accustomed to and benefit from e-commerce or e-purchasing. According to the report published by Statista Market Insights in August of 2023, as shown in Figure 1.1, the online revenue share of men's apparel in the global market is exhibiting an annual increase, while the offline revenue share shows a

contrasting trend (Statista Market Insights, 2023). As indicated in the report on the state of China's garment industry, 70.6% of consumers have higher online consumption than offline since the onset of the pandemic (Henan Province Garment Industry Association, 2022). The cumulative year-on-year growth rate of online retail sales of apparel-related products in 2024 reached 4.1%, representing a deceleration of 5.5 percentage points compared to the same period in 2023 (China Garment Association, 2025).



Source: Statista Market Insights (2023)

Figure 1.1: Online Revenue Share of Menswear

The above report indicates that many consumers have attested to the time and effort savings, as well as the broader range of options, associated with online shopping for clothing. Simultaneously, a number of consumers expressed concerns regarding the potential risks associated with product returns, including the issue of damaged goods. According to research conducted by Body Lab, size-related issues accounted for 64% of apparel returns, as shown in Figure 1.2 (Cilley, 2016). Recent industry report by Alvanon

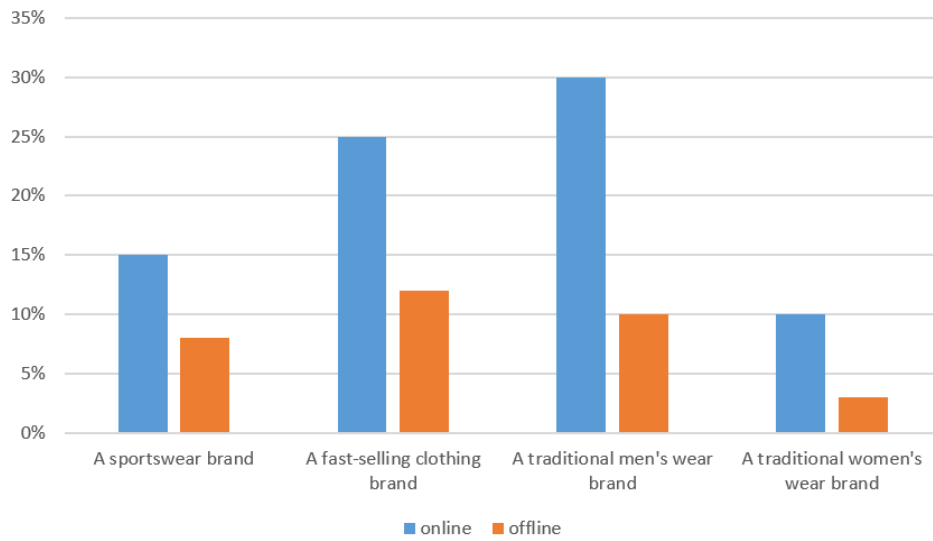
pointed out that 53% of returns in 2023 were due to sizing and fit issues (Alvanon, 2025). Over the past decade, this represents about a 10% reduction in return rates, which can be seen as a positive outcome.



Source: Cilley (2016)

Figure 1.2: Reason for Returning Clothing or Footwear

Additionally, the research report on 2022 China apparel supply chain industry by iResearch stated that online channels are characterised by a paucity of in-person fitting experiences, resulting in a higher rate of returns and exchanges compared to offline channels. The comparison of online and offline return rate for partial clothing brand in China is displayed in this report, as illustrated in Figure 1.3 (iResearch, 2023). As shown in the figure, compared to other apparel categories, men's wear has the highest online return rate.



Source: iResearch (2023)

Figure 1.3: Online and Offline Return Rate for Partial Clothing Brand

People's consumption patterns underwent a transformation, marked by a shift toward individuation and diversification of preferences in the 1970s, a trend that has become increasingly evident in recent decades (Yeung et al., 2010). With the improvement of the economic environment, consumers began to acquire greater purchasing power, which fueled the desire to express their individuality and affluence through personalization (Lang et al., 2021). Concurrently, the demand for variety among consumers prompted the production of multi-variety and small-batch products. With continued technological advancements, researchers have increasingly sought to integrate machine learning technologies to explore novel methods for further decreasing return rates.

1.2.2 Shifts in Production Model

The emergence of the multi-variety and small-batch garment market can be attributed to individual consumption preferences and online consumption trends (Shi et al., 2023). The online and offline integration business model has expanded in garment companies. Conversely, the garment manufacturing sector predominantly exhibits labor intensity and cost sensitivity characteristics. In recent years, rising labor costs in China have exacerbated production difficulties, prompting many manufacturers to relocate operations to countries with lower labor expenses (J. Yang et al., 2015). This shift has intensified global competition in the apparel industry, particularly for Chinese companies striving to maintain cost efficiency while adopting high-end technologies (De Giovanni et al., 2025). As a result, the industry faces dual pressure: to remain economically viable and technologically competitive in an increasingly saturated market.

In this context, it has compelled apparel manufacturers to rethink production strategies. Mass customization (MC) is a distinct production model compared to the other two traditional approaches: mass production (MP) and pure customization (Senanayake & Little, 2010). These three production models are three stages according to the degree of meeting personality needs. While MP dominates for affordability, its rigidity fails to accommodate individualized demand (J. Yang et al., 2015). Consequently, hybrid models like MC have emerged, employing digital technologies, modular design, and flexible manufacturing systems to improve competitiveness by offering personalized products

without sacrificing production efficiency (Da Silveira et al., 2001; Yeung et al., 2010; Perez et al., 2022).

MP has long been the dominant strategy within the apparel industry, primarily due to its capacity to deliver affordable, standardized garments efficiently, thereby satisfying the basic clothing needs of the general population at a lower cost. Mass production is a standardized method to produce garments using existing fabric and styles to manufacture ready-wear garment products at scale. Although apparel in mass production can achieve lower production costs, it doesn't remain easy to meet the aspect of personalization, especially in style and body type. Obviously, the aim of mass production is to lower cost through volume, but as the term implies, it is also about achieving fit on a wider scale (Nayak et al., 2015; Senanayake & Little, 2010).

Pure customization is the opposite of mass production, as it applies custom styles and custom fabrics to produce garments in a bespoke way from design to packing. Traditional pure customization aims to provide uniqueness and personalization, where the variation dimension can be very broad; the production cost remains high and the production period is long, hence, it cannot be applied to the masses or in mass customization form (Senanayake & Little, 2010).

With advancements in information technology, manufacturing systems and techniques, and the rapid pace of development in e-commerce, mass customization was

introduced as a new production model to the apparel industry to cater to market turbulences characterized by unstable and unpredictable demand levels, heterogeneous desires, price, quality and style consciousness, high buyer power, competitive intensity, product differentiation, and saturation (Senanayake & Little, 2010). It blends traditional customization with mass production. In today's highly competitive and globalized market, enterprises compete in terms of variety and cost. This is especially true for mass production, but in a more critical way due to its small volume. The outcomes of MC are that it provides a competitive edge in customer satisfaction, and implementation is achieved through innovative design with a consumer-centric fit, reflected in low return rates and the elimination of overstocking, which are significant challenges faced in the traditional mass production approach (Nayak et al., 2015; J. Yang et al., 2015).

Yang et al. (2015) noted that MC is a highly customer-driven strategy that combines mass production with customization (J. Yang et al., 2015). It intends to create a positive experience and effect, both satisfying varied consumer demands and providing cost benefits compared with mass production and traditional customization. Consequently, the different benefits offered by mass production, mass customization, and pure customization may be summarized in Table 1.1.

Table 1.1: Comparison of Mass Production, Mass Customization and Pure Customization

No.	Mass Production	Mass Customization	Pure Customization
1	High modularity/ low variety	High variety/high modularity	High variety/low modularity
2	Lower individual satisfaction and limited customer relationship	Higher individual satisfaction and communication with customers.	Higher individual satisfaction and provide personal experience
3	Standardized design and consistent quality and low cost	Customized product and high quality and affordable cost	Target individual need and high quality and high cost
4	Long product development cycle and life cycle	Short product development cycle and life cycle	Long product development cycle and life cycle
5	Inflexible production	Flexible production	Custom production
6	A pattern is developed and fitted to a fit model, a size range of patterns are made.	Accurate body measurements are collected and used to achieve individual fit.	Accurate body measurements are collected and used to achieve individual fit.
7	Misfit	Custom-fit	Custom-fit
8	Overstock	No overstock	No overstock

Source: Senanayake and Little (2010), J. Yang et al. (2015)

Today, apparel manufacturers adopt varied production strategies based on specific market demands, choosing among MP, MC, and pure customization to balance efficiency, cost, and personalization (Senanayake & Little, 2010; J. Yang et al., 2015; S. Aheleroff et al., 2022). With advancements in digital and manufacturing technologies, MC has increasingly become recognized as a viable strategy for the apparel industry. It has already been embraced by many clothing companies, particularly in the production of menswear and, to a lesser extent, womenswear (K. Liu et al., 2019). Among these applications, menswear has seen broader implementation of MC practices than womenswear. This disparity reflects both practical and behavioral considerations inherent to each market segment.

From a production standpoint, menswear exhibits a higher degree of standardization, characterized by a reduced variety of styles and more uniform pattern arrangements. This standardization supports the implementation of customizable features by manufacturers, thereby mitigating the need for substantial disruptions to existing production systems. Conversely, the domain of womenswear encompasses a more extensive range of styles, silhouettes, and fit preferences, substantially increasing the difficulty of developing scalable customization solutions. The diversity in women's garment design poses a significant challenge to the automation and mass personalization processes, hindering the adoption of MC in this sector.

Beyond manufacturing feasibility, gender-based differences in consumer motivation also play a significant role. Although both male and female consumers are driven by a desire for uniqueness, research suggests that men are more influenced by social identity and status expression, whereas women tend to be motivated by self-expression and self-promotion (Seo & Lang, 2019). In this context, customization appeals more strongly to male consumers, particularly in formalwear, such as suits and dress shirts, where personalized garments are associated with professionalism, authority, and prestige. These psychological and social factors further explain MC's earlier and more extensive integration in menswear markets.

Nonetheless, it is important to recognize that the fashion industry is dynamic, and consumer preferences continue to evolve alongside technological advancement. The implementation of MC in womenswear has gained momentum in recent years, largely driven by improved digital design tools, virtual try-on technologies, and enhanced data-driven pattern-making systems. However, significant technical and technological breakthroughs are still required before MC can be widely and efficiently applied to women's garments. Addressing these challenges remains crucial to achieving wider adoption and commercial scalability in this sector.

However, its implementation in apparel remains constrained by a persistent and critical challenge: achieving accurate garment fit. Fit has consistently been identified as one of the most intricate and unresolved issues in applying MC to clothing (Jo

Anderson-Connell et al., 2002; Lang et al., 2021; Nayak et al., 2015; Yeung et al., 2010).

Size guides and fit information were proposed to assist customers in selecting the right size for apparel to reduce returns for e-commerce businesses (Oakley, E., 2024).

To address this challenge, apparel companies have explored various approaches to obtain more precise body measurements and optimize size selection strategies. Some companies have incorporated 3D body scanning technologies to enhance the precision of sizing data. In contrast, others depend on consumer self-reporting systems or AI-driven fit prediction algorithms to improve customization accuracy. For example, Indochino, Bonobos, and Proper Cloth have adopted innovative sizing solutions to better align product offerings with individual body shapes and fit preferences. These practices highlight a growing industry focus on fit as a core factor in the successful deployment of MC strategies.

In conclusion, despite technological advances, challenges on fit in mass customization remain (Bae & May-Plumlee Traci, 2005; Nayak et al., 2015). These challenges can be summarized as follows: (i) accurately capturing complex human body shapes through body scanning and computational methods remains technically challenging, (ii) the interactions between body morphology, pattern configurations, and fabric properties produce a combinatorial explosion of possible fit outcomes, complicating efficient and precise customization, and (iii) the manufacturing system must be sufficiently

agile and adaptable to accommodate dynamic consumer preferences within an MC paradigm.

1.2.3 The Advocacy of Intelligent Manufacturing

In the context of intensified globalization and increasingly fragmented markets, the apparel industry is encountering unprecedented opportunities and significant challenges. These dynamics compel firms to explore new pathways for enhancing competitiveness, particularly through the strategic application of technological innovation in production systems (Yeung et al., 2010). As consumer demands grow more diverse and complex, conventional manufacturing models have become inadequate in addressing the need for efficiency, responsiveness, and personalization. Amid this industrial transformation, the emergence of Industry 4.0 marks a pivotal shift towards intelligent manufacturing. Originating from the information age, Industry 4.0 represents a new technological paradigm characterized by integrating cyber-physical systems, the Internet of Things (IoT), artificial intelligence, and big data analytics (Perez et al., 2022; Aheleroff et al., 2022). In response to this trend, nations across the globe have formulated strategic initiatives to promote intelligent manufacturing. Examples include “Made in China 2025,” the “National Strategy for Advanced Manufacturing” in the United States, and “The Future of Manufacturing” strategy in the United Kingdom. These policies reflect a global consensus on the need to modernize industrial capabilities through digital transformation. In line with these strategic directives, advanced manufacturing technologies are increasingly integrated

across all phases of the apparel product life cycle, from design and development to production, distribution, and retail. Notable examples include Lean Product Development, Computer-Aided Design (CAD), Manufacturing Execution Systems (MES), Intelligent Hanging Production Systems, Automated Warehousing, and a range of e-commerce and internet-based solutions. These innovations have redefined traditional operations by enabling real-time data exchange, automated decision-making, and highly responsive supply chains.

The application of such technologies illustrates the potential of smart manufacturing to provide both cost-effective and highly flexible production systems. Importantly, these capabilities are not only confined to mass production but are also applied in mass customization, where the ability to address individual preferences efficiently is becoming a key source of competitive advantage. As consumers increasingly demand personalized products, intelligent manufacturing offers scalable solutions that align production efficiency with customization. Despite these advancements, it is important to acknowledge the ongoing complexities involved in garment production, particularly in achieving optimal fit. Traditional processes, such as body measurement, sizing, patternmaking, cutting, sewing, and finishing, remain foundational to apparel manufacturing. However, in the context of intelligent manufacturing and mass customization, these processes must be redesigned to accommodate greater variation and individualization. The challenge lies in technological integration and in developing

adaptive workflows that can maintain precision and consistency while responding to changing consumer needs.

Body measurement, sizing, and patternmaking constitute the fundamental stages in delivering personalized garment fit. While modularization and automation have enabled more flexible production systems, especially within mass production frameworks, significant improvements are still required. To bridge the gap between individualized fit and scalable manufacturing, a more integrated and intelligent technological ecosystem must be developed. Such advancements would streamline the entire workflow, from MP to MC, increasing both efficiency and responsiveness. Although advanced body measurement technologies, such as 3D body scanning, have been developed to capture highly accurate anthropometric data, their application remains limited mainly to academic and research institutions. Their restricted adoption in commercial garment manufacturing is primarily due to high costs and the lack of smooth integration between 3D body data and Computer-Aided Design (CAD) systems. In parallel, some companies use image-based measurement techniques through mobile platforms; however, these measurements frequently require manual verification and correction by experts to ensure accuracy. This workflow, while promising, still falls short concerning scalability and automation needed for MC and industrial applications.

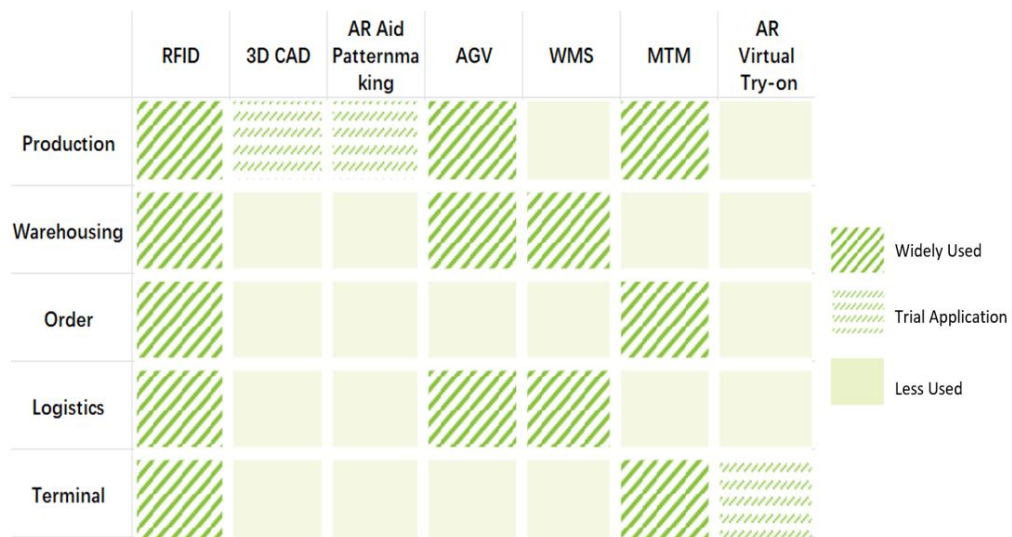
In traditional mass production, flat patterns are generated from technical sketches and garment specifications, often starting with a block pattern based on standard sizing.

These are typically created by experienced patternmakers using CAD software, which has become a primary tool in contemporary apparel design. However, sizing systems vary considerably across companies, resulting in inconsistencies in garment fit and complicating consumer size selection. In some cases, sizing information provided by brands lacks sufficient clarity or precision, which can adversely affect customer satisfaction and increase return rates. To address this, CAD systems can be improved with algorithmic functions that allow for automatic adjustment of patterns based on individual measurements, thus ensuring higher fit accuracy. Once finalized, digital patterns can be transmitted directly to computer-controlled cutting machines, allowing precise fabric cutting while minimizing material waste. During the assembly phase, apparel companies increasingly adopt agile manufacturing principles and lean production strategies to efficiently manage small-batch orders and respond swiftly to unique customer specifications. Technologies such as the Garment Hanging System, Radio-Frequency Identification (RFID), and barcode tracking systems are utilized to monitor and streamline material flow throughout production. At the systems level, Integrated Supply Chain Management (SCM) platforms play a critical role in real-time tracking of materials, order statuses, and production schedules, supporting the end-to-end coordination required for intelligent manufacturing.

On the consumer side, mobile applications equipped with Augmented Reality (AR) fitting tools are becoming an essential interface for virtual try-ons. These technologies

enable users to visualize garment fit based on selected sizes and styles, improving the overall shopping experience. Software such as Optitex, V-Stitcher, Clo3D, and Style3D provides effective virtual fitting environments. These platforms allow users to choose avatars that approximate their body shape or import personalized 3D body scans to simulate garment appearance more precisely. The resulting virtual try-on feedback can then adjust digital patterns, further refining fit before physical production.

As shown in Figure 1.4, China’s Apparel Supply Chain Industry Report in 2022 by iResearch stated that 3D CAD and AR aid patternmaking are in trial stage in the production process, virtual try-on is less used in the production and terminal processes (iResearch, 2023).



Source: China’s Apparel Supply Chain Industry Report in 2022

Figure 1.4: Intelligent Technology Applications in Supply Chain Links

Overall, the convergence of artificial intelligence, data analytics, and advanced manufacturing technologies is supporting the evolution of mass customization in the apparel sector. These tools enable the analysis of individual fit data and consumer preferences, allowing more accurate size recommendations and fit refinement. Through integrated data systems, digital pattern engineering, and intelligent production workflows, the apparel industry is progressively overcoming the inherent tension between customization and scalability, offering consumers improved fit and aesthetic options while maintaining the operational efficiency characteristic of mass production.

1.3 Problem Statement

i. Industry Challenges

The contemporary market is characterized by an increased demand for a more diverse range of clothing products, emphasizing smaller batches. Conversely, as e-commerce continues to expand, an increasing number of individuals are choosing to acquire clothing through online channels. However, if the manufacturing process or the product itself is flawed, resulting in an inaccurate fit, there is a higher likelihood of returns. This phenomenon can lead to a suboptimal shopping experience for consumers and, concomitantly, increased expenditures for clothing enterprises (Lang et al., 2021; Moon & Lee, 2014; Seo & Lang, 2019).

Current mass production systems cannot meet the demand for small-batch, personalized apparel (Yeung et al., 2010). The four body shapes Y, A, B, and C in current size system cannot reflect the detailed differences among various body shapes, which leads to the fit problems in men's ready-to-wear, for example, the main fit problems of men's shirts include shoulder wrinkles and shoulder line misalignment caused by shoulder misfitting (Kim K et al., 2017), chest wrinkles due to different chest protrusions, side seam skewing or uneven hem caused by improper length between the front and back of the shirt (Peng, 2018), and hem lifting or opening of the front due to abdominal protrusion (Wang et al., 2023). Although manual pure customization can tailor to each specific body shape, it remains costly and inefficient (Bae & May-Plumlee Traci, 2005). Therefore, mass customization has been proposed as a crucial strategy to balance the discrepancy between current consumer demand and industrial production. That is to say, it provides a variety of products based on various body shapes, with added flexibility and quick responsiveness at a lower cost, as in mass manufacturing (MacCarthy, 2013; Nayak et al., 2015; Senanayake & Little, 2010; J. Yang et al., 2015). Therefore, the industry faces a critical challenge that how to leverage existing technologies to effectively implement mass customization to balance consumers' fit demand with enterprise production costs.

ii. Technological Gaps

In the context of the clothing industry, the implementation of mass customization presents significant challenges, particularly regarding fit customization. This difficulty

arises from the complexity of body shape variation and the limitations of current technological capabilities and process knowledge (Ashdown, 2014; Bae & May-Plumlee Traci, 2005; Jo Anderson-Connell et al., 2002; Senanayake & Little, 2010). Consequently, factors such as size, pattern, and fit ease, which are interconnected with fit, must be considered in the manufacturing process (Hernández et al., 2018; Senanayake & Little, 2010; Sohn et al., 2020). Despite advances in 3D body scanning, CAD, and virtual try-on technology (Ashdown, 2014; Gupta, 2020; K. Liu et al., 2019; Sohn et al., 2020), a significant gap remains in their practical implementation. Specifically, it remains challenging to determine how these technologies can adequately handle fit customization and flexibly enhance its implementation (Elbrecht & Palm, 2016; Lang et al., 2021; MacCarthy, 2013; J. Yang et al., 2015). As previously noted, the process of fabricating attire for consumers involves numerous components, including body dimension measurement, sizing system development, and pattern creation (Ashdown, 2014; Hernández et al., 2018; Nayak et al., 2015; Senanayake & Little, 2010).

Gap1: *The current size system does not provide consumers sufficient information to help choose fit clothing due to the variety of body shapes and sizes (Bellemare, 2014; Gupta, 2020).*

Determining the appropriate size and fit of a product remains one of the major obstacles shoppers face when purchasing online (McKinsey, 2022). Despite the appeal of virtual try-on software, designed to help customers assess the fit of garments, the practical

difficulties of creating a 3-D model that accurately depicts the fit of a garment for a specific individual are considerable. This is due to the wide variety of body shapes and sizes (Gupta, 2020; Špelic, 2020).

Gap2: *3D body scanning lacks standardized landmarks (Gupta, 2020), leading to inconsistent measurements.*

It is sufficient at this juncture to state that 3D anthropometry has the capacity to extract specific key measures from the 3-D human body with considerably greater accuracy. However, it should be noted that there are currently many different methods, and there is not yet a widely acknowledged system for recognizing, classifying, and tracking anatomical landmarks on the human body. The selection and combination of methods are of paramount importance, as they have the capacity to exert a significant influence on the outcomes, processes, and results (Ashdown, 2020; Gupta, 2020; Kouchi, 2020).

Gap3: *No CAD systems integrate 3D body data directly into patternmaking (Elbrecht & Palm, 2016), forcing reliance on 1D approximations.*

The ability to create well-fitted clothing is also directly influenced by the quality of the block pattern. As posited by Bellemare (2014), the creation of block patterns designed for various figure types can encourage pattern customization (Bellemare, 2014). Furthermore, the development of a comprehensive set of block patterns derived from three-dimensional human body models may provide a pivotal method for enhancing the fit

of clothing and ensuring its suitability for the wearer (Gupta, 2020; Špelic, 2020).

Moreover, the variability in body shapes and computational complexity present certain challenges in the pattern generation of a 3D human body for fit customization. The three-dimensional to two-dimensional conversion technology is available, which enables the direct production of two-dimensional pattern pieces from a three-dimensional virtual prototype design (Hidellaarachchi et al., 2018; Kulińska et al., 2022; Park et al., 2017). However, contemporary pattern-making technologies are exclusively designed to process unidimensional data. Consequently, the development of 3D patternmaking and virtual try-on will be greatly assisted by bridging the gap between 3D body scanners and CAD software that would allow the conversion of 3D body data into import files for CAD systems (Elbrecht & Palm, 2016; Gupta, 2020; Scott & Sayem, 2018).

iii. Research Focus

Therefore, faced with fit challenges in apparel industry and the limitation of the technologies for FC, the research problem is how to incorporate 3D body data collected from 3D body scanning into patternmaking procedures to improve fit in mass customization.

The objective of this study is to propose a pattern generation method based on 3D body model to achieve efficient and adaptable fit customization for menswear. This objective is pursued by developing a theoretical understanding of shape, size, and fit, and

integrating this knowledge with 3D technologies into patternmaking procedures. The present study aims to address the technical gaps by pursuing three primary objectives: (1) the classification of body shapes, (2) the development of a landmark standardization protocol, and (3) the creation of a parametric body-to-pattern model. The fit validation of the patterns will occur through virtual try-ons.

1.4 Research Scope

Mass customization is proposed as a solution to the increased market demand for individualized products. This approach involves the production of smaller batches, with the objective of meeting the specific fitting requirements of customers and reducing the costs associated with clothing production. As indicated by Nayak et al. (2015), Senanayake & Little (2010), and Yeung et al. (2010), fit customization is identified as the most critical component in apparel MC (Nayak et al., 2015; Senanayake & Little, 2010; Yeung et al., 2010). Due to the interaction among body shape, pattern shape, and fabric quality, the number of potential fittings can be exponentially large. However, given the early state of the underlying procedures and technologies, fitting the complex human body shape remains both essential and a challenging task, even with the introduction of body scanners and computer technology (Lang et al., 2021; Nayak et al., 2015).

The goal of this research is to develop a 3D body-driven fitting method. To this end, the research first identifies the key factors influencing fit in the processes of measuring body, sizing, and patternmaking. The selection of 3D body models is based on the body

shape classification, and they are subsequently used to generate block patterns for various figure types. Thereafter, personalized patterns are created from the block patterns, and their fit is evaluated by a virtual try-on experiment.

The following scopes are consequently outlined and should be considered during the entire research process: (i) the population of this study consists of male college students between the ages of 18 and 24 residing in Tianjin and Fuzhou, China, where the body scanning is conducted, (ii) the research examines personalized pattern generation based on the block pattern. However, it should be noted that the patterns exclusively concern body pieces and do not include the sleeves or collar, and (iii) in this research, the term "clothing category" refers to the specific domain of men's shirts, excluding other components of menswear.

1.5 Research Questions

The research questions have been formulated to serve as a framework, directing the investigation towards the objectives of this study. The following research questions have been developed:

i. What are the significant garment fit factors and the applied technologies in the production processes for menswear industry?

ii. What parametric approach can generate patterns that adjust to diverse male body shapes while preserving production efficiency?

iii. How does virtual try-on technology objectively assess the fit of generated patterns compared to conventional methods?

The primary elements that influence the fit of garments are addressed by the first research question, which is based on the study's objective. The subsequent issue concerns the pattern, which exerts a direct effect on the garment's fit. Another significant issue in the field involves identifying effective methods for validating the fit of patterns.

1.6 Research Purpose and Objectives

The objective of this research is to propose a body-to-pattern framework based on 3D body model to develop a theoretical understanding of shape, size, and fit, and to integrate this knowledge with three-dimensional technologies into pattern-making procedures to achieve efficient and adaptable fit customization.

Therefore, it is essential to investigate the current implementation of FC in practical production, including the application of advanced technologies and the key factors influencing garment fit. The identification of the relationship between body shape and garment fit is crucial for the field of pattern design. The integration of this understanding with three-dimensional technologies has the potential to support the rapid generation of personalized patterns. Finally, virtual fitting technology is employed to objectively evaluate the fit of the generated patterns. The specific objectives of this research are as follows:

i. To investigate the garment fit factors and the integration of advanced technologies in menswear production processes.

ii. To develop a CAD parametric method for generating menswear block and personalized patterns based on 3D body model and body shape classification by analysing the quantitative relationship between body size, body shape, and garment fit.

iii. To validate the effectiveness of the proposed CAD-integrated pattern generation method in producing accurate personalized fits from 3D body data.

The objectives of this study indicate that it is both a theoretical investigation and a practical solution aimed at achieving fit-customized men's shirts. The initial objective, the investigation of the present application of advanced technologies and the factors influencing garment fit, is grounded in first-hand data collected from actual production environments. The objective of this investigation is to identify which technologies play a critical role in the implementation of fit customization, what limitations or challenges they present, and how garment technologists perceive the key factors affecting fit. Furthermore, it promotes a more profound comprehension of the underlying factors contributing to suboptimal fit in practical production environments. The analysis of this empirical data provides an essential foundation for the subsequent stages of the research.

Subsequently, an analysis of the relationships among body shape, body size, and garment fit is conducted. These theoretical insights are then incorporated into pattern

design to investigate a personalized pattern generation method. Consequently, the body shape classification by the examination of the interrelationships among body shape, size, and fit; the block patterns derived from 3D body models that adjust to diverse male body shapes; and the development of a personalized pattern generation method represent a pivotal and substantial phase of the research. In this process, focus is placed not only on building a theoretical framework for the body-to-pattern relationship but also on investigating the use of 3D technologies in pattern generation.

The application of virtual fitting technology serves to validate the fit of the patterns generated by the proposed personalized pattern generation method. This approach provides an objective means to evaluate fit, thereby reducing the potential for subjective biases that may be influenced by individual consumer preferences.

Therefore, the central hypothesis of this study is that the proposed theoretical body-to-pattern model and practical solution based on a 3D body model can improve menswear fit compared to conventional ready-to-wear patterns. In addition, the parametric personalized pattern generation that is based on the block patterns from 3D human body models and body shape classification, grounded in a theoretical understanding of body shape, size, pattern, and fit, has the potential to effectively enhance garment fit and address fit demands within the context of mass customization.

1.7 Significance of Study

The present study concentrates on the subject of garment fit customization, encompassing the broad spectrum of human body shapes, the generation of block patterns from 3D human body models, and the fit. The objective of this study was to explore a feasible fit customization method driven by a 3D human body model. In accordance with the research problem, questions, and objectives, this research makes a substantial contribution to the existing body of knowledge concerning fit customization.

This study undertakes a comprehensive investigation of the theoretical foundations of shape, size, and fit. It proposes a theory-based model of the body-to-pattern relationship and incorporates it into the patternmaking process to effectively address fit-related issues. Furthermore, this research explores the potential of 3D body models in generating block patterns to improve the fit in mass customization, emphasizing adaptability and efficiency. The present study therefore bridges the gap in academic research in this area, namely the concerns raised by Gill (2022) regarding the theoretical relationship between the human body and pattern design, as well as Gupta's (2020) observation that there is a paucity of theoretical understanding of shape, size, and fit, and the incorporation of these concepts into patternmaking procedures.

Moreover, the issue of fit can be clarified through a comprehensive investigation of sizing and patternmaking practices within the garment industry. This research offers three practical contributions to industry and academia.

i. **Reduced Return Rates:** By classifying body shapes via 3D scans, the sizing system could reduce return rates that are as high as 53%, according to Alvanon's 2025 data on sizing-related returns.

This research identified the application status of technologies and the factors influencing fit in production. Based on those findings, the research proposed a sizing strategy for selecting a fitting garment to reduce the return rate caused by improper sizes when consumers shop online and reinforce consumers' loyalty. The discussion also included standards for classifying body shapes. The body types were divided into different dimensions, which could transform the garment from a loose fit to a fitted fit, depending on the body shape and size. This demonstrated how body shapes influence clothing selection.

ii. **Cost Savings:** Automated pattern generation from parametric block patterns reduces manual labor, addressing labor-cost challenges (J. Yang et al., 2015).

The research contributes to the existing body of knowledge in generating men's shirt block patterns for figure types based on 3D body models. This methodology enables the manufacture of individually fitted shirts through mass customization. Initially, a human body surface model is developed to define the distinctive characteristics of the figure type. This model is constructed through the use of feature points and feature curves. The body surface model serves as the foundational framework for developing parametric block

patterns, which are employed in creating specific figure types. The generation of customized patterns can be accelerated through the use of block patterns.

iii. CAD Integration: A standardized landmark protocol enables seamless 3D body-to-CAD data transfer, resolving the ‘last-mile’ gap identified by Elbrecht & Palm (2016).

The discussion addressed the criteria for standardizing body landmarks for 3D body models, and the aim of this discussion is to clarify the anthropometric measuring process for patternmaking. Therefore, this research demonstrated the integration of body size and body shape into patternmaking methodologies, enhancing the fit in a flexible and effective manner. This research explores the potential of 3D body scanning, 3D patternmaking, and virtual try-on as an adaptable and efficient fit customization method for garments.

1.8 Limitations of Study

The concept of fit customization encompasses the consumer's silhouette, fit perception, and fit aesthetic, along with factors such as measurements, body shape, and fit ease (Ashdown, 2014; Hernández et al., 2018; Lang et al., 2021; Nayak et al., 2015; Senanayake & Little, 2010; Sohn et al., 2020; Yeung et al., 2010). The present study primarily focuses on the factors of body dimensions, body shape, and fit ease. In contrast, the elements of fit perception and fit aesthetic of the customer are limited in scope. The experimental design is predominantly oriented towards quantitative analysis, thereby

employing an objective method that uses virtual try-on software to assess the fit. This approach does not consider the individual's fit preference or aesthetic considerations.

Moreover, given the constraints imposed by the 3D body scanning apparatus and the ease with which it can be accessed, the target population for this study is male college students between the ages of 18 and 24 residing in the cities of Tianjin and Fuzhou in China.

Due to the temporal constraints imposed on the study, its scope is inherently limited. The present study is limited in scope, as it exclusively encompasses the domain of men's shirts, while failing to address the broader spectrum of menswear. Shirts are a type of garment that is frequently worn in everyday life and has a greater fitting demand compared to other categories of menswear.

1.9 Definition of Terms

This section provides the definitions of apparel subjects, especially in the field of fit customization, which is defined as shown below:

Mass Customization (MC) – it has a broader and a narrower approach. The broad concept defines MC as the ability to provide individually designed products to every customer through high process agility, flexibility and integration whereas the narrowly defined more practical concept discusses MC as a system that uses information technology, flexible processes, and organizational structures to deliver a wide range of products that

meet specific needs of individual customers, at a cost near that of mass production items. (Da Silveira et al., 2001).

CODP – Customer Order Decoupling Point (Senanayake & Little, 2010).

Fit Customization (FC) – It is defined as the allowance or possibility for variation or adjustment, specifically referring to the ability for customers to determine the necessary measurements, general fit, ease, and silhouette related to fit (Senanayake & Little, 2010).

Sizing System – The body sizing system is the method or system used to create a set of clothing for a variety of people in the target market (Xia & Istook, 2017).

Ease Allowance – It is defined as the difference between the pattern and body dimensions. Wearing and design ease are two types of ease allowance. Wearing ease is the amount of extra fabric allowed over and above actual body measurements to ensure the comfort, mobility and drape of the clothing. Design ease is the additional amount of fabric added to achieve certain design effects by changing the line and shape of a clothing (Lagè & Ancutienè, 2019).

Anthropometric Measuring Landmark – It is related basically to anatomical features or bony prominences that should be located touching the body. However, for contactless scanning and automatic measurement extraction, the landmark location criteria are re-defined using geometric features of the body instead of anatomical features (Alemany, 2022).

Basic Block Pattern – It is a basic foundational pattern used as a template for creating various styles and designs of garments (Lagè & Ancutienè, 2019).

Basic Pattern – It is a foundational garment template developed from a basic block by incorporating standard wearing ease. It represents a simplified version of a garment that maintains the essential fit and proportions of the human body while allowing for basic comfort and movement. Unlike the basic block, the basic pattern can be directly used for constructing garments with minimal design details and serves as a starting point for further style modifications (Lagè & Ancutienè, 2019).

Datum Planes – Datum planes are reference planes used in 3D modeling or measurement systems to define the origin and orientation of an object in space (Au & Ma, 2010).

Virtual Model – it is based on an individual's own scan data. It will be an exact replica of the body and will be used for an authentic virtual try-on (Loker, 2007).

Fit model – it represents the range of target market customer body shapes and sizes. fit model's measurements are used to develop size specifications and to test the fit of garment samples (Loker, 2007).

Agile Manufacturing – it is the ability to thrive and prosper in a competitive environment of continuous and unanticipated change to respond quickly to rapidly changing markets driven by customer-based valuing of products (Da Silveira et al., 2001).

Supply Chain Management – it concerns the coordination of resources and the optimization of activities across the value chain to obtain competitive advantages (Da Silveira et al., 2001).

Customer-driven Design Manufacture – it actively considers the market trends in general and individual customer requirements in particular during the design, manufacturing and delivery of the products (Da Silveira et al., 2001).

Lean Manufacturing – it is an efficient way to satisfy customer needs while giving producers a competitive edge (Da Silveira et al., 2001).

1.10 Chapter Roadmap

This thesis is structured into seven chapters. Chapter 1 has introduced the background, problem statement, research scope, research questions and research objectives of this study. Chapter 2 reviews the relevant literature on fit customization, body shape classification, and pattern generation. By identifying the gaps in existing theories, this chapter establish the theoretical framework and the conceptual framework of the study. Chapter 3 outlines the methodological approach. It justifies the use of the mixed-method approach. It describes the data collection and analysis procedures for case study, interviews, body shape classification, pattern generation, and fit validation. Chapter 4 presents and discusses the findings of case study and interviews. The case study focuses on the limitation of technologies used in body measuring and patternmaking. The interviews

focus on the factors influencing the garment fit. This chapter addresses research objective one and informs the subsequent quantitative analysis. Chapter 5 presents and discusses the findings of body shape classification and personalized pattern generation to address research objective two. Chapter 6 presents and discusses the findings of the fit validation of the generated personalized patterns by virtual try-on to address research objective three. Chapter 7 concludes the study. It summarizes the main finding model and arguments, the limitations of the study, and future works and recommendation.

1.11 Chapter Summary

In the context of the market's individualized needs and smart manufacturing, mass customization is a highly customer-driven approach that combines mass production and customization to create variety and personalization through flexibility and rapid response aligned with consumer demand (Senanayake & Little, 2010; Yang et al., 2015). However, despite its importance, the implementation of fit customization remains limited in the apparel industry due to the prevailing uncertainty surrounding the process (Moon & Lee, 2014; Senanayake & Little, 2010; Sohn et al., 2020; Yang et al., 2015).

Despite the considerable potential offered by existing technologies for the application of FC in clothing, there are still some research gaps that are difficult to resolve. Consequently, the present chapter is dedicated to FC, with a comprehensive review of the research background, the problem, and the existence of research gaps. This detailed explanation is undertaken to clarify the primary research questions and objectives of the

current study. It is apparent that the scope, significance, and limitations of the study are described with utmost clarity. The present study focuses on the classification of body shapes and the generation of block patterns for different figure types from 3D human body models. The objective is to establish a 3D body-driven fitting model for men's shirts.

Therefore, the primary factors that influence garment fit during production and the advanced technology employed will be investigated first in this study. The investigation results indicate that the principles of body shape clustering will be presented for classification of body shapes. Additionally, the theoretical understanding of shape, size, and fit will be explored. 3D human body models based on body shape classification are used to generate block patterns for different figure types. Then, it addresses the criteria for identifying body landmarks on a 3D human body, aiming to accurately reconstruct its surface. A parametric computation model will be employed to generate block patterns for various figure types and personalized patterns based on block patterns. These patterns will be derived from the theoretical relationship between body measurements and pattern size. The effectiveness of pattern design will be rigorously assessed through the use of virtual try-on software.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter presents a review of the related literature. The aim of conducting a comprehensive and concise literature review is significant as it provides an account of the various research studies conducted in fit customization and highlights the current development trends and achievements.

With respect to the context of the research, extensive literature focused on fit customization was searched, reviewed, and organized strategically. Figure 2.1 illustrates the organization of the literature in this chapter.

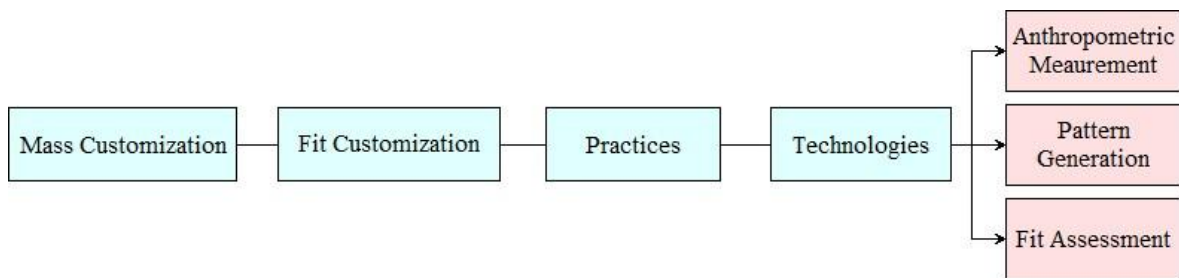


Figure 2.1: Organization of the Literature

Mass Customization (MC) is the origin of fit customization, and the definition and practices of fit customization were explained comprehensively to provide background to the research area. The technologies used in implementing fit customization were explored

and detailed in subsections to create awareness of the latest developments within the research field and offer new insight into possible progress and advancement in the area. This literature review lays the theoretical foundation for the research domain. Finally, this chapter concludes with a summary of the challenges of fit customization and the theoretical and conceptual frameworks of this research.

2.2 Mass Customization

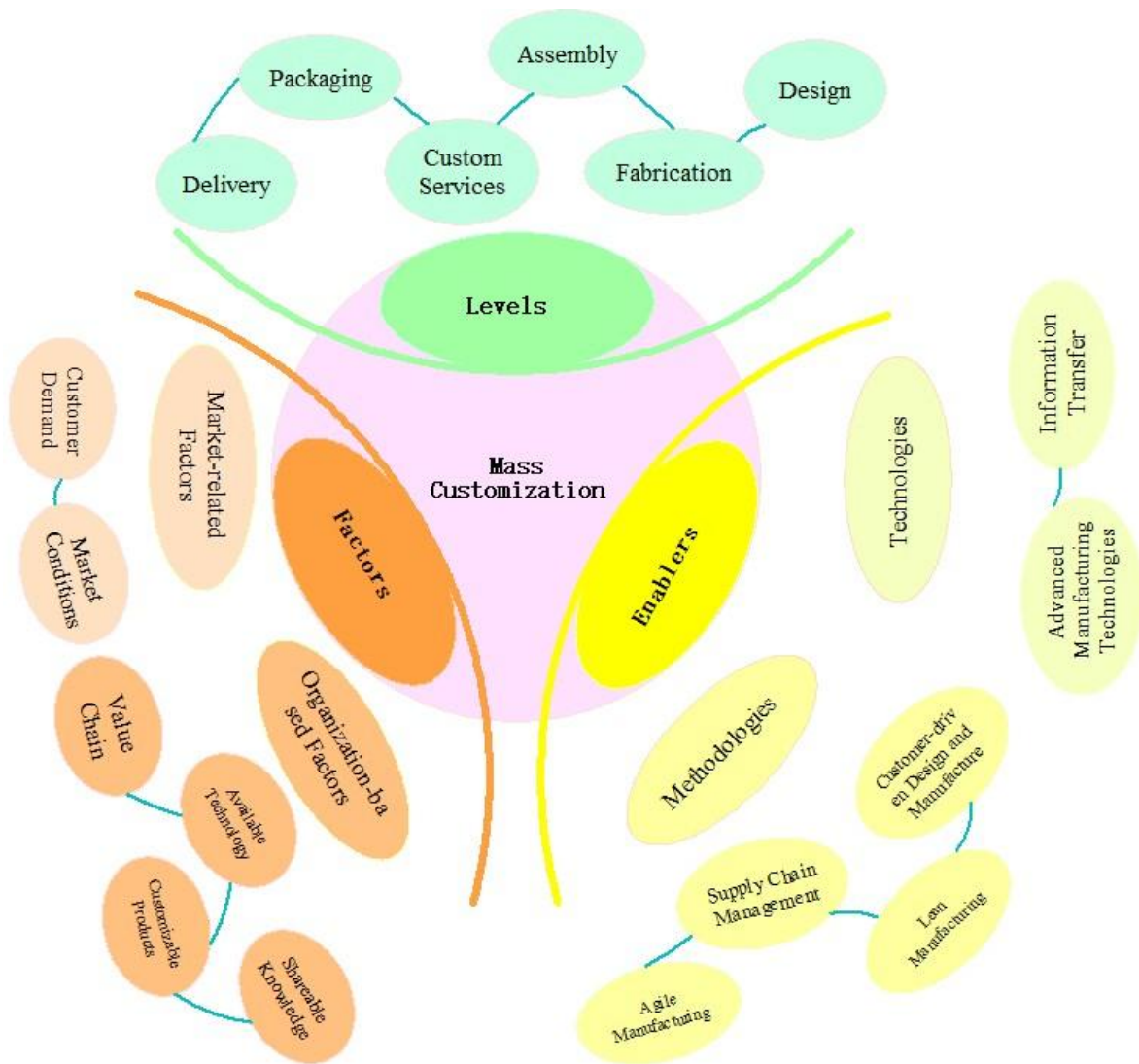
In light of the increasingly sophisticated demands of contemporary consumers, businesses are confronted with the imperative to deliver elevated degrees of variety and personalization, a challenge intensified by the proliferation of product diversity across numerous categories. This suggests that the producer must be capable of providing customization services to a substantial number of customers without incurring significant additional costs and without requiring the customer to compromise on response times or product quality. The proliferation of product variety generates numerous challenges for producers in the context of mass production, compelling them to address the evolving demands and preferences of consumers in terms of emerging trends and culinary inclinations (MacCarthy, 2013). The term “mass-customization” (MC) was first introduced by Toffler and was described as the system that combines mass production and craft customization by Stan Davis in the book “Future Perfect” in 1987 (Yeung et al., 2010).

2.2.1 Definition of Mass Customization

Silveira et al. (2001) proposed a definition of MC as the capacity to deliver

custom-designed products to each customer with high process agility, flexibility, and integration. In a narrower sense, MC can be understood as a system that relies on information technology, flexible processes, and organizational structures to provide a diverse range of products tailored to the specific needs of individual customers at a cost comparable to that of mass production items (Da Silveira et al., 2001).

Silveira et al. (2001) pointed out the success of MC systems depends on market-related factors, organization-based factors, the methodologies and technologies that support the development of the organization-based factors. As shown in figure 2.2, customer demand for variety and customization, market conditions are primary market-related factors. Value chain, available technology, customizable products and shareable knowledge are primary organization-based factors. Agile manufacturing, supply chain management, customer-driven design and manufacture, and lean manufacturing are four main business practices relating to MC, while the technologies, such as flexible manufacturing systems (FMS), computer-aided design (CAD), computer-aided manufacturing (CAM), computer integrated manufacturing (CIM), and electronic data interchange (EDI), support MC implementation. The most important in MC implementation is the efficiency in information transfer from customers to manufacturers through the used technologies (Da Silveira et al., 2001).



Source: Da Silveira et al. (2001)

Figure 2.2: Model of Mass Customization Strategy

Therefore, the aim of MC strategies is to deliver customization at the lowest possible cost with high efficiency, a goal that is typically achieved in mass-production environments. This results in a win-win situation for both companies and customers. In essence, customers can attain satisfaction through active participation in the design process, thereby fostering a sense of individuality. Meanwhile, the MC company achieves value by

recognizing the superior quality of their products, consequently acquiring loyal customers who demonstrate a high degree of satisfaction (Nayak & Padhye, 2017; Yeung et al., 2010).

2.2.2 Extension of Mass Customization

- **Points of Mass Customization**

In the implementation of MC, it is important to identify the key elements that are customizable and capable of creating an impact on rapid design-to-manufacturing, especially for small-batch production at reasonable costs. Silveira et al. (2001) proposed the framework for MC to achieve successful apparel customization. Senanayake and Little (2010) stated that a successful mass customization strategy must address five critical points of customization (Senanayake & Little, 2010), which were

i. Post-production customization point. The company's production capabilities enable it to deliver customized apparel, either through the creation of new products or by repurposing existing stock.

ii. Fabrication customization point. It involves providing customers with choices regarding the materials within the existing product category.

iii. Fit customization point. The term "flexibility" is defined as the allowance or possibility for variation or adjustment, specifically referring to the ability for customers to determine the necessary measurements, general fit, ease, and silhouette related to fit.

iv. Feature customization point. At this stage, the customer has the option to select or define features.

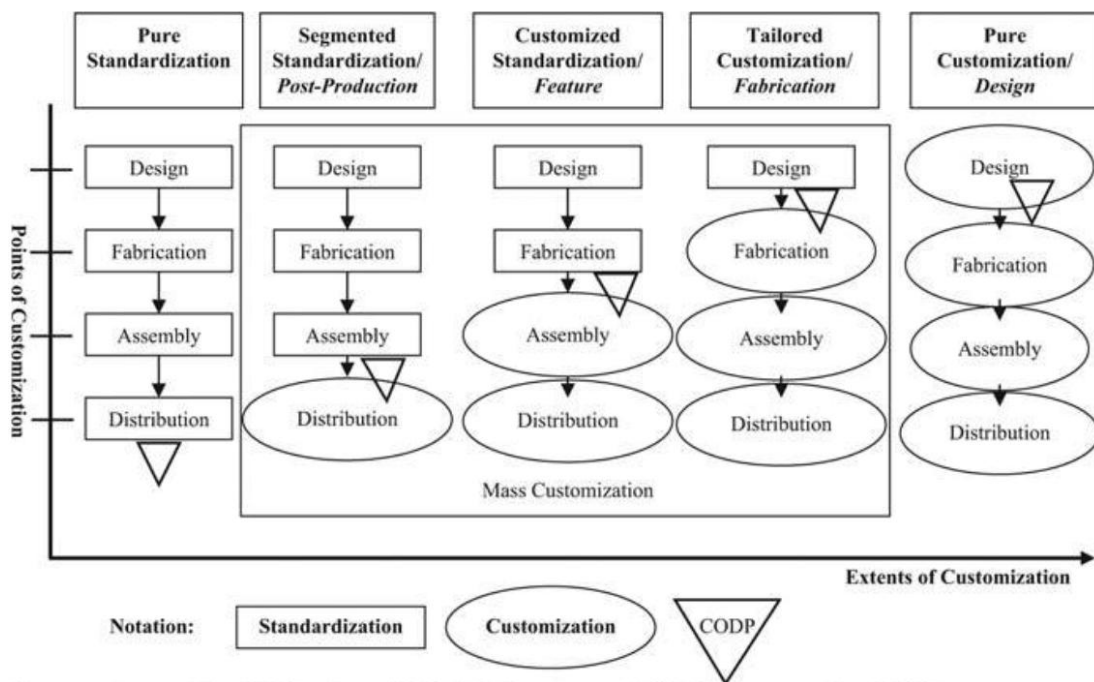
v. Design customization point. It concerns the manner in which customers are empowered to design apparel products.

In line with the five critical points for apparel MC implementation, according to Kurt Salmon Associates Annual Consumer Outlook Survey for [TC]2, personalization, fit, and design are the three applicable dimensions in apparel MC (Senanayake & Little, 2010). However, fit customization is regarded as the most important challenge and critical aspect in apparel MC (Jo Anderson-Connell et al., 2002; Yeung et al., 2010). Nayak et al. (2015) indicated that fitting the complex shape of a human body is a very difficult task even with body scanners and computer technology (Nayak et al., 2015). Fit seems to be the determining element when it comes to personalization (Lang et al., 2021).

- **Extent of Mass Customization**

Eight generic levels of MC rang from pure customization to pure standardization. The top level is design, the following is fabrication, assembly, custom services, packaging, delivery (Da Silveira et al., 2001). Senanayake and Little (2010) depict points and extent of customization adopted from the levels of MC, as shown in Figure 2.3. The extent of customization ranges from pure standardization to complete customization. It is critical to acknowledge that a trade-off exists in relation to the extent of customization. Therefore, Senanayake and Little (2010) offered further clarification on the meaning of MC. Two

additional definitions for a customized apparel product were identified. The two types of customized apparel are as follows: "consumer-customized" apparel, which can be tailored to fit the customer's preferences, style, and other specifications, and "occupation-customized" apparel, which includes uniforms designed for specific occupations (Senanayake & Little, 2010).



Source: Senanayake and Little (2010)

Figure 2.3: Points and Extent of Customization

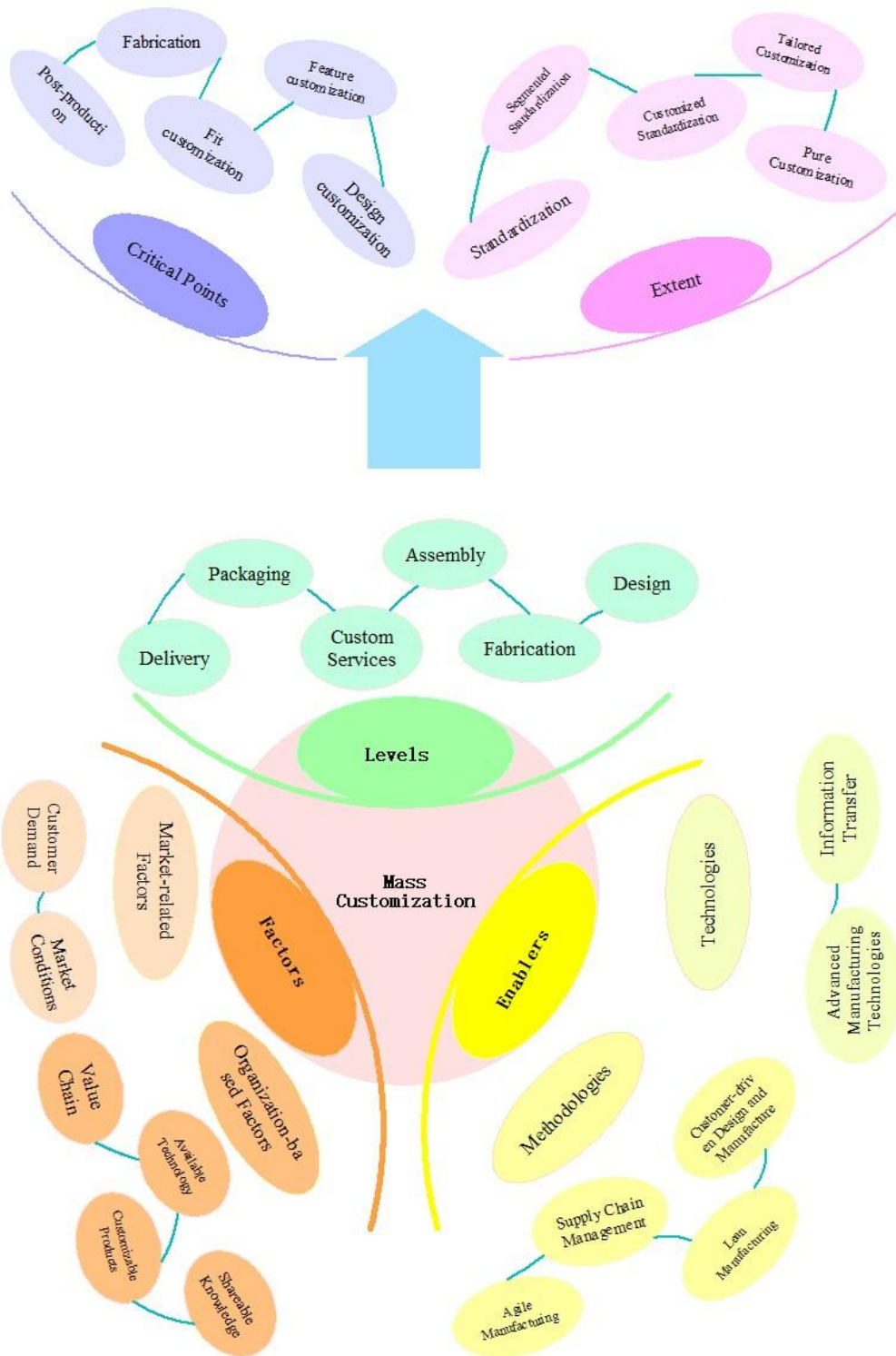
MC imposes constraints on the extent to which customers are allowed to specify product attributes. The limitation of customization permits the preservation of "mass" characteristics in terms of economics, response time, and quality. The objective is to

provide a product offering that enables customers to customize, select, and differentiate their purchases in terms of salient attributes. This approach is designed to address customers' fundamental needs and enable them to satisfy a portion of their desires and preferences regarding product attributes (MacCarthy, 2013).

In a more precise sense, MacCarthy (2013) clarified that "mass" signifies the achievement of mass production in economic terms, particularly in procurement, manufacturing, and logistics. This approach entails avoiding substantial additional overhead costs in producing a high volume of products. In the context of customization, the term encompasses various dimensions, including shape, functionality, design, aesthetics, styling, personalization, and services. These dimensions extend to the delivery process, pricing structure, and contractual agreements. Therefore, the MC model is extended as shown in figure 2.4.

Additionally, the variety of MC strategies has expanded due to technological advancement (Helms et al., 2008). Major corporations adopt design and production technology earlier than small firms, even though they might not fully engage in MC. However, small businesses are noticeably more likely than larger businesses to offer higher levels of customized products. This enables consumers to experience the MC service from companies that were the earliest aware of MC strategy. Although consumers can customize apparel products based on their own preferences such as style and color, and then the producer can produce and provide a well-fitting product according to individual body

measurement, this is achieved through technology and during the exploration phase.



Source: Da Silveira et al. (2001); Senanayake and Little (2010)

Figure 2.4: Extension of Mass Customization Model

The above provides a solid theoretical foundation for the present study on fit customization. Therefore, the following sections will introduce the definition of fit customization, the practice of apparel fit customization, the processes and technologies for fit customization.

2.3 Fit Customization

2.3.1 Definition of Fit Customization

There are many definitions of fit customization, but they are all similar, being closely and mainly related to body measurements, body shape, and fit ease. Senanayake & Little (2010) defined fit customization as the flexibility offered to the customer to decide on the measurements needed, the general fit ease, and the silhouette related to fit (Senanayake & Little, 2010). In addition, Bae and May-Plumlee (2005) presented customers' relevant size information as well as the shapes of the body as important options to specify a customer's preferred fit (Bae & May-Plumlee Traci, 2005). Furthermore, Sohn et al. (2020) stated that fit customization allows consumers to buy products with fitting customized to their body sizes and shapes, so the implementation of technology should be examined with body size, pattern, and apparel fit relations all considered (Sohn et al., 2020).

Additionally, fit perception is another important factor in the definition of fit customization. Ashdown (2014) pointed out that fit issues included both the company's fit aesthetic and the fit preference of the customer (Ashdown, 2014). High-structured

garments, which demand elevated fit requirements, necessitate a greater understanding of body size and shape to accommodate diverse body types. Consequently, translating body measurements into actionable sizing and fit information is essential. In support of this assertion, the concept of a garment's fit is contingent upon achieving an equilibrium between the garment and the body on which it is to be worn. In this regard, ease allowance emerges as a pivotal parameter. In addition to the body, the perception of garment fit is also individual. Variations in fit preference among individuals necessitate a reliable sizing system, effective pattern construction, and high-quality production to enhance garment fit (Hernández et al., 2018).

Therefore, FC is defined as the level of flexibility provided to the customer, which includes choosing not only the required measurements, the overall ease of fit, and the silhouette of the garment related to the fit (Senanayake & Little, 2010; Sohn et al., 2020), but also the company's fit aesthetic and the customer's fit preference (Ashdown, 2014; Hernández, 2018). Table 2.1 summarizes the relevant content of FC based on the literature study into three categories: body measurement, pattern, and fit assessment.

When it comes to personalization, fit is regarded as the most important factor in MC apparel and the primary determining element (Da Silveira et al., 2001; Lang et al., 2021; N. Liu et al., 2020; Xu et al., 2021; Yeung et al., 2010). The interactions among body shapes, pattern shapes, and fabric properties can create an exponential number of potential fittings that need to be narrowed and addressed, as the underlying technology and

processes remain in their early stages.

Table 2.1: Elements in the Definition of FC

No.	Elements		Main Reference
1	Body Measurement	Body Measuring	Kohlschütter & Herout (2012); Ashdown (2020)
		Measurement Data	Ashdown (2014); Tsoli (2014); Xia & Cynthia (2017); Loercher et al. (2018); Faust (2019); Song (2019); Lauria (2022); Zakaria & Ruznan (2020)
2	Pattern	Fit Ease	Ashdown (2014); Liu et al. (2019); Park et al. (2019)
		Patternmaking	Sohn et al. (2020); Gupta (2020); Han et al. (2021); Lei & Li (2022)
3	Fit Assessment	Virtual Fitting	Miell (2018); Harrison (2018); Gill et al. (2022)
		Fit Satisfaction	Ashdown (2014); Hernández (2018); Bizuneh (2023)

Loker (2007) pointed out that mass-customized sizing is the key to achieving well-fitting customization, which is different from standard sizing in mass production. As shown in Figure 2.5, size development, pattern-making, and fit evaluation are the main strategies of mass-customized sizing (Locker, 2007). The purpose of size development is to provide a fit that is individualized based on the customer's objective body measurements, body type, or preferences for a tighter or looser fit. Body scanning and the virtual models

obtained from scanning provide more accurate data for size development. In the pattern-making strategy, using CAD to generate block patterns and using AI to generate made-to-measure patterns are two common methods. In terms of fit evaluation, using fit models for virtual fitting is the future trend. Loker's research proposed the main strategies and techniques for achieving well-fitting customization, laying a theoretical foundation for this study.



Source: Locker (2007)

Figure 2.5: Strategies of Mass-customized Sizing

Similarly, Gupta (2020) noted that the process of creating clothing that fits customers is a concern for the apparel production sector (Gupta, 2020). The procedure includes several steps, including anthropometry, which entails measuring the body, patternmaking, which involves converting the measurements into 2-D patterns, assembly, which consists of joining the patterns to create a 3-D shell, and fit testing that involves draping the shell over a 3-D form to evaluate how the garment fits and moves on the body. The measurements, general fit ease, and silhouette are the primary deciding factors for the fitted garment. Each of these industries has undergone rapid technological developments,

and nearly all processes are currently digital.

2.3.2 The Extent of Fit Customization

The term "custom-fit" refers to a product that is personalized regarding shape and size. The extent of fit customization depends upon the characteristics of the product and the customer's requirements. The range of services offered includes the modification of product characteristics according to the customer's specifications and the production of a customized product with specific physical dimensions.

As Senanayake and Little (2010) have demonstrated, the flexibility of the fit is due to the range of available options, which includes a spectrum from limited measurement options to comprehensive body measurements. This spectrum ranges from looser fits to tailored fits (Senanayake & Little, 2010). Mpampa et al. (2010) implemented a strategy determining a primary and secondary size to achieve various levels of fit (Mpampa et al., 2010). Therefore, both body measurement and the definition of a size system for fit issues are significant. A survey of industry practices relating to the customization of apparel reveals a diversity of methods used to obtain measurements for such customization. It is widely accepted that measurements obtained from body scans are regarded as high-end, whereas the general fit options offered by the company are considered low-end (Senanayake & Little, 2010; Sohn et al., 2020). The practice of making fit adjustments by customer try-on of an existing size is considered standard protocol by most companies, along with measurements taken at the store or as instructed by the company. Some

companies use the practice of measuring customer-provided garments to ensure a precise fit. General fit descriptions represent an additional method used by certain companies.

As previously mentioned, the various companies implement distinct sizing strategies to access different markets. These varied sizing strategies consequently give rise to different production models, resulting in a higher degree of variation in fit across a broader range of sizes.

2.3.3 Significance of Fit Customization

The fit factor is of paramount importance in addressing customer concerns and promoting the growth of the apparel industry. Fit customization is a crucial component in addressing both personalized needs and minimizing fit returns, while simultaneously enhancing manufacturing innovation. This is because it employs effective strategies and technologies to avoid process risks.

- Offering unique products to meet personalized needs and reduce fit returns

The desire for uniqueness and social identity is a key factor in shaping perceptions of customization (Moon & Lee, 2014). Furthermore, it should be realized that differences exist in antecedents toward customization perception between genders. Males are more driven by social identity and the need for uniqueness, but females by self-promotion. Sohn et al.(2020) underlined that fit and size issues were the main concerns of young male consumers (Sohn et al., 2020). According to McKinsey's "State of Fashion Technology

Report 2022," 71% of global consumers want companies to deliver personalized communications and products, and 76 percent are dissatisfied when this is not offered (McKinsey, 2022).

The aim of fit customization is to provide one-of-a-kind products that can be fully adapted to meet the user's requirements. Delivering uniqueness in products and meeting the primary needs of customers are the most important aspects of FC. Therefore, the value of fit customization lies in its ability to supply customers with products tailored to their specific needs and preferences. This can lead to higher customer satisfaction and loyalty, as well as enhanced product performance and functionality (Lang et al., 2021).

- Strengthen the firm's manufacturing competitiveness to reduce production cost

Fit customization can assist companies differentiate themselves from their competitors by not only offering unique products that cannot be found elsewhere (Lang et al., 2021), but also increasing production capacity. In 2021, the value of the top 50 investments in technology related to fashion grew 66 percent compared to 2019, and the advanced personalization techniques are emerging within apparel industries, for example, artificial intelligence to analyze datasets and make predictions, big data to support AI models, cloud computing to enable real-time processing of customer data, virtual reality and augmented reality to allow customers virtually try on clothing, CAD to create product models, digital workflows, and radio-frequency identification (McKinsey, 2022). This

shows that apparel companies are using technologies to improve their personalization capacity to drive customer engagement and loyalty.

Fit is one of the key attributes for personalization and is not easy for MC to achieve quickly. Despite progress in the Artificial Intelligence (AI) field and 3D body scanning systems that provide effective solutions for measurement data collection, fit customization remains a significant challenge, even for online customization. Apart from the cost of implementation, considerable progress is still required before machines are intelligent enough to fully understand the meaning of fit requirements.

2.4 Practice of Apparel Fit Customization

FC has been applied in many different types of apparel industries. Some large companies implemented FC earlier. For instance, Lands ' End Inc. first offered fabric customization and style customization, and also required customers to enter measurement data into a website for fit customization. The electronic pattern would be generated with an algorithm according to the customers' measurement data and the answers obtained via self-assessment questionnaires related to the individual's fit preferences. Additionally, Brooks Brothers Inc. offered customized products on individual fit and style, both online and in stores, because of the application of process modularity and an automatic model fitting system. Measurement data can be entered onto the website or collected by a 3D body scanning tool employed in the stores. The Made-to-Measure system was used to automatically modify the pre-existing standardized patterns according to the customer's

measurements. Moreover, Levi's was trying on a pre-produced best-fit prototype for the fit-well product (Yeung et al., 2010).

As digital technology advances, more and more apparel industries offer sizing or fitting assistance on their websites to customize the fit.

Indochino, a made-to-measure menswear brand, combines advanced measurement technologies with traditional tailoring techniques to offer customized suits, shirts, and other garments. Through its online platform, customers can obtain measurements via two methods: manual input guided by step-by-step instructions, or algorithm-driven prediction based on height and weight data. Additionally, customers can visit physical showrooms for in-person measurements and personalized design consultations, ensuring garments are tailored to individual body shapes (Indochino, 2023).

Bonobos, another notable brand, emphasizes inclusive sizing and fit diversity. Unlike traditional mass production that relies on standardized sizing, Bonobos utilizes multiple fit models, such as slim, athletic, and standard builds, to accommodate a broader range of body types. Their website also offers personalized fit guidance, helping consumers identify their optimal size more efficiently. These efforts reflect a strategic investment in sizing inclusivity, customer feedback, and technological support to deliver garments that better meet the demands of modern consumers (Bonobos, 2023).

IWODE employs online and offline approaches to enable flexible and accessible

measurement collection. Through its mobile app, users can upload front and side-view body images, which are processed using Structure-from-Motion (SfM) technology to reconstruct 3D body models and extract key measurements. In addition to digital options, consumers can follow in-store measurement tutorials or opt for on-site measuring services, offering multi-channel access to precise fit solutions (IWODE, 2024).

Similarly, Proper Cloth offers an online platform for customized men's shirts, using an algorithmic questionnaire that generates measurement estimates based on users' self-reported body characteristics. While these approaches mark significant progress in digital customization, online platforms still face inherent limitations. Common issues include low recommendation accuracy, insufficient virtual fitting realism, and unsatisfactory fit outcomes, particularly in scalable mass customization contexts. These persistent problems show that body measurement remains a critical determinant of garment fit, and that achieving consistent accuracy across diverse body shapes remains a major challenge (Proper Cloth, 2024).

A more integrated and technologically advanced example can be found in Kutesmart, a Chinese apparel company that has successfully implemented a data-driven mass customization system (Kutesmart, 2025). The company developed an open internet-based customization platform that integrates the entire value chain, from ordering and design to production, logistics, and after-sales service. By combining CAD, CAM, intelligent manufacturing systems, and big data analytics, the platform houses extensive

databases for fabrics, styles, body sizes, patterns, and manufacturing processes. This digital infrastructure enables rapid generation of individual garment patterns based on modular frameworks and real-time customer body measurements, collected either online or in-store, while supporting flexible production through a comprehensive manufacturing execution system. For apparel of the same quality, users only pay 20% to 50% of the industry average. The company's net profit grew by about 46% year over year in the first three quarters of 2022, a sign of economic progress. This illustrates that while implementing new technologies takes time and money, the return on investment can be substantial once a strong ecological model is formed. Although Kutesmart's system represents a thorough integration of intelligent customization technologies, accurate body measurements are still primarily obtained through manual processes, highlighting a continued reliance on traditional methods even within advanced frameworks.

Bodi. Me Ltd (2020-2022) applied a made-to-measure model to solve fit problems. In the made-to-measure model, technology exists to collect basic data from consumers quickly, easily, and remotely and convert this into measurements that can be used to create a custom-made garment. Virtual Fitting is another innovative technology that allows designers to adapt basic patterns developed for type bodies to create custom-fit clothing. Body scanning, virtual try-on, computer-assisted design (CAD), and computer-assisted manufacturing (CAM) technologies have become more compatible and can now accommodate fit-customized clothing specific to individuals and target markets (Bodi. Me,

2021).

McKinsey's "State of Fashion Technology Report 2022" shows that Zalando has invested heavily to help solve fit issues. It acquired a virtual dressing room company in 2020, has an entire size and fit department, is establishing a technology hub in Zurich dedicated to the task, and is trying to achieve results by 2030. What they are doing at this stage for the fit of apparel is mostly based on data obtained from customers to help them make better choices. It is very much based on returns, why customers return certain items, and customer feedback. In this way, they have already been able to reduce size-related returns by 10 percent. They believe that returns will be reduced much more when moving further toward whole-body measurements and experimenting more with 3D technology and body measurement technology (McKinsey, 2022).

Furthermore, an analysis of consumer feedback on their actual experiences with clothing FC platforms of Sumissura identified the primary advantage of FC as its functional value, followed by ease of use and emotional value (Lang et al., 2021). Functional value is predominantly characterized by comfort, the quality of tailoring and materials, and the fit of the products. Three main cost-related concerns were unsatisfactory service, disappointing product performance, such as poor fit, and financial risk, such as a mismatch between price and perceived quality. Consequently, ensuring high satisfaction with product performance emerges as the foremost benefit consumers seek from FC. Additionally, user-friendly interfaces, exceptional service, and aesthetic appeal are critical

considerations for enhancing the overall consumer experience.

Fashion technology for fit customization has seen many interesting improvements, but there are also some difficulties. One of the key components of custom tailoring, the capacity to make alterations depending on individual preferences, may be missed by some devices that guarantee a perfect fit through computerized analysis of the body (Paganelli, 2019). When gathering personal data for personalized apparel, there may also be concerns with data privacy and security.

In general, fit is defined as the interaction between a person and their clothing, impacting the user's comfort, performance, appearance, and self-esteem. Fashion companies ramp up their investments in technology from between 1.6 and 1.8 percent of sales in 2021 to between 3 and 3.5 percent by 2030, according to McKinsey's "State of Fashion Technology Report 2022" (McKinsey, 2022). Although automation and information technology have developed rapidly, it remains challenging to explore how technologies can address fit customization online or onsite, and further enhance the implementation of fit customization. To more fully comprehend the current status and trends of existing technologies in fitting customization, the following will mainly introduce technologies in the aspects of anthropometric measurement, pattern generation, and fit assessment.

2.5 Processes and Technologies of Apparel Fit Customization

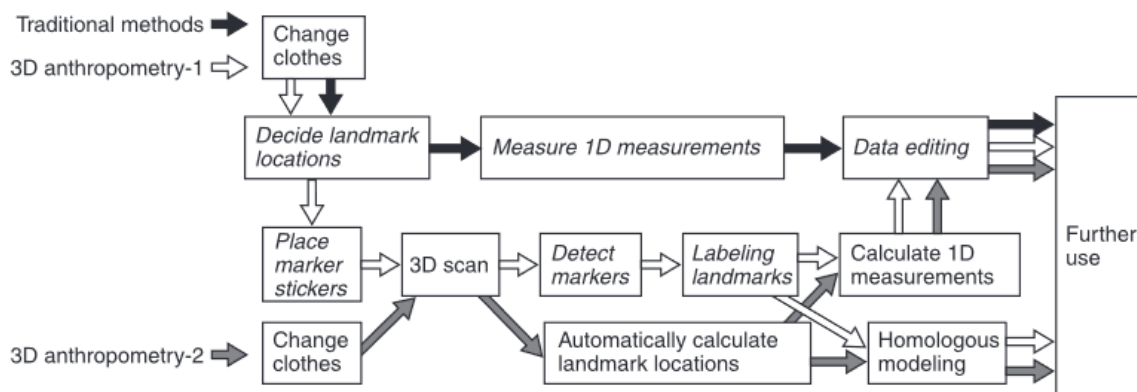
Mass Customization was introduced early to balance variety and cost (Da Silveira et al., 2001; Senanayake & Little, 2010). However, due to the complexity of body shape and limitations of technology, fitting is considered the most important issue and the most challenging task in MC for apparel (Elbrecht & Palm, 2016; Gupta, 2020; Hernández, 2018; Lang et al., 2021). Anthropometric measurement, pattern generation, and fit evaluation are three main manufacturing processes relating to fit in apparel MC. Until now, many studies have improved fit through technological advancements (Li & Chen, 2018; Z. Liu et al., 2019; Sohn et al., 2020). Advanced technology is essential to achieve fit in the practical application of the manufacturing processes.

2.5.1 Size Development

2.5.1.1 Body Measurement Techniques

The first step in clothing FC is taking body measurements. In traditional anthropometric methods, human measurers identify the landmark positions and manually take the measurements using conventional instruments like calipers and tape measures (Kouchi, 2020). In recent decades, noncontact techniques for measuring the human body have become available and are now used in size surveys, for example, photographic body measurement, depth cameras, and 3D body scanning. The accuracy of anthropometric data is required by users, so that instruments, measurement postures, procedures, landmarks, and measurement attire are all standardized for this purpose (Kouchi, 2020).

A comparison of noncontact and manual techniques reveals that the latter are significantly more expensive and time-consuming than the former. However, following scanning, some time may elapse before acquiring 1-D measurements, which may not be directly comparable to those obtained through conventional methods. As demonstrated by Kouchi (2020), the flow of anthropometry is evident in two distinct ways, as shown in Figure 2.6. Manual procedures are indicated by italics (Kouchi, 2020).



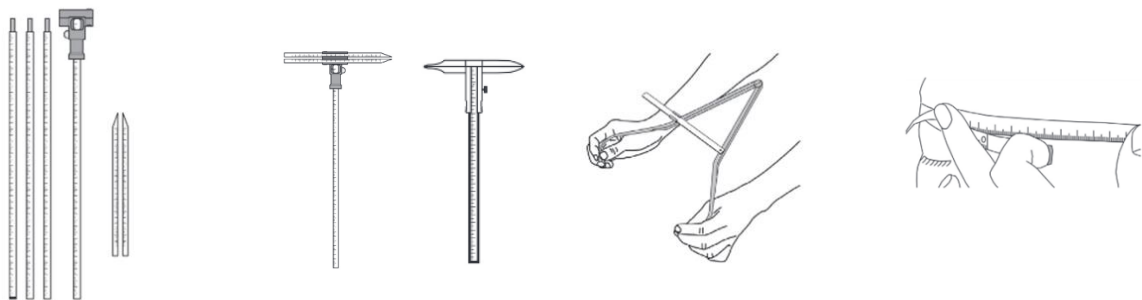
Source: Kouchi (2020)

Figure 2.6: the Flow of Anthropometry

- **Traditional Manual Measurement**

In conventional manual measurement, the fundamental postures of the subject, the measuring instruments, and the measurer are essential. According to Kouchi (2020), the measurer must ensure that the subject maintains the appropriate posture during the measurement process. For instance, the standard standing posture is characterized by an upright, two-footed stance with relaxed shoulders. The arms should be positioned in a

natural hang-down, with the orientation of the head maintaining horizontal alignment. The instruments used in conventional anthropometry include an anthropometer, a sliding caliper, a spreading caliper, a tape measure, and similar apparatus (Kouchi, 2020), as illustrated in Figure 2.7.



(A) Anthropometer (B) Sliding Caliper (C) Spreading Caliper (D) Tape Measure

Source: Kouchi (2020)

Figure 2.7: Traditional Measuring Instruments

The measurer takes actual measurements and records the values in a data sheet, so the measurer must have anatomy knowledge about landmark locations, definitions of landmarks, measurement items, and measurement errors. In addition, the measurer requires training in landmarking and measurements with different body shapes (Kouchi, 2020). In traditional methods, the accuracy of measurements mainly depends on the skill of the measurer, and accurate understanding of landmarking can help reduce bias and random error within a measurer.

The conventional approach remains a viable method in the present day, as evidenced by its use by experienced professionals in the field of tailoring. This method, combined with two-dimensional measurements (photographs), was recently applied in the research conducted by Park et al. (2017). In his study, Park classified the lateral upper body shapes of wheelchair users to define their body measurements and enhance their clothing fit. A sample of 144 Korean male wheelchair users was selected for this research. Their anthropometric data were collected using tape measurement techniques and photographs. A cluster analysis was performed, which produced the identification of three distinct lateral upper body shapes. Subsequently, discriminant functions were developed for the three lateral upper body shape groups. It was shown that the lateral upper body shapes and discriminant functions can be applied to adjust the pattern for fitted suit jackets for wheelchair users (Park et al., 2017).

- **2D Anthropometry**

Photograph body measurement as a type of 2D measurement is also applied in some apparel companies that take photographs of the body, such as the body front, body side, and body back, to computationally obtain body measurements and reconstruct a 3D mannequin (Kohlschütter & Herout, 2012; Li & Chen, 2018). Effective algorithms were employed by Makeev et al. (2020) in recent work to extract the 2D contour of the human body from a single photograph of a clothed individual (Makeev et al., 2020).

The properties of 2D slices of selected body regions are extracted using various

filters and detectors. The body dimensions and contour data are then utilized to create a three-dimensional model. Recent advances in generative adversarial networks (GANs) now enable 3D body estimation from 2D images (Alvanon, 2023). SizeStream's AI can generate over 240 accurate body measurements using a smartphone from just two poses, reducing scanning hardware costs (SizeStream, 2025).

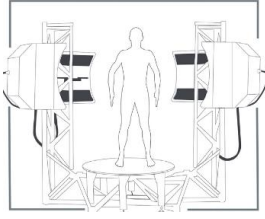
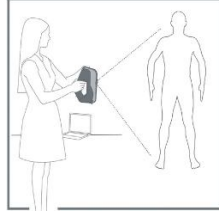

Although this method is easy and low-cost to acquire body data, it is difficult to control the key measurements of the body model, so the model usually lacks realism. The main reasons these methods are not widely used are their computational complexity and the challenge of regulating crucial body model measurements, especially when the consumer is wearing clothing that is inappropriate and could alter the actual underlying body shape. Once these issues are resolved, this method can be rapidly implemented for online clothing FC because it does not require complex tools or gadgets, and the instructions are simple to understand and follow.

- **3D Anthropometry**

Digital 3-D body scanning methods are currently the primary technique used in any significant anthropometric study conducted worldwide (Gupta, 2020). The Civilian American and European Surface Anthropometry Resource (CAESAR) project, carried out in the late 1990s, was the first survey employing 3-D scanners that were scientifically developed. It evolved with the advancement of body scanning devices from booth-type body scanners to portable body scanners and hand-held scanners, and then to mobile

scanners, as shown in Table 2.2. It can be observed that less costly and more adaptable methods of generating 3-D models of the body will be the trends in body scanning (Ashdown, 2020).

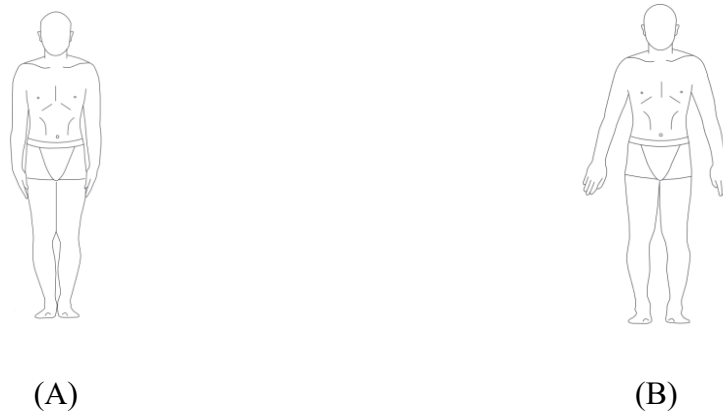
Table 2.2: 3D Body Scanning Systems

Scanner Type	Booth Scanner	Portable Scanner	Mobile Scanner
Scanning Time	5–15 seconds	1–2 minutes	10–30 seconds
Accuracy	Millimeter-level accuracy	5–10 mm error	Centimeter-level accuracy
Best Use Case	High-end apparel	Low-budget projects	Retail stores
Diagram			

Source: Gupta (2020)

There are several international standards for anthropometry; for instance, measurement items for technology design and clothing design are described in ISO 7250-1:2017 and ISO 8559-1:2017, respectively. ISO 8559-1:2020 now defines 48 landmark points for apparel. Key changes include using “Chest apex” as a more gender-neutral term to replace “Nipple point” and adding “posterior armpit point” for sleeve fitting; waistline is now measured at its narrowest point but not necessarily at the umbilicus.

ISO 20685-1 recommends two postures shown in Figure 2.8. A basic standing posture (A) is only used for height measurements. The posture (B), in which the arms are abducted 20 degrees and the distance between the foot axes of both feet is 20 cm, is intended for girth measurement. The scanning posture balances shape distortion and obscured areas (Kouchi, 2020). Additionally, general specifications for creating anthropometric databases, including the number of individuals to be measured and procedures for removing anomalous values from measured data, are outlined in ISO 15535:2012.

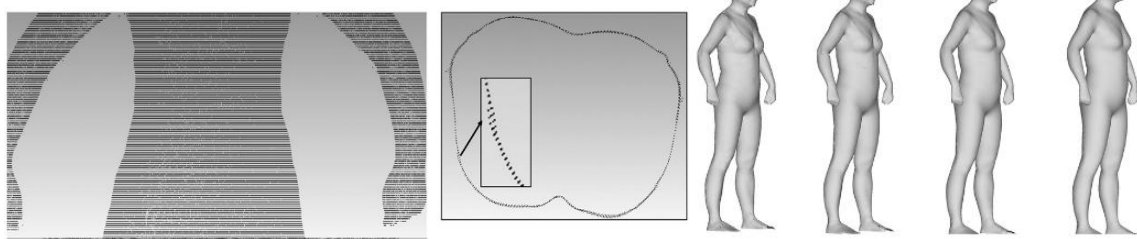


Source: Kouchi (2020)

Figure 2.8: Standing Posture for Anthropometry

Basic 3-D body scan data from these scanners is generally expressed in an XYZ coordinate space (Ashdown, 2020). These scanners capture and plot points from the surface of the body, and the output depends on different stages of the data process such as appropriate calibration, number of sensing devices, body landmarks, data integration from

multiple sensing devices into a 3D model, valid combination of surface points, and valid choices on measurements following the body shape or torso axis of limbs. The scanner varies greatly in the mode of representing the scan data on the computer screen, from a simple point cloud to a model with triangulated and surfaced points highlighted with simulated lighting and offering different options in perspective rules for viewing the model, as shown in Figure 2.9.



Source: Ashdown S.P. (2020)

Figure 2.9: Point Clouds and Stages in Smoothing Points

The quality of scan-derived measurements depends on the accuracy of machine and software performance, posture, landmarks, and body sway of the subject. The best automatic measuring system for a project may not be the scanner that produces the finest scan for that project (Ashdown, 2020). Many additional factors affect the accuracy of scan-derived measurements compared with traditional measurements. The process of generating body dimensions automatically is critical for data accuracy. The measurement error ranges for 2D and 3D are shown in Table 2.3 (Bartol et al., 2021). Furthermore, Kouchi (2020) pointed out it is essential to establish a protocol for evaluating the accuracy

of automatically calculated landmark locations in the future (Kouchi, 2020).

Table 2.3: Measurement Error Ranges

Measurements	Mean Absolute Error	Mean Absolute Error	Allowable Error (mm)
	2D (mm)	3D (mm)	
Neck Base Girth	11.4	9.1	11
Chest Girth	16.2	12.7	15
Waist Girth	14	12.4	12
Hip Girth	15	8.9	12
Thigh Girth	11.1	7.9	6
Ankle Girth	6.3	6.2	4
Height	7.9	7.5	10

Source: Bartol et al. (2021)

3D body scanning technology is mainly used in research institutes or in some large apparel companies recently. This is because it can acquire much more precise body data but is costly. Sohn et al. (2020) explored the potential for resolving fit and size issues using 3D body scanning and 3D virtual simulation technology (Sohn et al., 2020). The 3D body scan image data was saved in the .obj file format, which was then fed into a garment simulation system to produce a virtual digital jacket. The fit of the final virtual jacket was also compared with the fit of the real mass-customized jackets and the ready-to-wear jackets. The results showed that the fit evaluation for the final virtual jacket improved

drastically compared to the virtual jacket initially scanned. Despite the promising trend of the technology and approach, certain technological improvements are still needed before the technology can be used commercially for apparel fit customization.

As 3D body scanning technology has evolved, body scanning and measurements can now be obtained not only from static positions but also during dynamic motion (Loercher et al., 2018). The dynamic anthropometric data enhance the ergonomic fit of garments, particularly for workwear and sportswear. There are two measuring methods to obtain motion data: functional measures, where the body is in static poses typical for a particular activity, and dynamic measures, which capture measurements during movement. The appropriate scanner system should be chosen for final use.

Therefore, 3D scanning technology is identified as an innovative tool for future tailoring applications and the fit customization process. Although 3D body scanning holds immense potential as a value-adding tool, challenges remain due largely to complications caused by incomplete data from missing or shadowed areas, body posture and movement, surface texture, body landmarks, etc. For example, there is not yet an accepted method for locating, labeling, and tracking landmarks on the body. There is no proven correlation between manually drawn and digitally scanned landmarks (Gupta, 2020).

It is critical to establish a procedure for evaluating the accuracy of automatically determining landmark locations from the collected scan data for garment design (Ashdown,

2020; Kouchi, 2020). Specific international organizations and standardization initiatives, such as ISO and ASTM, significantly improve uniform standards to ensure the interoperability of data obtained through 3D scanning. Alvanon, Inc. created 3D avatars to assist in visualizing posture and shape based on standard measurements. Therefore, 3D technology-oriented functions may be recognized as the most likely future tailoring approaches for the fit process if accuracy and compatibility are confirmed (Kooi et al., 2022; Shariff et al., 2022).

2.5.1.2 Body Shape Classification

Gribbin E. A. (2014) pointed out that there are two main reasons for customers complaining about fit problems when they purchase clothing online or off the rack (Gribbin, 2014). One is that the basic body type that most companies start with accounts for only a very small proportion of the actual people that make up their target market. The other fit frustration results from grade rules, which are formulas for generating several sizes from a single base or core size. For those who do not grade linearly, the rules for linear grades are not entirely applicable. Therefore, a higher proportion of people who require the core size will discover that the shape of the product tends to correspond to the shape of their body. In contrast, a higher proportion of people who need bigger or smaller sizes are likely to have complaints regarding sizing and fit.

One-, two-, three-, and four-dimensional information of the body can now be gathered in anthropometric measurement. The body data provide opportunities to improve

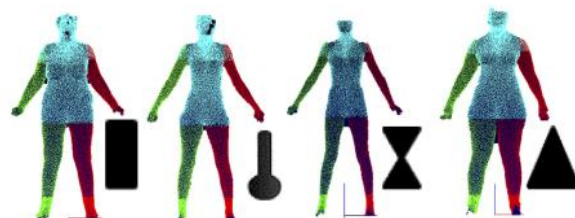
our understanding of the static and dynamic shapes of a population and offer advanced knowledge of shape analysis and classifications, as well as proposed methods for capturing or animating virtual body models (Bougourd & Treleaven, 2020). Therefore, morphological classifications play a critical role in consumers selecting a suitable body type for fitted clothing.

For the apparel industry, these shape data analyses assist in establishing the framework for expansion of the ranges of body shape and sizing systems with morphological classifications and grading, understanding body shapes throughout the aging process or a specified market, confirming the body shape and size of physically fit models and creating physically fit mannequins, 3D digital design and virtual garment visualization, automating block and style pattern generation, digital in-store and online fitting and purchase, reducing the number of iterations of samples with shorter lead times.

Morphological classifications contribute to characterizing body shape and improving garment fit. Each female participant's body shape was classified by using principal component analysis and cluster analysis (H. K. Song & Ashdown, 2012), which made it possible to select fit models from the body shape group and construct the basic block designs for each body shape. In addition, a thorough classification of various shapes for men was produced through a training model using neural networks, and how each body type influences the selection of appropriate fit apparel was illustrated (Bellemare, 2014). Besides, a physical investigation of the fit evaluations of females with different body

shapes was conducted to demonstrate how body shapes influence garment fit (Chrimes et al., 2023).

More recent studies have employed other novel methods paired with 3D technology to define body morphotypes more accurately. For instance, upper lateral somatotypes were classified based on directional angles of 3D spatial vectors (Yoon et al., 2016). Han (2019) investigated the relationship between men's upper body dimensions to provide specific numerical body shape alterations based on chest girth and height, serving as a basis for grading values for men's upper-body garment designs (Han, 2019). Furthermore, differences in body proportions and measurements between basketball players and an untrained group from the general population were found to examine the effect of physical variation on garment fit (Brlobašić Šajatović et al., 2019). Body types were identified based on hypertext preprocessor technology as shown in Figure 2.10, and a new normative method was developed to make visual assessments of body types and derive the necessary anthropometric data, which provided a universally established and standardized protocol for predicting body morphotypes (Pandaram et al., 2020).



Source: Pandaram et al. (2020)

Figure 2.10: Body Types of Female Body

Furthermore, Barnes (2014) indicated that the Body Volume Index (BVI) is specifically used in healthcare. However, it is also intended to be a follow-up patient-oriented clothing application that allows patients to utilize their own scans with the usual consent and regulatory conditions (Barnes, 2014). This would be especially useful for those with unique body shapes who might have difficulty obtaining clothing that perfectly fits because it is typically made to fit a generic shape. The path to attaining that benefit does not begin with clothing, and when BVI is more commonly used, apparel producers will be able to target a specific body shape or use BVI to modify clothing to fit people more comfortably.

With the development of 3D scanners, anthropometric data was employed by some project participants and sponsors to update their own internal size designations. Take a national survey conducted in the United States as an example; the analysis was done by clustering many measurements extracted from 3D body scans of more than 6000 women, from which correlations between weight and girth circumferences of the sample individuals are shown in the results of the analysis (Faust & Carrier, 2010). Based on the correlations of body dimensions, a complete body profile from a few measurements with a high degree of accuracy can be extrapolated using machine learning and optimized algorithms, just like Size-Me, which is a garment size recommendation tool for B2B and B2C apparel businesses, uses high-quality data from more than 350,000 3D body scans and

models for garment fit solutions.

According to Bougourd & Treleaven (2020), some international size and shape survey data have been assembled or mined, including iSize, Eurofit (2012), World Engineering Anthropometry Resource (WEAR) (2012), and ISO/TC 7250-2 (Bougourd & Treleaven, 2020). Eurofit, as a collaborative European project, was designed to implement an online 3D body shape measurement data platform. The objective of the technical study in ISO/TC 7250-2 is to serve as a continuously updated library for the most recent anthropometric data for technological design applications. It includes statistical summaries of body measures, along with database background data for adults of working age in the national populations of various ISO member bodies.

2.5.1.3 Sizing System

The sizing system is significant for pattern generation. Each country has established its own anthropometric sizing method and garment specifications. A sizing system is designed to clearly identify the fit required for the particular style and target market. To meet the fit and the market, some apparel companies have created a much more detailed sizing system, after which the grading rules and garment specifications can be established. Therefore, a body measurement chart is less needed in the design and manufacturing process after establishing the size system.

Some suggestions have been made for the size of the system that is intended to enhance applications. The least number of sizes used in the sizing system may benefit both

the manufacturer and the customer (Ashdown, 2014). The sizing system is crucial to provide a good fit for the greatest number of customers with the fewest sizes, because more sizes may offer the consumer more choices, but may also introduce difficulty in locating their correct size if there are numerous sizes and shapes from which to choose. As is well known, the inseam, waist, hip, and occasionally the thigh girth should be noted as the key elements for pants size designation (Faust, 2019).

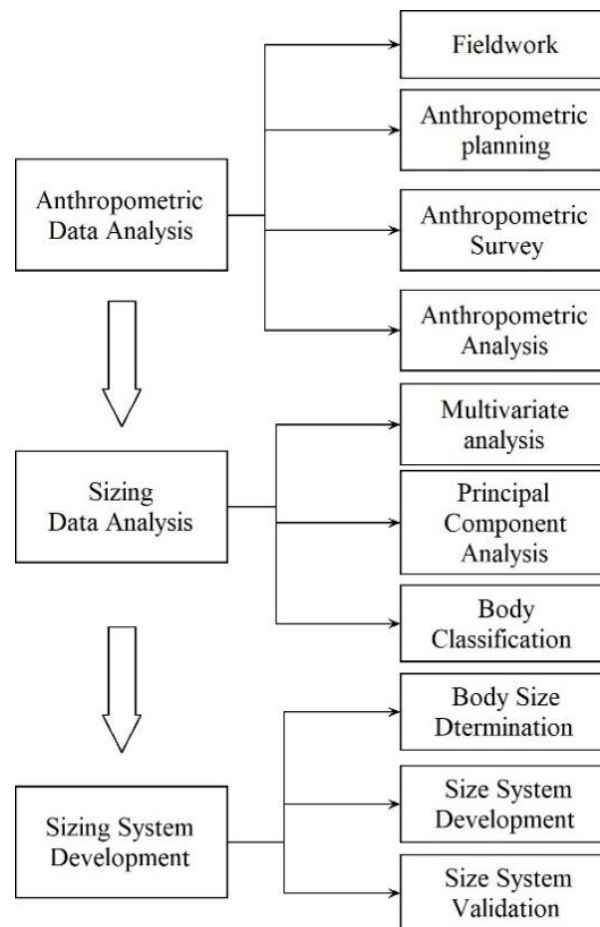
In addition, it would be preferable if a new standardized method of expressing size, shape, and fit could be devised without altering the manufacturing process. Meanwhile, size designations would be more useful if they took into account variations in height and girth measurements across age groups and ethnicities, as well as the association between ethnicity and body measurements (Faust, 2019). This suggestion is certainly worth considering so that more accurate sizing techniques and guidance can be provided to serve a wide range of ages and races. It will enable global communication about fit and comfort, and also require collaboration among companies, technology developers, and ethnic groups.

- **Sizing Technique**

Zakaria and Ruznan (2020) demonstrated that the collection of anthropometric data, the analysis of the sizing data, and the development of the sizing system are important stages in the creation of a sizing system. Figure 2.11 illustrates each stage.

For the analysis of the sizing data, key or control dimensions are crucial because

key body dimensions categorize the population into size groups. The selection of global key dimensions must satisfy the standards of size identification, designation, body height, type of figure, and drop value. ISO 8559/1989 is a standard that specifies the terminology used for various body dimensions. After data screening, including examination for data entry errors, missing data, or outliers, the collected data was analyzed sequentially by descriptive analysis, sampling adequacy test, principal component analysis, cluster analysis, and classification analysis. Finally, the size system was developed with elements of size range, size interval, size scale, and size roll (Zakaria & Ruznan, 2020).



Source: Zakaria and Ruznan (2020)

Figure 2.11: Workflow of Sizing System Development

- **Sizing Strategy**

The sizing system depends on the sizing strategies and the body type. The most commonly used sizing strategies employ primary or control dimensions to adjust fit. For example, key measurements, secondary dimensions, and intervals were identified to develop a sizing system (Xia & Istook, 2017). The components of size range, size interval, size scale, and size roll based on the ISO 8559/1989 standard are also used to create a sizing system (Zakaria & Ruznan, 2020).

Size charts created by clustering and averaging a population's body measurements have been published as results for many countries. Based on this methodology, size charts for men, women, and children were developed for populations in the US, UK, France, China, Korea, and other countries (Gupta, 2020). While size intervals for men in different countries are often categorized based on height and drop value, all sizing systems show similarities and differences around the globe (Gribbin, 2014). For instance, most women's brands in the US provide sizes 4 through 16, with many also offering smaller and larger sizes. Between the smallest sizes, the intermediate sizes, and the larger sizes, the grade intervals vary. However, the grade intervals are typically 4 cm for all sizes in Europe or China. The grade intervals between all sizes typically measure 5 cm in the UK and Australia.

Sizing strategies change with fit requirements, and different sizing strategies result

in different production models (Ashdown, 2014; Morlock et al., 2019). During the period of mass production, a sizing system can provide large-scale ready-to-wear production under the control of lower cost, but fitting problems remain obvious. In this method, it fits people whose body shape is relatively standard, but does not fit those whose body shape may be a special type. For mass customization in the clothing industry, the extreme variation of body sizes, body shapes, and body postures makes it difficult to clearly identify the target market for the company. Consequently, Ashdown (2014) pointed out the sizing system must be created with appropriate clothing dimensions and be convenient for communication so that customers can easily find their size in the system (Ashdown, 2014).

Sizing systems are developing based on the use of alterations to customize the fit. Some studies have been conducted to refine the sizing system. For example, Xia and Istook (2017) used data from SizeUSA and presented a sizing system creation method based on anthropometric data, applying body measurement data to improve the overall fit of garments (Xia & Istook, 2017). In the study, key measurements like height, girth, and width, control variables which have little or no intercorrelation and are used to classify size groups, secondary dimensions which describe body shape details and correlate with control variables, and intervals that increment between sizes have been defined to create the sizing system. Once values were determined for all size centers, the center values of key measurements were calculated for each size using formulas from multilinear regression.

- **Motion-based Sizing System**

To reduce how much clothing restricts a user's motions, the change in body proportions caused by movement must be measured and taken into account, as thus the measurements can map the change in body lengths and girths with movement, reveal compression and elongation of tissues, and help determine the axis of rotation of joints. It can be seen that a motion-related sizing system is important for a specific activity.

The importance of a motion-based sizing system is also emphasized (Jolly et al., 2019; Lapkovska, 2022; Vasile et al., 2019). As motion functionality has filled the gaps left by static avatars, this field of study has progressed to include soft tissue deformation to more accurately simulate changes in body shape, making it possible to convert into a new sizing system and assess how the body interacts with clothing and how this interaction changes with different body postures (Demirel et al., 2022; Sun et al., 2019; Loercher et al., 2018).

The difference in measurement between the static posture and movement poses was estimated by Loercher et al. (2018) of the Hohenstein Institute, Germany, using motion data from multiple participants. The smallest and greatest differences in a body part resulting from various positions were calculated (Loercher et al., 2018). Additionally, dynamic anthropometry studies (Pettrak et al., 2023) showed significant differences in measurements in three dynamic positions compared to the upright standing position according to ISO 20685. In the bend-forward position, the mean change value of the back width, measured at the armpit level, was found to be 30.5% of the mean value in the static

posture. Additionally, the shoulder width measurement exhibited an average decrease of 19.7%. A substantial increase of 47.8% in the lower back length, measured from the waist to the hips, was observed. In the squat position, an average change of 11.5% of the average value of the same measurement in the static posture was measured on the hip circumference line between the outseams. The mean change in upper leg circumference was 16.6% of the mean value of the same measurement in the static posture. The mean change in lower leg circumference was 6.8% of the mean value in the static posture.

A fully animated parametric skinned multiperson linear model (SMPL) has been created by the Max Planck Institute in Germany (<http://smpl.is.tue.mpg.de/>). The model in real working postures can be animated, and the natural pose-dependent deformations and soft-tissue dynamics in the body can be observed. It is highly useful for functional clothing design because it can realistically represent a wide range of human body shapes in extreme postures (Gupta, 2020). Moreover, Nike's 2023 "Motion-Fit" concept was based on data-driven design, body mapping, and motion capture to create clothing that moves with the body for optimal comfort. This area of research supports the development of dynamic models and enhances the accuracy of the fitting process. However, measurement standards should consider function-oriented movement and the size reference of the body in the design process.

2.5.1.4 3D Human Body

The 3-D human body model created from the scanned data offers potential

applications for body shape, size, and fit analysis (Chan et al., 2022; J. I. A. Yang et al., 2013), as well as the subsequent stage of patterning, garment design (Alemany et al., 2022; Daanen & Psikuta, 2018; Z. Liu & Luo, 2022), and even custom avatar creation for realistic virtual fittings as part of online marketing and consumer experience solutions (Ashdown, 2020; Chan et al., 2022; Daanen & Psikuta, 2018). However, the 3D body model obtained through 3D scanning must then be reconstructed and translated into accurate representations for various apparel-related applications (Elbrecht & Palm, 2016). This is because the representative model of the human body must be adaptable for different uses, as shown in Figure 2.12. The requirements or key criteria vary at each stage of the representation process; it is essential to understand and identify the feature points that need to be fully or abstractly represented.

- **Techniques of 3D Human Body Reconstruction**

There are many modeling techniques used in creating 3D human body models for CAD models and designs, such as Nonuniform rational B-spline (NURBS) modeling, polygonal modeling, subdivision modeling, and parametric modeling. Although there are certainly similarities, some significant differences still exist.

NURBS modeling uses control points that are connected by splines to create curves, so it is suitable for geometric shapes that require an absolutely smooth curve in order to create quality products. Polygonal modeling works by meshing thousands of flat triangular planes to create a shape. Smoothing groups and huge numbers of polygons grouped must

be used if you want to create a perfectly smooth curve using polygonal modeling, because the computer always calculates polygons as straight lines between two control points.

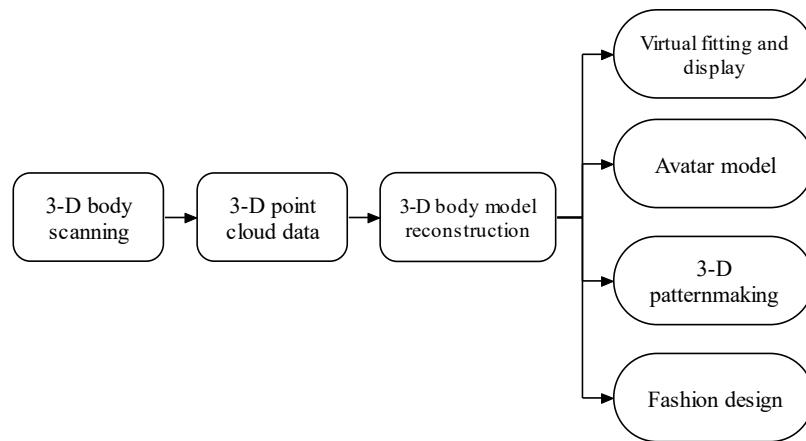


Figure 2.12: Different Purposes of 3-D Body Model

Subdivision modeling creates a 3D mesh that can be manipulated via a push-and-pull method. The 3D model can be constructed after a series of geometric processing for a target point cloud or depth map, which is obtained from the use of sensor equipment such as 3D body scanning systems, Kinect, and Multi-view Stereo (Elbrecht & Palm, 2016; R. Wang et al., 2012). It is better suited to organic shapes combined with the benefits of NURBS and polygons. This method can divide a low-resolution mesh into smaller, more detailed sections to create a more realistic human model. It is a popular technique for modeling the human body and can achieve lifelike movements and facial expressions (Tsoli, 2014; Xie & Zhong, 2020).

Parametric modeling for the 3D human body relies on a statistical parametric model

of the human body, which can describe human shape in a set of low-dimensional vectors. There are some standard parametric human models, such as SCAPE, SMPL, and others. Shape Completion and Animation of People, as a successful parameterized body model, belongs to edge-based transformation and is applied widely. Skinned Multi-Person Linear was a classic peak-based transformation parameterized body model. Subsequently, much related research about parametric body modeling was proposed; however, these body reconstruction methods differed in the body model, input data, and the mode of establishing the relationship between them (Cheng et al., 2018).

There is also much research on the reconstruction of the 3D human body based on the modeling techniques introduced above.

Tsoli, A. (2014) demonstrated data-driven modeling to capture and model the non-rigid intrinsic shape variation of the human body during breathing (Tsoli, 2014). He created a 3D model of the human body based on anatomical structures and physical properties. Hong et al. (2017) reshaped the 3D human body using the multivariate imputation by chained equations (MICE) technique to fill in the missing parameters from limited data (Hong et al., 2017a). Mesh-based body shape was adopted to analyze the deformations of each triangular facet. Lauria et al., (2022) researched reconstructing and modeling the human body and garments from images using machine learning techniques (Lauria et al., 2022). Similarly, Edelmers et al., (2022) took multiple photographs of an object or person from different angles and used software to create a 3D model from the

photographs (Edelmers et al., 2022). This method has been used to create digital 3D models of human bones. Rudolf et al. (2021) took a 3D scan of a person in a standing posture and then posed it to a required posture. The process includes using 3D human body-mesh modeling techniques and surface-reconstruction methods to obtain 3D body models in standing and sitting postures. Lee & Song (2021) developed an automated process for modeling the average 3D human body according to body types using both NURBS-based modeling (Lee & Song, 2021). The process included determining the main reference lines on the 3D-scanned lower bodies, including six horizontal reference lines and six vertical reference lines. Zhang, J., et al. (2015) used Rhino and Grasshopper algorithms to automate the process of modeling the average 3D human body according to body types using NURBS-based modeling (J. Zhang et al., 2015). Liu et al. (2017) proposed a mixed human-body modeling method to create digital human models (DHMs) for the clothing industry (K. Liu et al., 2017). Soft body avatars that mimic the compressibility of bodily tissues have been developed (Harrison et al., 2018). It is possible to create a soft avatar from any rigid 3D scan. It is feasible to realistically mimic the behavior of a body-fitting garment on a deformable body using finite-element methods.

In general, polygonal, subdivision, parametric, and Non-Uniform Rational B-spline (NURBS) modeling are the most commonly used techniques for reconstructing 3D body models for fashion applications. Table 2.4 compiles important studies carried out over the past ten years that have reconstructed 3D body models using various modeling methods to

produce more accurate representations for various fit purposes. However, there is a lack of standardization in 3D modeling techniques to create accurate 3D models of the human body for different fit purposes.

Table 2.4: Summary of 3-D body Modeling for Different Fit Purposes

Purpose	Modeling Method	Authors
Pattern-making	Parametrization technique	(Hong et al., 2017a)
Fashion Design	Shared identical topology	(Xie & Zhong, 2020)
Virtual Display	Forward modeling, photo modeling, and reverse modeling	(K. Liu et al., 2017)
Virtual Fitting	Register vital body templates onto existing rigid avatars and use the finite element method to simulate	(Harrison et al., 2018)
	A part-based semantic 3D body reshaping	(D. Song et al., 2019)
Avatar Model	A surface-based modeling process	(Tsoli, 2014)
	3D human body mesh modeling and surface reconstruction techniques	(Rudolf et al., 2021)
	NUBRS	(Lee & Song, 2021)
	Structure-from-Motion and machine learning techniques	(Lauria et al., 2022)

- **Challenges of 3D Human Body Model**

The 3D human body has several applications in fit customization that can help

improve efficiency, accuracy, and customer satisfaction. It can be used for body measurement and analysis (Chan et al., 2022), garment design and development (Alemany et al., 2022; Daanen & Psikuta, 2018; Z. Liu & Luo, 2022; J. I. A. Yang et al., 2013), virtual try-on (Chan et al., 2022; Daanen & Psikuta, 2018), as well as marketing and advertising (Daanen & Psikuta, 2018).

In addition, the 3D body model is essential for apparel CAD/CAM. The human body measurements acquired by 3D scanning can be processed more efficiently by CAD systems and applied to automated pattern-making procedures. Hence, CAD apparel systems usually involve one or more key processes such as 2D pattern design, pattern pre-positioning, virtual try-on, drape simulation, and design modification in 2D or 3D. All those functions must be based on the precise body model, so that the 3D body model for fit customization usually uses parametric body models. These parametric body models can be customized according to individual measurements, allowing designers to visualize how the clothing is likely to drape on different body types (Špelic, 2020). The accurate representation of the human form is one of the principal factors for creating fit patterns and virtual garment simulation. Therefore, 3D parametric models of the human body, garment parametric patterning, and garment simulation should be integrated into the development of CAD virtual try-on, fitting evaluation, and style editing systems.

However, the challenges persist in practice.

Data from 3-D measurement acquisition systems cannot yet be automatically extracted and utilized by patternmaking CAD software (Dāboliņa et al., 2018; Gupta, 2020). Most raw and processed data from 3-D scanners are currently accessible in 3-D format, where many large-scale 3-D anthropometric surveys were conducted. Anthropometric data can be presented as a 3-D body scan, a single image, a multiview image, or a body contour (Gupta, 2020). Consequently, it is now extremely difficult to organize, analyze, and distribute such diverse data. There is an increasing need for algorithms that can accurately extract human body information from digital data (Gupta, 2020).

Additionally, the efficiency of reconstruction from scanned data, that is, converting raw scan data into 3D models, must be improved. This technique poses significant challenges on many fronts because it involves time-consuming and complex computational methods. Therefore, even manual reconstruction is extremely time-consuming and should be enhanced to enable automatically restored scans based on actual material properties and body postures. Moreover, computational complexity hinders the creation and manipulation of 3D models in real-time for interactive fashion design and other real-time applications.

The accuracy of reconstruction is another major challenge in using 3D human body modeling for clothing fit, due to variability in body shapes and poses. Different individuals have varying body shapes and sizes, and they may pose differently. This makes creating a 3D model that accurately represents the fit of a garment on a specific individual difficult.

Furthermore, designers can visualize stresses and strains on the skin and body with animated avatars that mimic different postures. There is a need for avatars that can imitate human softness and compressibility, as well as the ability to morph to resemble real bodies as they change with age and movement.

That is to say, currently, the modeling of 3D body shapes still requires improvements in free feature modeling, easier scan reconstruction for preparing 3D models from raw scan data, automatic 3D parametric human body models, and 3D parametric garment model adaptation (Špelic, 2020). The automatic generation of human body models, customized according to various body measurements and direct implementation of computer models obtained by 3D body scanning, as well as interactive adjustment of the 3D parametric body model according to individual body measurements, is desirable.

2.5.2 Pattern Generation

Pattern generation is highly dependent on body shape and garment style. Essentially, this means sizing will consequently depend on the measurements required, body shape, and structure – the fit. In other words, the garment modeling process involves measuring the human body model, the general fit ease of the garment model, and the silhouette of the garment, as well as evaluating both models or their differences, to complete the fit customization process. It can be seen that the sizing system, the human body model, and garment ease are important factors for the fit and silhouette (Ashdown, 2014). The human body model and sizing system have been discussed previously, so the following will

highlight the important factors in garment ease, pattern generation method, and CAD.

2.5.2.1 Fit Ease

Clothing ease, or the estimated volume of air between the body and the garment, is essential for both static and dynamic poses because it affects the movement of the user. Clothing ease and tailor knowledge, such as wear comfort, product appearance, and fabric materials, should be considered for fit (Bi et al., 2021; Elbrecht & Palm, 2016; Kuzmichev, 2019; Z. Wang et al., 2021). The distance ease distribution of a garment is shown as a critical factor in accurately achieving garment fit (Park et al., 2017). To achieve realism, it is also necessary to precisely calculate the volume of air inside the clothing, as well as the total volume of the clothing relative to the naked body (Pettrak et al., 2018). At the same time, how the distribution of static and dynamic ease of clothing changes with motion at the chest and waist can be measured by using a motion scanner (K. Liu et al., 2019). Furthermore, the constructed 3D apparel model is then used to generate the finished garment model using predefined areas combined with user preferences and previously calculated distance ease values to accurately represent the intended style effect (Hidellaarachchi et al., 2018).

- **Sensory Evaluation of the Optimal Ease Allowance**

The optimal ease allowance can be determined based on the subjective satisfaction of the actual wearer regarding garment fit. Park and Lee (2013) investigated the ease allowances of men's formal jackets by comparing seven pattern drafting methods for men's wear through sensory evaluations. The pattern drafting method that obtained the best result

in the motion adaptability evaluation had 13.2 cm of ease allowance for the chest circumference, while the pattern drafting method that obtained the best result in the appearance evaluation had 9.5 cm of ease allowance at the same part of the jacket. Thus, this study showed that motion adaptability tends to be sacrificed to achieve the optimal appearance of a men's formal jacket (Park & Lee, 2013).

Kim et al. (2019) investigated the ease allowances of 62 male customers by the same sensory evaluation method, once in the initial fitting jackets designed using the graded sizing chart of ready-to-wear, and once again in the custom-made jackets customers ordered. Regression equations were developed to estimate preferred ease allowance by inputting body size measurements showing the highest correlation with the preferred ease allowances. The estimated ease allowance ranges by inputting the 5th to 95th percentile of body sizes were 5.17–8.25 cm for the chest circumference, 6.90–2.09 cm for chest–waist circumference on the jacket, –3.82 to 1.34 cm for the chest–hip circumference on the jacket, 1.58–5.86 cm for the upper arm circumference, –1.80 to 1.95 cm for the bi-shoulder length, and 0.406–0.425 for the ratio of jacket length to stature (Kim et al., 2019).

The authors employed two women's shirts (samples I and II) to investigate the effect of differences in body size and shirt measurements on the appearance of women's shirts in different styles (fit and straight). The authors modified the size of the bust, waist, and hips with a changeable-size dress form using 1 cm intervals. They observed the shape changes. With photographs at 2 cm intervals, the authors conducted a sensory test to

evaluate appearance. Twenty Japanese university students in their 20s made assessments using seven items (wrinkles, fit, silhouette, beauty, fashionable impression, comfort, and purchase intention) with a five-point scale. The appropriate ranges of ease allowance differed according to style and evaluation items. Regarding appearance and purchase intention with sample I from the front, the suitable range of ease allowance was 1–7 cm for the bust, 2–6 cm for the hips, and 1–3 cm for the waist. From the side, the range was 0–6 cm for the hips and 0–7 cm for the bust. With sample II from the front, the suitable range of ease allowance was about 4 cm for all parts. From the side, the range was 0–11 cm for the bust and 0–4 cm for the hips. Changes in shirt appearance due to body shape changes (Sakata et al., 2020).

According to the findings of the above studies, the research by Park & Lee (2013) demonstrates that visual evaluation is one of the most intuitive methods for determining the optimal ease in garments. The study by Sakata et al. (2020) illustrates the impact of different body types and sizes on the appearance of shirts. As body types vary, the corresponding ease allowances differ, providing a theoretical foundation for the application of different ease allowances for different body types in this study. Moreover, the study by Kim et al. (2019) derived a reference range for ease allowance design based on subjective comfort perceptions. However, given the variability of individual perceptions of comfort, such individual differences may introduce significant bias in the research results. Consequently, the subjective comfort preferences of different individuals are not

considered in the ease allowance design in this study.

- **Objective Evaluation of the Optimal Ease Allowance**

The most basic method used to determine the optimal ease allowance is to measure the change in body surface length caused by joint movement or respiration, and the difference in the entire circumference between the garment and the human body. Occasionally, the entire circumference is divided into several segments, and the difference between garment size and human body size is measured separately for each segment. The objective method most frequently used by researchers is to determine the linear distance between the human body and the garment, which allows quantification of the distance between the human body and the garment in various locations (Kim et al., 2019).

Thomassey and Bruniaux (2013) adopted a reverse process in which they first carried out a perfectly fitted garment for the subject and tried to revert to the design phase in 3D. With this methodology, they investigated the distance of the garment from the body. Then they used these distances to evaluate four discrete values required to design the garment in 3D, so that it replicates the actual garment as it falls on the reference body (Thomassey & Bruniaux, 2013).

Lage and Ancutiene (2019) demonstrated that distance ease distribution between a fitted virtual dress and 3D body depends on fabric mechanical properties and ease allowance value of basic construction. Garment basic construction can be adjusted by certain ease allowance values to achieve particular 3D garment ease values (Lage &

Ancutiene, 2017). In addition, a further study was conducted on the distance ease between body and garment to investigate basic block pattern modification according to fabric used and the mismatch between 2D and 3D measurement lines at bust, waist, and hip girths when ease allowance is changed uniformly. The straight shape dress fitting was done using seven cotton and cotton-blended plain weave fabrics in Modaris 3D Fit of CAD Lectra. After virtual try-on, the mismatch (bust, waist, hip) between 2D and 3D measurement lines was measured to determine base pattern adjustments using different fabrics. It was found that the position and length of 3D measurement lines at bust, waist, and hip girths do not match the position and length of corresponding lines in 2D base patterns after virtual try-on due to fabric deformation, which is related to mechanical properties. It was demonstrated that derived linear equations presenting a relation between mismatch and ease allowance values could be used for basic block pattern modification so that 3D and 2D measurement lines would coincide during clothing try-on (Lagè & Ancutienè, 2019).

Zhang et al. (2023) used 3D space vectors to explain the relationship between the female upper body and the fitted garment. The upper body prototype garment without a collar and sleeves was obtained by 3D draping and cutting technology. Then, a type of fitted garment was placed on a female mannequin and scanned for shape. The scanned data were further processed, and the 3D body and garment were reconstructed using Bezier spline curves (Zhang et al., 2023). The cloud data were processed automatically by MATLAB software. After that, the 2D space vectors of the mannequin upper body and

garment were extracted within cross-sections, and 3D space vectors were obtained by 2D space vectors and distance of cross-sections. The distance ease was determined by comparing the body vectors and garment vectors. The 3D distance ease was calculated with Fourier series mathematical models and added to a new target human body of the same type to form new clothing virtually. Finally, the garment pattern was obtained by surface geometric flattening technology, and the fit of the target garment was validated by real try-on (Y. Zhang et al., 2023).

The aforementioned studies demonstrate that different ease allowances result in varying amounts of space between the human body and the garment in three-dimensional space. This approach serves as an effective method for evaluating garment fit, providing a theoretical foundation for the design of ease allowances and fit evaluation in this study.

2.5.2.2 Patternmaking Method

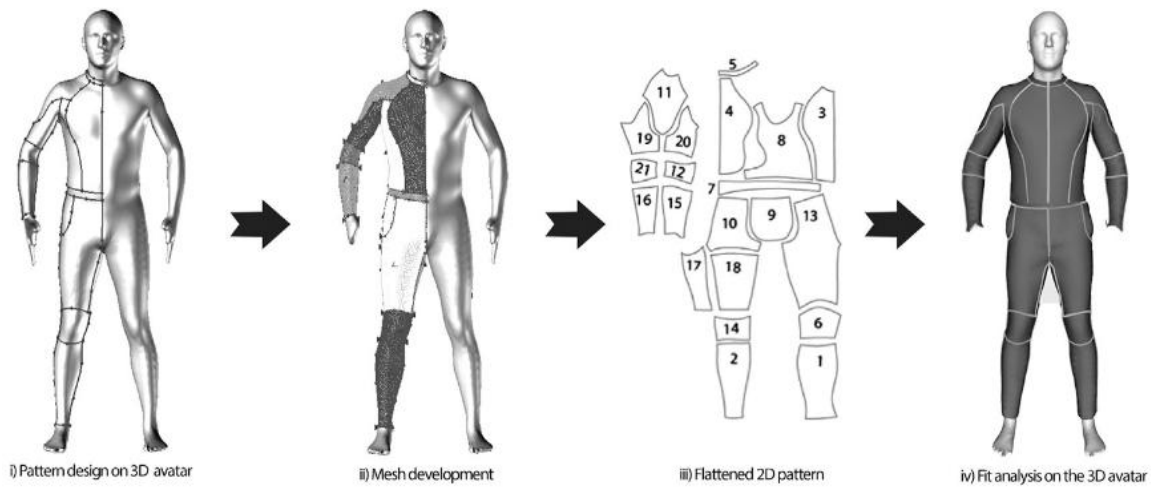
Several methods are used to create patterns in the garment industry. Firstly, the direct application of fabric to the body is known as modeling or draping, which is suitable for creating custom clothing with intricate designs. The drafting method is used to produce made-to-measure clothing. Traditional tailors have been effective and continue to be so because they not only use a tape measure to measure the body and record linear measurements but also take notice of the intricacies and quirks of the 3-D form and incorporate this "shape data" into the designs.

Additionally, the flat-pattern method has served as the foundation of the

ready-to-wear industry for almost a century. With the help of empirical principles and "size charts" or averaged body measurement data, basic blocks are created using this method (Gupta, 2020). A prototype garment is created from the proposed fabric, and the fit is perfected on the fit model. This perfected pattern is then used as the base size, which is graded up and down to create patterns for all of the sizes in the range. Additionally, base patterns developed for different figure types instead of one standard pattern can significantly enhance the fit of the pattern and offer a practical and rapid way to implement efficient and effective apparel MC (Bellemare, 2014; Han et al., 2021).

Besides the above mainly patternmaking methods, Gupta (2020) indicated that there are some advanced technologies used to address the challenges of fit, inadequate size charts, the lack of data, and so on. For instance, the use of three-dimensional avatars can simulate the body shape and sizes to improve fit, and even the use of animated avatars can interact with garments in different body poses, as shown in Figure 2.13 (Gupta, 2020). Furthermore, 2-D pattern generation directly from garments sketched on the avatar is also a new technique. It became possible to design in 2-D and visualize the fit in 3D using software like Clo3D and Optitex. The fit of the garment can also be evaluated in different poses if the avatar is animated. Zhang et al. (2015) used 3D modeling techniques to produce an upper garment model (J. Zhang et al., 2015), and Lei & Li (2022) proposed a new approach to 3D pattern-making for the apparel industry (Lei & Li, 2022). The method allows users to acquire key points on the fabric in a 3D shape and obtain the patterns on the

mannequin or body directly.



Source: Gupta (2020)

Figure 2.13: Pattern Design on 3D avatar

Therefore, while the flat-pattern method remains popular, techniques for converting 3-D designs to 2-D patterns have enabled the production of 2-D pattern pieces directly from a 3-D design (Abteu et al., 2018; Kulińska et al., 2022). To some extent, advanced 3D technologies can address shortcomings and inconsistencies in traditional 2D-patternmaking methods. Figure 2.14 illustrates the processes of obtaining flat patterns by 2D patternmaking methods and 3D design. However, even though there is currently a considerable amount of 3-D scan data available in 3D design, most patternmakers employ only the linear measurements taken from the scans and neglect the form data.

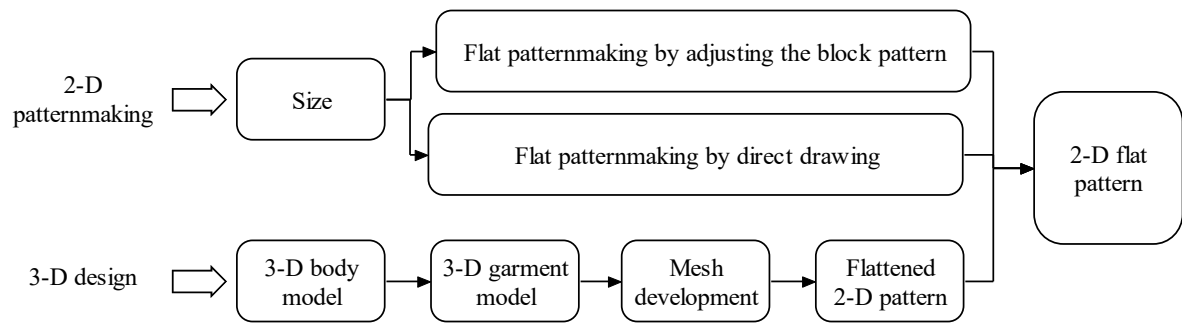


Figure 2.14: Patternmaking Processes by 2-D and 3-D

2.5.2.3 Challenges of CAD Application in Patternmaking

Nayak et al. (2015) stated that CAD prototyping and fit evaluation are essential steps in apparel development for FC (Nayak et al., 2015). Once the garment specifications are defined, CAD technology can then be used to assist in the design of garment products to address specific issues like garment assembly methods by following particular pattern-making rules and evaluating the quality of fit on 3D human models. For example, emerging open-source solutions like Valentina (valentina-project.org) enable parametric pattern adjustments via Python scripts, 3D preview with Blender integration, and community-developed blocks for body types.

The new innovative 2D/3D CAD systems, such as Gerber, Lectra, and Optitex, which are used for the design and simulation of clothing, have shown significant advances in the simultaneous modification of several patterns and offered 3D to 2D solutions for patternmaking (Špelic, 2020). 3D to 2D conversion methods enable the production of 2D

pattern pieces directly from a 3D design virtual prototype. These solutions substantially cut down development time and costs while accelerating time to market.

Therefore, it is noted that fit problems can now be addressed thanks to advances in computer-aided design (CAD) technologies. However, the primary cause of the current problem is legacy system incompatibility. The main issue is the gap between the 3D body scanner, client order, and CAD software that would enable the translation of 3D measurements and customer order into import files to CAD systems (Elbrecht & Palm, 2016). Moreover, 3D shape data cannot be used directly in the fit simulation or pattern-making process (Gupta, 2020; Scott & Sayem, 2018). The greatest difficulty is to organically integrate the scanned 3D body data into the CAD applications and convert flat 2D pattern data into a 3D simulation with various fabrics. Another limitation of the current CAD systems is their inflexibility in making changes and the time needed for regenerating a complex parametric model is excessive (Špelic, 2020). Therefore, the efficient pattern generation method is vital in creating a better, faster, and more efficient CAD garment production system, with flexibility for design adjustment and fit production.

2.5.3 Fit Assessment

Fit is described as the correlation between body size and garment size. A well-fitted garment results from accurate measurement, good pattern design, and careful consideration of the material's mechanical and physical properties (Gupta, 2020). In conventional assessment methods, fit is assessed and approved by fit experts who work with internal fit

models using a combination of subjective judgment and objective evaluation. Body scanning-based virtual fit assessment techniques are gaining popularity, and emerging digital technologies are changing the process of fit assessment.

2.5.3.1 Virtual Fitting

Virtual fitting techniques based on body scanning are gradually entering the public. Clo3D, V-Stitch, Optitex, Clo3D, and Style 3D are the main virtual try-on software. As shown in Figure 2.15, the model demonstrated the method of collecting body measurements and also presented a virtual fitting system to resolve fit issues (Ashdown, 2014; Kouchi, 2020; Miell, 2018). A virtual try-on provides a computer-generated visual representation of how a garment will appear on the wearer and improves the fitting outcome. A generic automatic method was proposed to correct 3D wearable items from a reference body mesh to a target body mesh (P. Hu et al., 2020). A landmark-guided virtual try-on method was also used for clothes to solve the problem of clothing trials on e-commerce websites (Roy et al., 2022). Furthermore, to address the problem of difficulty in warping clothes to align with the new body, the clothes warping module and cross-domain fusion module were employed to generate the composition mask and compose the final try-on result (X. Hu et al., 2022).

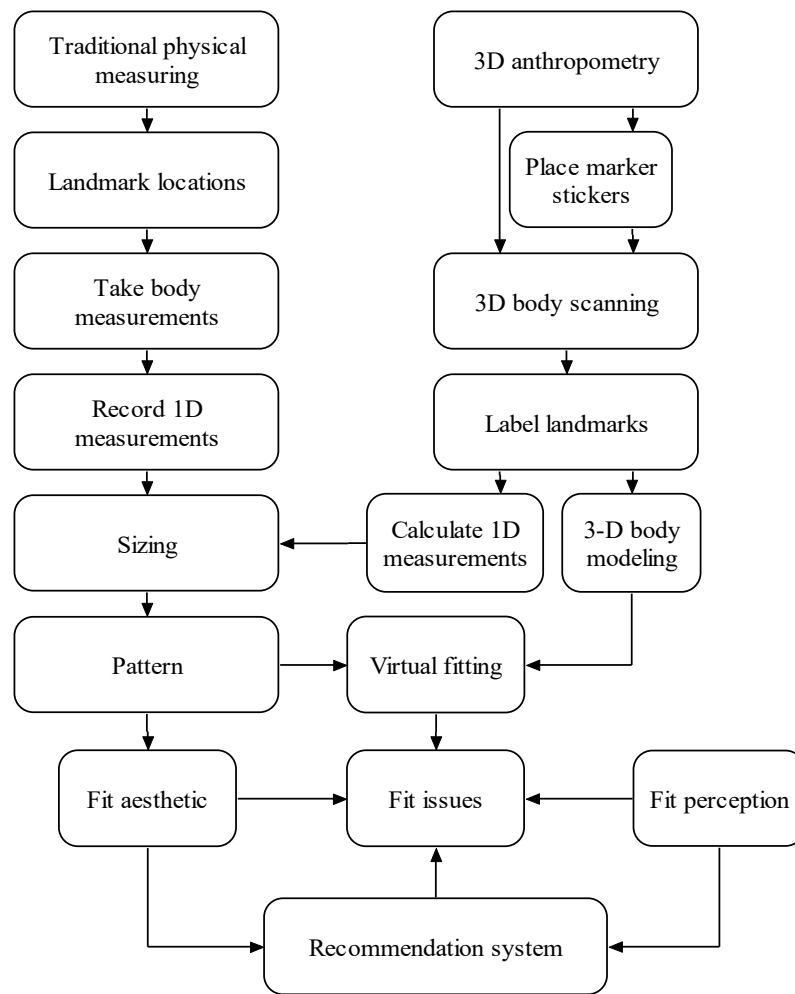


Figure 2.15: The Solution to Fit Issues

However, the virtual try-on fit is only an approximation of the visual effect, not the actual production, due to the complexity of the fabric, the human body model, and the way the body and garment interact (Gill et al., 2022). Some studies have focused on the appearance of a tight-fitting virtual garment in terms of the mechanical properties of textile materials (Ancutiene et al., 2014), geometric shape of the basic pattern according to the key poses of the skating sport (Xiao et al., 2024), pattern simulation in the 3D virtual

sewing and fitting system (Zhu & Song, 2020), and the basic block pattern modification according to the fabric used and the mismatch between 2D and 3D measurement lines at the bust, waist, and hip girths when the ease allowance is altered uniformly (Lagè & Ancutienè, 2019). Once the fabric and virtual body model are resolved, other functions such as sizing or fit assessment can be added to virtual try-ons to support custom manufacturing.

2.5.3.2 Fit satisfaction

Precise measurement, body shapes, patterns, and careful consideration of the material's mechanical and physical properties all contribute to a well-fitting garment (Bizuneh et al., 2023; Gupta, 2020). Additionally, customer value, which includes service, price, quality, and emotions, also has significant effects on their satisfaction. Therefore, customer fit preferences should be investigated extensively, not only from the customer's body shape, lifestyle, age, culture, previous purchases, and returns (de Barros Costa et al., 2017; Qian et al., 2014), but also customer psychological aspects (Lang et al., 2021).

Customer fit satisfaction helps to reduce return rates for clothing manufacturers and decrease textile waste for the environment. In order to improve fit satisfaction, clothing manufacturers need to emphasize fit aesthetics and technology application. The fit aesthetics can guide the innovation and development of technology, such as recommendation systems, which provide advice on which style will fit the customer. However, prediction accuracy is the most crucial and difficult aspect, as it is influenced by

users' fit preferences and expert fit aesthetics in addition to recommendation algorithms (Shani & Gunawardana, 2011; Yu-Chu et al., 2012; Zhou et al., 2017).

2.6 Theoretical Framework

As previously mentioned, the theoretical framework for this research study was formed based on the insights and findings of the literature review. This study was performed with a focus on the knowledge base of the theory of MC (Da Silveira et al., 2001; Senanayake and Little, 2010) and the theory of mass-customized sizing (Locker, 2007). Figure 2.16 illustrates the theoretical framework that provides a depiction of the systematic review process. It also outlines the key criteria or requirements and the sequence of the overall process for achieving fit customisation.

Through understanding anthropometric measurement, sizing, pattern-making methods, and fit evaluation, this study mainly focuses on three research gaps. Firstly, due to the complexity and variety of human body shapes and sizes, the current size system does not provide consumers enough information to help choose well-fitting clothing (Spelic Ivana, 2019; Gupta, 2020). Secondly, although 3D human body models can accurately reflect human body dimensions and shape characteristics, there is no standard protocol for processing 3D body models for different purposes of fit, such as recognising, classifying, and tracking anatomical landmarks on 3D body model (Kouchi, 2020; Gupta, 2020; Ashdown, 2020). The lack of standard protocol limits the communication of data. Although many studies have shown that the application of 3D human body models plays

an important role in improving the fit of clothing, 3D body data cannot be directly integrated into patternmaking (Elbrecht & Palm, 2016), and there is also lack of 3D human body models for pattern-making (Spelic Ivana, 2019; Kouchi, 2020; Gupta, 2020; Ashdown, 2020), which is the main gap in the development of 3D pattern-making technology.

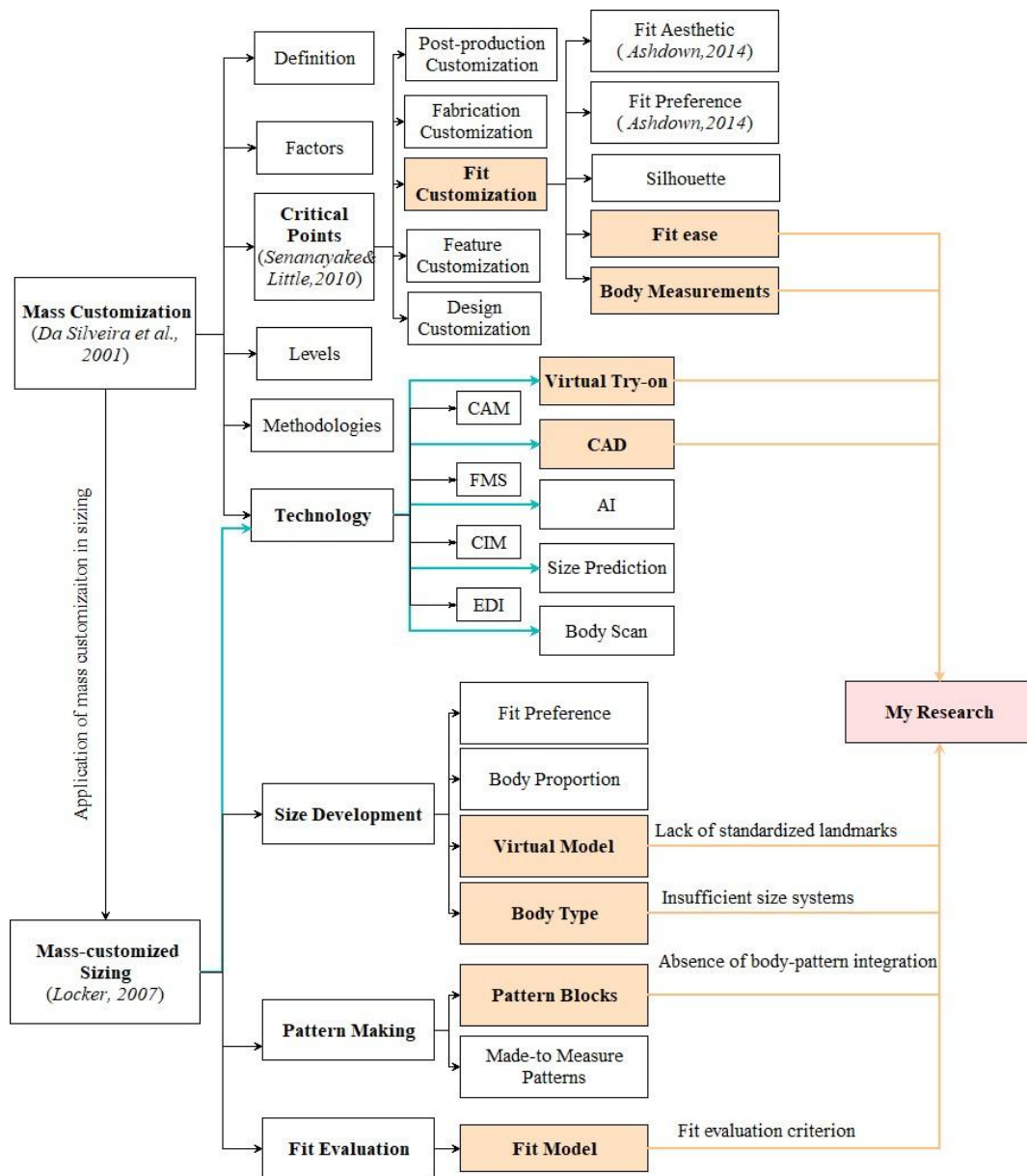


Figure 2.16: Theoretical Framework

Therefore, based on the theoretical framework, this study analyses human body measurements and body shapes to explore a size development method suitable for mass customization, employs 3D human body models to generate parametric block patterns for the generation of well-fitting personalized patterns, adopts virtual fitting to evaluate the fit of the patterns. Thereby, this study fills the research gaps in mass-customized sizing by addressing issues such as body type classification, landmarks on 3D human body models, and the pattern generation method based on blocks.

2.7 Conceptual Framework

According to the overview of the literature, technological innovations in body measurement, pattern, and fit assessment can better meet customer personalized fit demands, improve cost control, increase profitability for apparel manufacturers, and reduce textile waste and pollution for the environment. However, there are still some key issues that need focus.

The first is the availability of garment measurement data obtained through body measurement. Guidelines or standards for categorizing the body morphotype must be integrated into the sizing system. It is essential to determine the body morphotype according to age and ethnicity because clothing fit is greatly influenced by body size, shape, and posture. Further research should be conducted on body shape changes to develop a comprehensive motion-related sizing system for certain professional or competitive clothing.

Much research has been done to find methods or develop algorithms that can accurately identify landmarks directly from 3D scanned data of the human body, as well as 3D body modeling techniques. The real problem, however, is that it remains unclear how to effectively apply the relationships between body data and garment dimensions. The difficulty of application is compounded by differences in measurement methods used by various manufacturers. As a result, there is currently no industry-accepted technique for locating, labeling, and tracking landmarks on 3D bodies about garment dimensions.

The technical compatibility of body measurement data must be carefully considered to increase general availability, ease of integration, and affordability of these technologies. Manufacturers of apparel CAD manufacturing systems need to align with appropriate standards for exchanging 3D body data to effectively combine fit patterns, virtual garment simulation, fit assessment, style modification, and garment suggestions. The availability of standards will also help improve communication and promote more consistent representations of the various body types needed for CAD/CAM.

3-D pattern-making is a sustainable digital production method and a challenge for the future. There is still room for improvement in 3-D body modeling technology regarding pattern generation for actual production. All relevant factors influencing the pattern, such as fabric and sewing technique, should be considered. Therefore, further research is required to explore the relationship between fabric performance, clothing ease, and body model to accurately and effectively construct a 3D garment model suitable for production.

This has the potential to significantly advance the CAD-driven apparel fit modification process if done accurately and consistently in the near future.

The flexibility and accuracy of virtual fitting in real-world production should be improved. Most virtual try-ons based on samples are widely used to demonstrate effects, but are rarely used in actual manufacturing due to accuracy issues. Additionally, virtual fitting online needs improvement in ease of use, such as user-friendly interfaces and clear navigational structures. Moreover, fit aesthetics and customer value are critical factors for fit assessment and should be studied further to enhance customer satisfaction.

As explained, by acquiring knowledge and data based on industrial practices and academic research, a conceptual framework was designed to guide the direction and pathway of this research. The conceptual framework is depicted in Figure 2.17.

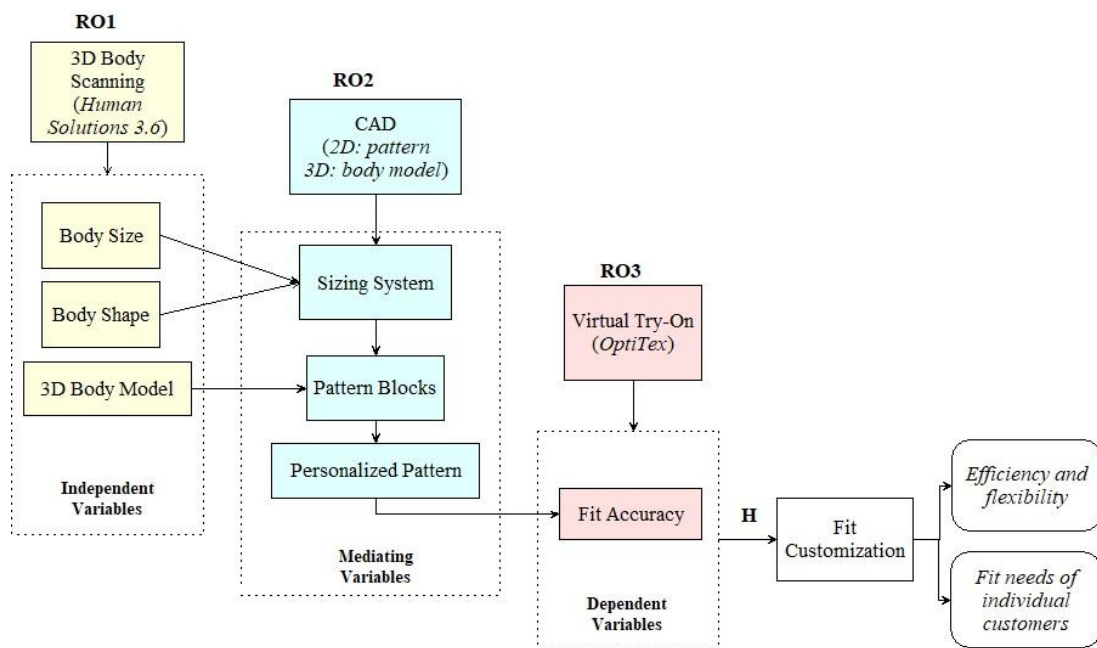


Figure 2.17: Conceptual Framework

2.8 Chapter Summary

Mass customization, as one of the strategies in apparel manufacturing, is developed to address market turbulences characterized by unstable and unpredictable demand levels, heterogeneous preferences, price, quality, and style awareness, high levels of buyer power, competitive intensity, product differentiation, and saturation. Until recently, the explanation for mass customization has become increasingly distinct.

MC can be subdivided into post-production customization, fabric customization, fit customization, design customization, and feature customization according to the production process. In general, personalization, fit, and design were the three main dimensions in apparel MC (Senanayake & Little, 2010). Fit customization is recognized as the most vital aspect and also a major challenge for MC due to the diversity of body shapes. The main problems lie in defining anthropometric measuring landmarks, overcoming time-consuming computation, constructing or defining the base pattern, and automatically modifying the body measurement database. Additionally, it is significantly valuable to realize the digital communication requirements in the production process, ranging from body measurement to manufacturing language.

With the development of technology such as 3D body scanning, virtual try-on, and related tools, fit customization is expected to achieve more effective implementation. It can be summarized that the most important steps are rapidly processing the 3D body data, accurate body shape classification, quick pattern generation, and flexible manufacturing.

Based on the literature, the clothing industry is evolving from a low-tech, labor-intensive sector to one that is software-driven. 3D body scanning is an effective method to acquire body data quickly and precisely. It is necessary to develop a theoretical understanding of shape, size, and fit and how to integrate it into patternmaking procedures (Gupta, 2020). However, the technology for pattern generation from 3D human body models is still in the development stage. The literature gaps can be summarized in the following aspects:

- The criteria used in extracting measurements by standardizing body landmarks and the rules for classifying body morphotype categories need further discussion.

- Different people have different body shapes and sizes, and the impact of clothing selection on these body shapes remains uncertain. Hence, the sizing system for better-fit customization and garment specifications should be improved in further studies.

- Garments can have intricate designs and details that are difficult to capture in a 3D model due to garment design complexity. Neither the ease allowance between body and garment models nor its influence on fit has been clearly defined. Therefore, an appropriate basic block pattern should be established, and the efficient pattern generation method should be enhanced in terms of time required, accuracy, and flexibility.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The purpose of this study is to improve the men's shirt size method based on body shape classification and create customized patterns for figure types from 3D body models to produce fitting garments in an efficient and adaptable manner suitable for mass customization.

The approaches and methods applied in this research depend on the purpose of the study, the timeframe, and any potential funding limitations. This study employs the sequential exploratory design in the mixed-method approach (Creswell & Plano Clark, 2018), where the qualitative findings inform the quantitative analysis. The research approach is shown in Figure 3.1, which presents the main methods for each phase to address each objective. The qualitative Phase 1 serves to address the research objective 1 and is related to Chapter 4. The quantitative Phase 2 addresses the research objective 2 and is related to Chapter 5, while the quantitative Phase 3 addresses the research objective 3 and is related to Chapter 6.

The research activities and workflow are designed to complement each other in each stage of the process. Figure 3.2 presents the key steps involved in this research work. A literature review is conducted firstly, and information and knowledge gathered will be

used to establish the foundation for the design of the strategy and techniques for addressing the research problem.

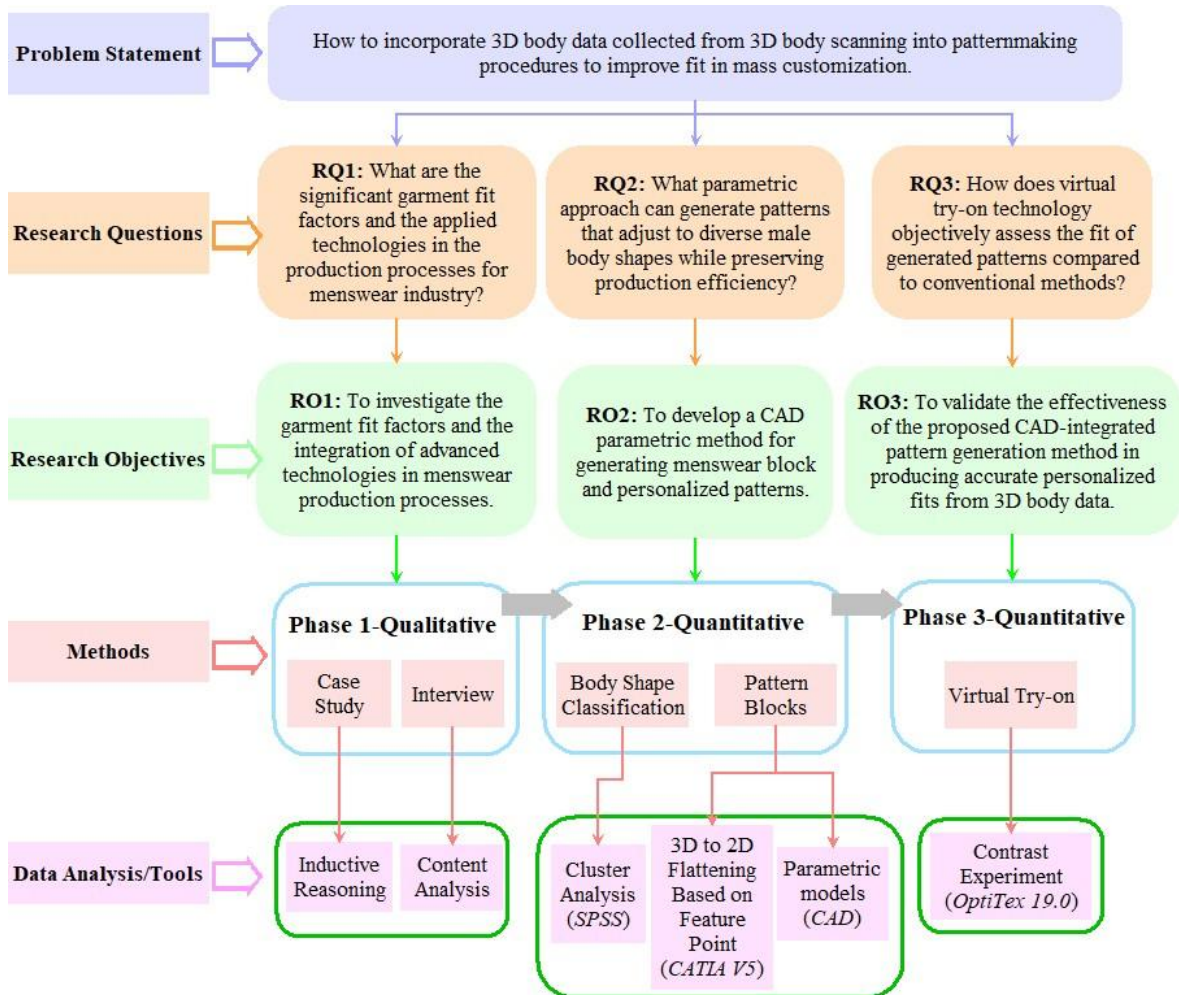


Figure 3.1: Research Approach

To delve deeper into the FC challenges, a qualitative Phase 1 is essential to be conducted to investigate the current situation of FC in garment industries, which includes the methods of sizing, fit challenges, and pattern creation techniques, as well as awareness of the difficulties faced in FC and its technological implementation problems. Therefore, in

Phase 1, case studies are employed to investigate the practices of technologies in the implementation of apparel MC, and interviews are conducted to identify the essential factors and technical challenges for achieving an appropriate fit from an expert perspective in menswear manufacturing. This key aspect is important as it forms the critical element used in the succeeding processes.

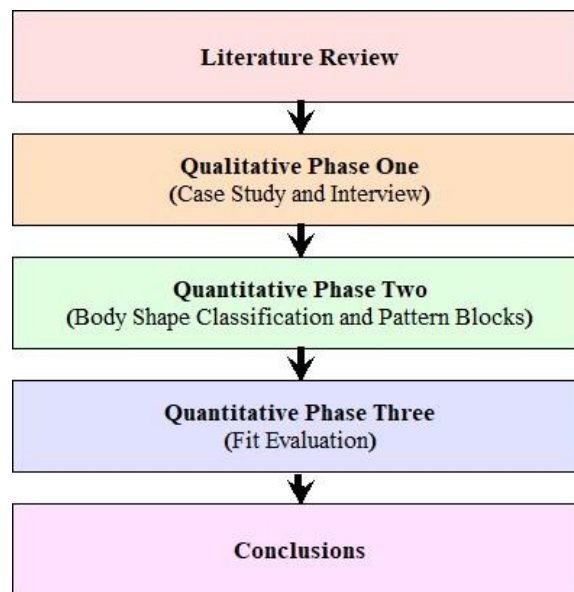


Figure 3.2: Research Workflow

The findings from qualitative Phase 1 are incorporated into the quantitative Phase 2, leading to the development of body shape classification and pattern generation that can enhance the fit in MC. This quantitative Phase 2 is the main focus of this study, which mainly includes body shape classification and pattern generation based on the 3D body model. The body data from 3D body scanning was quantitatively analyzed by cluster

analysis for body shape classification which supports the size development with various fit demands. Pattern blocks for each body shape should be developed for garment fit in MC (H. K. Song & Ashdown, 2012). This concept inspired the creation of a parametric block pattern for various figure types based on the 3D body model in this study. Hence, parametric block patterns were developed from each body type's body surface flattening based on the anthropometry-based feature points on 3D body model and the parametric models between body size, body shape and pattern (Alemany et al., 2022; Chi et al., 2022; Lee & Song, 2021). The personalized patterns for various body sizes and body shapes can be generated based on the parametric block patterns (Kulińska et al., 2022; Yan & Kuzmichev, 2020).

To verify the fit of the body-shape-driven personalized patterns, fit evaluation in Phase 3 is necessary to be performed by a comparison experiment in the virtual try-on software. This validates the effectiveness of the research in Phase 1 and Phase 2, and ensures methodological triangulation.

The research design aligns with pragmatist epistemology, prioritizing problem-solving over paradigmatic purity (Morgan, 2014). The following sections will provide the details on data collection, sampling techniques, data analysis for each method.

3.2 Investigation of the Fit Customization (Objective One)

The purpose of this research is to provide insights into potential technological developments and deepen the understanding of expert perspectives on garment fit in MC. Qualitative research examined the current application of technologies that improve garment FC and analyzed the factors influencing fit in FC implementation from the perspective of industry professionals. The response to this inquiry encompasses two overarching objectives:

i. The objective of this study is to investigate the production stages and the technologies currently utilized for FC in practical production settings.

ii. The objective of this study is to identify the factors that influence garment fit in FC within industrial production processes.

Therefore, a case study was utilized to generate a comprehensive understanding of the technologies currently employed to implement FC in practical apparel production settings. Semi-structured interviews were conducted to identify the influencing factors. In the case study, the observation method was employed for data collection, while inductive reasoning was used for data analysis. The interview data underwent content analysis for coding and analysis. Figure 3.3 presents the details of each method.

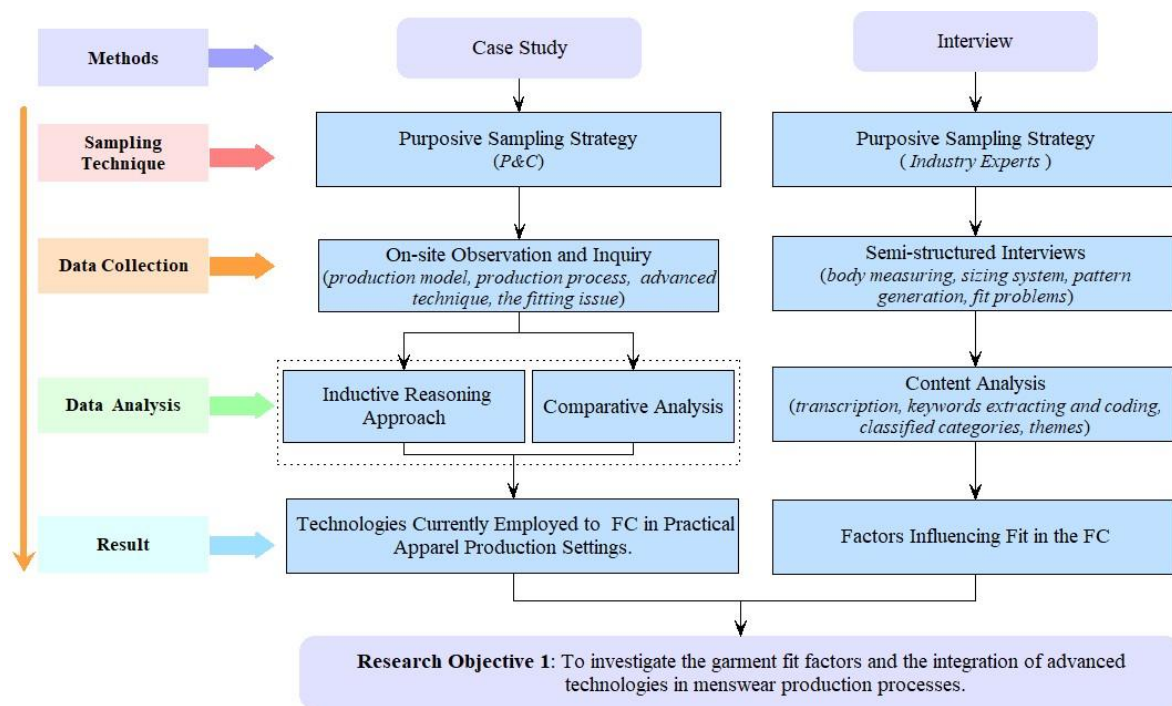


Figure 3.3: Qualitative Method for Research Objective One

Ethical Consideration. This thesis does not provide commercially sensitive information or personal data about the companies and participants involved in the chosen study cases, interviewees, or 3D body scanning. It confirms that such modifications have not distorted the scholarly meaning.

Written informed consent was obtained from each participant in this study. Subsequently, the application form for Human Research Ethics Clearance, attached with information sheet on study, written informed consent document, and instrument for each method of data collection, was submitted to Human Research Ethics (Non-Medical) Committee of UIMAS. At last, Research ethics approval for non-medical research on

humans was obtained for this study after the application is verified by the committee.

Ethical approval was granted by UNIMAS IRB (#2023-AC-028), adhering to: (i) Informed Consent: Participants signed forms detailing data usage (stored for five years), (ii) Anonymization: Scan IDs delinked from demographics; raw data encrypted (AES-256), and (iii) Compliance: Followed Malaysia's PDPA 2010 and EU GDPR (for international datasets).

3.2.1 Case Study

Sampling Technique. The case study method was employed to identify apparel companies for investigation. Two apparel companies in China, P & C, were selected for case study analysis due to their successful implementation of FC in both consumer-customized apparel and occupation-customized apparel, as well as their notable performance in production models and technological innovation. A detailed observation of the complete garment production process was conducted, encompassing body measurement, patternmaking, cutting, sewing, after-finish, and packaging. This comprehensive observation included the production models and technologies employed, focusing on understanding how FC is implemented within the apparel industry and the technology applied in actual production.

Company P was founded in 1995 and began its research on the "Internet + Industry" model in 2003. The company has developed a mass customization production

system by using big data, the Internet of Things (IoT), and intelligent technologies. The company's commercial activities include the provision of bespoke full-category apparel, including suits, trousers, coats, vests, and shirts for both men and women.

Company C was established in 1997. The brand has the capacity for both tailored customization and group customization through intelligent manufacturing production methods. The company's business operations cover a comprehensive range of apparel for both men and women, including suits, shirts, uniforms, jackets, and coats. Notably, suits and shirts constitute the company's flagship products.

Data Collection and Analysis. The investigative process was initiated by examining the official website and company profile. This was followed by site visits and observational research of the garment production process in its entirety. Data collection was completed through on-site observation in the design center, pattern making room, cutting workshop, sewing workshop, and packing workshop. Communication and inquiry were made with relevant garment personnel at the factory to understand the production model, the production process, the utilized technique, and its current situation of use, and so forth.

The collected data were primarily analyzed using an inductive reasoning approach. Initially, the data obtained from each company was individually synthesized, focusing on their respective production models and the technologies employed at each stage of the

production process. Subsequently, a comparative analysis of the data from the two enterprises was conducted across the synthesized data to elucidate the present state of technology implementation in the context of FC within the garment industry. Finally, the integration of advanced technologies in production process for FC was discussed.

3.2.2 Interview

This interview was conducted to learn about the factors influencing fit in FC procedures and the issues in the implementation of FC in practice production in industry.

Sampling Technique. A purposive sampling strategy was employed to select participants, ensuring that all interviewees possessed prior experience in FC and held roles with direct influence on garment fit during production. The interviewed persons are experts who work in garment manufacturing processes involving measuring, sizing, patternmaking, and sample making. They are individuals who take body measurements for customers, pattern makers who create the actual patterns, and production technicians who have final authority in the garment's production and can affect the fit. These experts possess extensive knowledge in various disciplines, including body measurements, sizing, pattern design, the CAD process, and fit customization. Information regarding the participants is provided in Table 3.1. The selection of ten participants was guided by the principle of theoretical saturation. To maintain the confidentiality of the subjects, the identities of all individuals interviewed in this study are kept anonymous.

Table 3.1: Participant Information

Variables		Number	Percentage (%)
Gender	Male	10	100
Job Experience	5–10 years	1	10
	10–20 years	2	20
	>20 years	7	70
Job-status	Technical Director	1	10
	Technical Supervisor	2	20
	Team Leader for Patternmaking	1	10
	Team Leader for Sample Garment (Technician)	1	10
	Pattern Maker	5	50

Data Collection. The interview questions are designed based on four sections. The first section is for body measuring - to understand standards of the landmarks defined by various tailoring methods used and the criteria applied in body measurements in the industry; The second section is for sizing system - to investigate the sizing rules and garment specifications in practical production; The third section is for pattern generation - to comprehend the methods of patternmaking and to investigate the use of CAD and its advantages and disadvantages; The fourth section is for fit problems - to survey the fit

issues and difficulties in the implementation of FC. Based on the above sections, the interview questions with details are provided in Table 3.2. The interview questions were peer reviewed to ensure its reliability and accuracy for addressing research objective one.

Semi-structured interviews are used in this study. Data were collected through face-to-face meetings that lasted between 20 and 50 minutes each. To ensure the accuracy of these data, the researcher recorded every interview comprehensively using camera equipment. Following the interview, participants were identified, given an overview of the study's purpose and background, and informed that the questions and conversations would be open to all, with their responses remaining anonymous. The researchers asked the participants questions and allowed them to share their experiences freely. The researchers also provided additional information and followed up with the participants when necessary. Throughout the procedure, participants were free to express their opinions as much as they wished. Even for this informal interview, specific questions had been prepared in advance and related to four areas including body measurement, sizing system, pattern, and fit issues in manufacturing.

Data Analysis. The analysis of interview data requires a series of processing steps for the original vocal data, which is performed using the qualitative analysis. The subsequent analysis of the interview data was performed using content analysis. First, it is essential that the vocal data of each participant is transcribed into textual content in meticulous detail, including the participant's exact expression. Then, the critical

information in the textual material was subjected to keyword extraction. The keywords were coded and the keywords with the same meaning were subsequently categorized into the same group. This group was then defined as a category. Finally, essential themes were determined in order to ascertain the main influences on the conformity of the factors affecting the fitness of the text. Some participants appeared to downplay the limitations of the technology. To reduce bias, interview data were triangulated with production line observations and archival records. Intercoder reliability for keyword analysis was confirmed through peer debriefing, with 85% agreement on initial coding categories. Figure 3.4 illustrates the process of semi-structured interview conduct and the procedure of the outcomes.

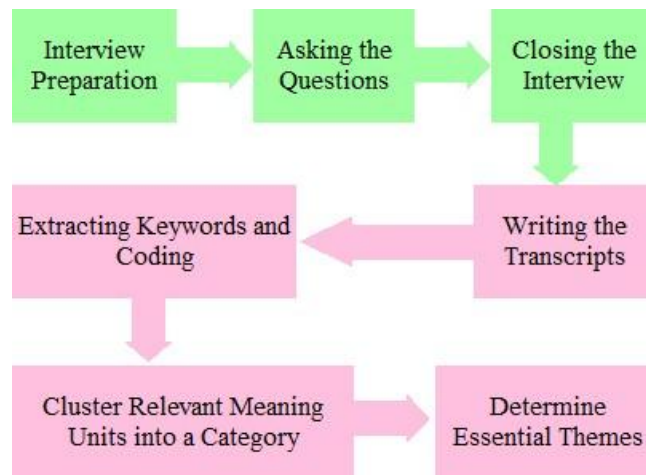


Figure 3.4: Process of semi-structured interview conduct

Table 3.2: Interview Questions

Section	Theme	Inquiry
I	Body Measuring	i. What are the methods of taking the body measurements in the factory?
		ii. What is the criteria for the body measurement in the factory?
		iii. How to find the landmarks and what is the standards?
		iv. What are the factors that influence the measuring methods?
II	Sizing System	i. What is the standard procedure for size?
		ii. What is method used to design the size in the factory?
		iii. How to do the size categorization?
		iv. What is the usage of the sizing system?
III	Pattern-Making	i. What are the influencing factors for the pattern?
		ii. Which method is used for patternmaking?
		iii. Which CAD software is used for patternmaking?
		iv. What are the advantage and disadvantage for the CAD software?
		v. What do you think about 3D patternmaking?
IV	Fit Issues	i. What are the main causes that result to the unfit?
		ii. Which steps are taken to improve the fitting in the factory?
		iii. What are the difficulties for unfit issue in the production?
		iv. What are other issues in menswear production?

First, transcription is completed: the vocal data of each participant must be transcribed in detail to capture their actual views accurately. The transcripts are then read in their entirety to gain an overall understanding, accompanied by note-taking. After transcription, the researcher repeatedly reads and interprets the detailed content to obtain deeper insights.

Subsequently, the transcripts are examined to extract keywords from each interview text, and these keywords are systematically coded until all ten interview transcripts have been thoroughly analyzed. During this process, words and phrases with similar meanings are grouped to form unified coding units.

Next, the clusters of relevant meaning units are organized into thematic groups based on their contextual relevance, and these are classified accordingly. The resulting categories can be structured into multiple hierarchical levels, such as primary, secondary, and tertiary categories, depending on the complexity of the themes.

Finally, essential themes are identified by analyzing all clusters to determine the core essence that underlies each group. These themes are interpreted as the primary findings derived from the interview data analysis. In addition, the frequency of each keyword within themes or meaning units is statistically calculated to evaluate the relative importance of specific concepts.

3.3 Personalized Pattern Generation (Object Two)

Building on the qualitative insights from investigation of the FC, which identified factors influencing fit and limitations in existing 3D technology, this study employs 3D body scanning and statistical modeling to establish a data-driven body shape classification framework, and then develops pattern blocks for various body shapes through unfolding the 3D body model to 2D pieces based on the landmark of feature points on 3D body model, finally generates personalized patterns based on the parametric models between body and pattern. Figure 3.5 presents details of the method to address the second research objective.

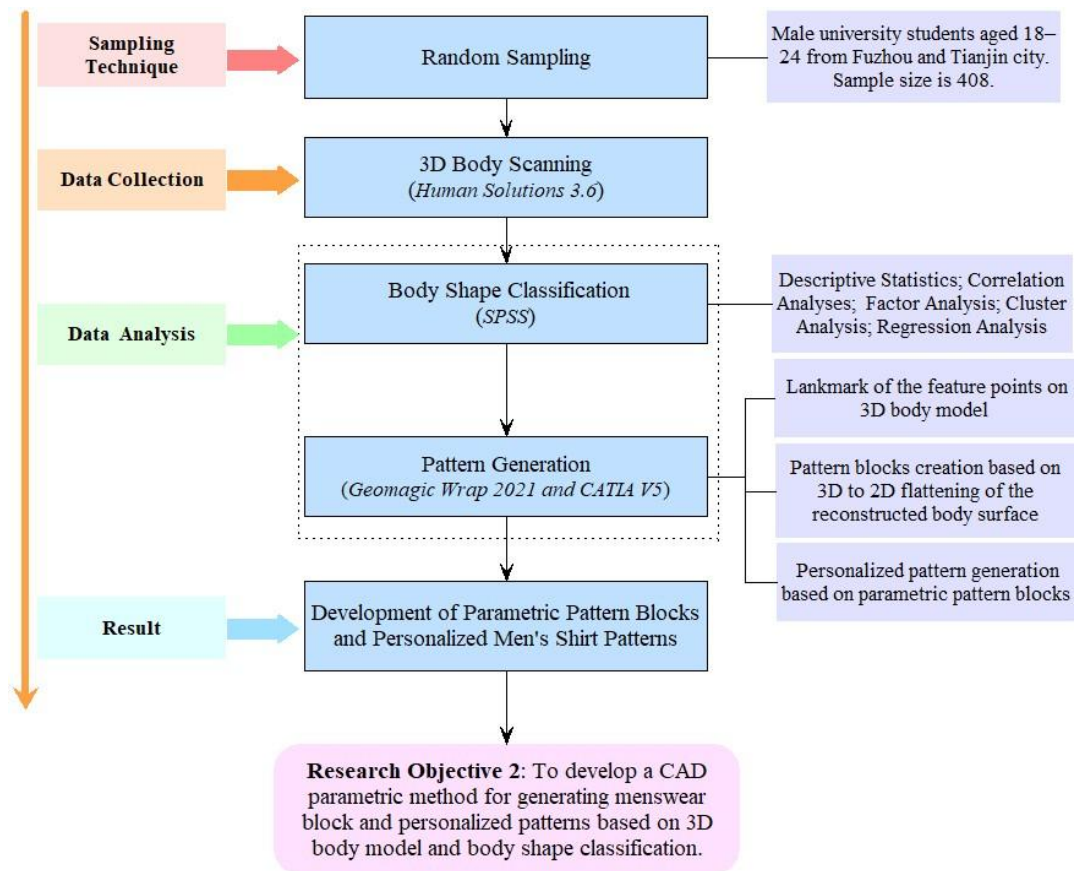


Figure 3.5: Quantitative Method for Research Objective Two

3.3.1 Sampling Techniques

The study's stratified random sample targets male university students aged 18–24 (n=400) from Fujian (south) and Tianjin (north) provinces, China. This cohort is selected because:

i. Technological feasibility: Universities in these regions contain standardized 3D scanning labs (Human Solutions 3.6), ensuring data consistency.

ii. Market relevance: This age group accounts for most of China's online apparel demand (Henan Province Garment Industry Association, 2022).

iii. Morphological representativeness: This cohort reflects the typical body morphology of currently enrolled university students. Meanwhile, a northern city and a southern city are selected to collect samples, which can increase the diversity of body types and reduce the body type deficiency caused by regional factors.

iv. Control for confounders: Age restrictions reduce posture variability related to osteoporosis/arthritis (WHO, 2020).

For the validity of subsequent experiments, the minimum sample size was calculated using the following equation derived from GB/T22187-2008 China Standard for establishing an anthropometric database. Since body measurements of different parts will be analysed to understand size and shape, the smallest sample size can be estimated by the measured parts with the largest variable coefficient.

$$n = \left(\frac{1.96 \times CV}{a} \right)^2 \times 1.534^2 \quad \text{Equation 3.1}$$

where:

1.96: The critical value of the standard normal distribution at 95% confidence

CV: Variable coefficient $\left(CV = \frac{s_x}{\bar{x}} \times 100 \right)$

\bar{x} : Population mean of human body dimensions

s_x : Population standard deviation of human body dimensions

a : Relative accuracy (percent)

n : Estimated sample size

Table 3.3: Smallest Sample Size Calculated by the Initial Body Measurements

Parts	\bar{x} (cm)	s_x (cm)	CV	Calculated Sample Size
Height	174.5	6.9	3.95	36
Bust Girth	93	9.3	10	226
Waist Girth	77.7	9.7	12.48	352
Hip Girth	95.1	7	7.36	123
Neck Girth	41.2	2.8	6.8	105
Shoulder Width	41.2	2.9	7.04	113

The standard deviation and mean value can be estimated from the initial sample in

the preliminary research. In this study, the initial sample consists of 200 male students aged 18-24, half of whom are from Fujian Province in China and the other half from Tianjin Province. The smallest sample size can be calculated according to the equation with 2% relative accuracy and 95% confidence. Table 3.3 shows the sample sizes calculated from the initial body measurements. Compared with the calculated results in Table 3.3, the minimum sample size is 352. The actual sample size in this research is 408, exceeding the requirement. Hence, it shows that the number of samples for this research is adequate.

3.3.2 Data Collection Technique

3D body scanning as a quantitative method was applied to collect the body data. The 3D scanning instrument used in this study was the Anthroscan scanning system (Human Solutions 3.6), which is conducted in accordance with the standards ISO 7250, ISO 20685, and ISO 8559 for anthropometric measurements. The 3D body can be captured to generate a detailed 3D model from the scanning system, which applies laser triangulation technology (Ashdown, 2020).

Training the measurers and subjects must be done before body data collection. The measurers are those who control the 3D scanning machine. They must be familiar with the operation of the scanner and the measurement requirements; meanwhile, they also help to measure the subjects' body weight and record the data.

The measured persons are the subjects of this study. They are required to remain naked on the upper body during the measurement, without wearing accessories such as necklaces and watches, and wear light-colored, tight shorts with bare feet. When they are measured, they need to stand on the footprint mark in the measuring platform area, the whole body being relaxed and the head and the neck remaining straight. They keep a natural standing posture and extend their arms slightly to the sides of the body (A shape from ISO8559/1989), so that the armpits are not covered throughout the measuring process, and keep the posture unchanged before the end of the measurement (ISO8559/1989). The 3D body model will be saved in the form of .obj after scanning. Each subject's measurement process takes 8–10 seconds.

These landmarks on 3D body model, listed in Table 3.4, serve as reference points for measurement extraction. Key anatomical landmarks for anthropometry are identified in 3D body scanning system which refers to the anthropometric standard ISO8559/1989. For example, the vertex (Point 1) is derived from the intersection of the transverse plane and central axis, while the shoulder point (Point 5) corresponds to the acromion's lateral prominence. Consistent landmark identification ensures reliability across datasets.

The body measurements were calculated based on these key anatomical landmarks in scanning system. A total of over one hundred body measurements were obtained using the 3D body scanner. From these, a subset of dimensions that effectively represent body shape characteristics was selected for data analysis. Based on knowledge related to

garment pattern design, body measurements were screened from four aspects: height, girth, width, and angle, corresponding to the labels L_i , G_i , W_i , and A_i in Table 3.5, resulting in a selection of 40 key measurements. In addition, in-depth interviews with apparel experts presented in Chapter 4 revealed that abdominal protrusion has a significant impact on pattern design. Furthermore, sizing must consider the overall proportional balance between the upper and lower body. Accordingly, two additional terms, D11 and R1, were introduced to address these factors, as defined in Table 3.5. Thus, a total of 42 body measurements were selected for data analysis.

Table 3.4: Anatomical Landmarks for Anthropometry

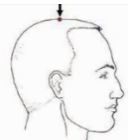

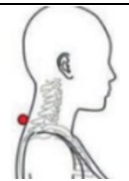

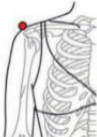
No.	Term	Definition	Diagram
1	Vertex	The intersection of the central axis and the transverse plane created by the centroid axis is defined as the vertex.	
2	Lateral Neck Point	Select the point of maximum curvature along the anterior contour line at the neck region.	
3	Cervical Point	At the point of the seventh cervical vertebra (C7) in the cervical spine.	
4	Anterior Neck Point	The midpoint of the connection between the left and right clavicles.	
5	Shoulder Point	The most laterally protruding point on the superior edge of the acromion of the scapula.	

Table 3.4 continued


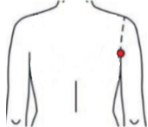
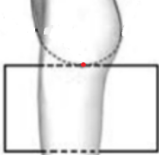

6	Anterior Axillary Point	The lowest point of attachment of the pectoralis major muscle, located at the anterior axillary fold.	
7	Posterior Axillary Point	The lowest point of attachment of the teres major muscle, located at the posterior axillary fold.	
8	Bust Point	The point of the nipple.	
9	Crotch Point	A sagittal plane is created through the centroid axis. The intersection of this plane and the base of the torso is defined as the crotch point.	
10	Centre Point of Kneecap	The midpoint of the line connecting the highest point of the inferior border of the patella and the lowest point of the patellar apex.	

Table 3.5: Definition of the Body Measurements

No.	Terms	Lables	Definition
1	H	L1	Vertical distance from top of the head to the level of the soles.
2	NH	L2	Vertical distance from C7 vertebra to the level of the soles.
3	BH	L3	Vertical distance from chest prominence to the level of the soles.
4	WH	L4	Vertical distance from the narrowest point of the waist to the level of the soles.

Table 3.5 continued

5	HH	L5	Vertical distance from the hip circumference line to the level of the soles.
6	AL	L6	Length from shoulder point to the elbow and then to the wrist.
7	CH	L7	Vertical distance from the perineum to the level of the soles.
8	KH	L8	Vertical distance from the midpoint of the knee to the level of the soles.
9	BWL	L10	Length from the side neck point to the posterior waist circumference line.
10	SBH	L11	Vertical distance from the scapular prominence to the level of the soles.
11	WBH	L12	Vertical distance from the posterior waist indentation to the level of the soles.
12	NHF	L13	Vertical distance from the anterior neck point to the level of the soles.
13	NWCB	L14	Surface length from the posterior neck point to the waistline.
14	AH	L15	Vertical distance from the position of the abdominal prominence to the level of the soles.
15	BPN	L17	Length along the body surface from the side neck point to the chest prominence.
16	UAL	L18	Length from the shoulder point to the elbow.
17	FSTL	L19	Surface length from the anterior axillary point to the waistline.

Table 3.5 continued

18	BSTL	L20	Surface length from the posterior axillary line at the mid-back to the waistline.
19	FWL	L21	Distance from the side neck point to the anterior waist circumference line.
20	NWCF	L22	Distance from the anterior neck point to the anterior waist circumference line.
21	CS	W1	Length over the left shoulder point to the posterior neck point and then to the right shoulder point.
22	CBW	W2	Body width between the posterior axillary points.
23	WA	W3	Distance along the body surface from the left anterior axillary point to the right anterior axillary point.
24	WW	W4	Width between the sides of the waist at the waistline.
25	SW	W5	Distance from the side neck point to the shoulder point.
26	UAD	W6	Width between the vertical lines of the anterior and posterior axillary points.
27	ND	W12	Distance between the side neck points.
28	BPW	W13	Distance between the chest prominences.
29	BG	G1	Circumference at the level of the chest prominences.
30	WG	G2	Circumference at the narrowest point of the waist.
31	HG	G3	Circumference at the maximum point of the hip prominence.
32	NG	G4	Neck base circumference through the posterior neck, side neck, and anterior neck points.

Table 3.5 continued

33	AG	G5	Circumference at the maximum point of the abdominal prominence.
34	CL	G6	Length from the anterior waistline through the perineum to the posterior waistline.
35	TG	G7	Thigh root circumference.
36	KG	G8	Knee circumference.
37	UAG	G9	Circumference of the arm at the biceps.
38	MH	G10	Circumference halfway between the waist and hip.
39	SA	A1	Angle between the minor shoulder line through the side neck point and the horizontal line passing through the side neck point.
40	HA	A4	Protrusion angle of the hip prominence relative to the posterior waist indentation.
41	D _{AP-FNP}	D11	The horizontal displacement between the sagittal plane of the abdominal protuberance point and that of the front neck point.
42	R _{W-H}	R1	Ratio of waist height to body height.
43	D _{B-W}	D1	Difference between the chest girth and waist girth.
44	D _{H-W}	D2	Difference between the hip girth and waist girth.
45	D _{BWL-FWL}	D5	Difference between BWL and FWL.
46	D _{H-B}	D10	Difference between the hip and bust circumferences.
47	R _{S-H}	R2	Ratio of shoulder width to body height.

3.3.3 Body Shape Classification

Individual body characteristics vary substantially, and few individuals conform exactly to average body proportions. For instance, many people display relatively narrower shoulders compared to wider hips and thighs, while others may have a shorter upper torso and a longer lower torso (Bellemare, 2014). Designing clothing solely based on standardized body types often fails to address the fit requirements of diverse body shapes. Therefore, it is necessary to understand how an individual's body proportions deviate from standard or idealized norms, whether they are proportionally shorter or longer, narrower or broader in particular regions. By identifying such discrepancies, pattern divisions can be modified to achieve a more balanced and visually proportional appearance. Consequently, recognizing both the differences and similarities among body types is essential for developing effective sizing systems and generating patterns that ensure proper garment fit.

Quantitative analysis methods were employed to classify body shapes and examine the relationships among body shape, body size, and garment fit. The process of analyzing the body data includes the following steps:

- i. Firstly, outliers were removed using the standard deviation method to ensure a normal distribution of the dataset. Descriptive statistics and correlation analyses were then conducted using SPSS to gain an initial understanding of the data characteristics.

- ii. Subsequently, the data were evaluated using the Kaiser-Meyer-Olkin (KMO)

measure and Bartlett's test of sphericity to verify their suitability for factor analysis. Factor analysis was then performed to extract the principal factors influencing body shape.

iii. Thereafter, the K-means clustering method and analysis of variance (ANOVA) were applied to group the training samples and establish a body type database. The F-test was used to assess the validity of the clustering solution, where a significance level of $p < 0.05$ indicated that the categorization was statistically acceptable.

iv. Finally, based on the clustering results, regression analysis was performed to establish relationships among various body measurements. These regression models serve as a fundamental basis for understanding the interactions between body shape, size, and fit.

Following the above analyses, body types were further classified into multiple levels according to the significance of the influencing fit factors. Based on this classification, an optimized sizing system, corresponding to the varying degrees of fit requirements for men's shirts, was redesigned to better accommodate the needs of fit customization.

3.3.4 Pattern Generation Method

As shown in Figure 3.6, the main steps make up the primary flow of the process of creating a 2D menswear pattern blocks from a 3D body model, where the landmark of feature points and parametric relationship between body and pattern blocks are the most critical steps. A 3D-to-2D surface flattening method is applied to unfold the reconstructed

body surface through the feature point and feature line on 3D body model. A quantitative approach is then employed to analyze the relationship between body shape and unfold 2D body pieces to create parametric pattern blocks. Finally, the personalized pattern for various body shapes is developed based on the parametric pattern blocks.

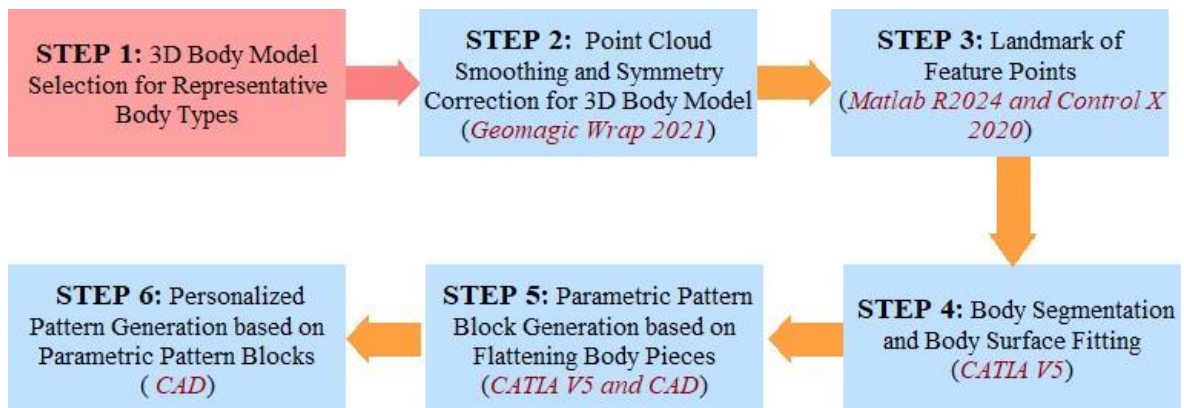


Figure 3.6: Steps of Pattern Generation

Step One. The body types with the highest representation in the population are selected for generating pattern blocks for each body shapes. The selected 3D body models have the best scanning quality.

Step Two. In order to obtain significantly more precise body models for the succeeding process, the selected raw 3D body models were first subjected to point cloud pre-processing, including data screening, denoising, hole filling, smoothing, and symmetry correction, in a reverse engineering modeling software Geomagic Wrap 2021. The reverse engineering modeling software Geomagic Wrap 2021 was selected for its precision and

widespread adoption (Chi et al., 2022). The processed model is obtained and saved in the form of a mesh and point clouds.

Step Three. The key points of the human body must be identified firstly, usually including the cervical point, anterior neck point, shoulder point, anterior axillary point, and posterior axillary point. Landmarking key points on the human body is always essential and challenging for 3D human body reconstruction. It should be noted that the key points for garments include fit points and fashion points that are based on anthropometry and fashion design knowledge. The fit points are the anthropometric points such as cervical point and anterior neck point. Fashion points are the points on the body which control the garment patterns, including the underarm point, intersection of waistline and side seam line, and intersection of hipline and side seam line (Jiang et al., 2020; C. C. L. Wang, 2005; C. L. Wang et al., 2005).

Traditionally, during manual measurements, these key points are located on the body based on anatomical knowledge and experience. This study, combined with previous interviewees' views on key points on 3D body model, selected seven feature points for landmarking, including the cervical point (back neck point), anterior neck point (front neck point), lateral neck point (side neck point), shoulder point, anterior axillary point, posterior axillary point, and underarm point. The definitions of these feature points are shown in Table 3.4. The main landmarks of these feature points are taken from ISO8559-1:2017, ISO 7250-1:2017, China GB/T38131-2019, and China GB/T16160-2017. China standard

GB/T16160-2017 and GB/T38131-2019 are the standard of the anthropometric definitions and methods for garments. GB/T16160-2017 and GB/T38131-2019 are the standards for the acquisition method of datum points for clothing anthropometry. Both of them are provided for the reference of garment production in industry.

In previous studies, the author used planes to intersect the 3D unorganized points of a human body scan or projected points onto several planes to obtain 2D contours. The location of the back neck point and front neck point is identified on the 2D contours by the 'sharp' angles along the contour, where the definition of 'sharpness' follows the fuzzy logic concept. The height of the underarm point can be calculated by an anthropometric equation using the belly-button point height and the back neck point height. Therefore, the cloud points can be sliced there, and the four turning points on the contours can be located. The underarm point is positioned midway between the front and back turning points on the cutting plane (C. C. L. Wang, 2005).

Han and Nam (2011) provide a method to define the side neck point, front neck point, back neck point, shoulder point, crotch point, and armpit point on the 3D body model. The algorithm for measuring the armpit point is similar to Wang's. For the front neck point, the algorithm identifies the inflection points along the front center line in the neck region. The side view of the front neck shape is used as a body shape factor for the front neck point. Han and Nam noted that the relative height of the back neck point to the side neck point varies according to the degree of neck bending at the back neck point.

However, the uppermost point of the head, called bregma, must be very accurately defined when determining the side neck point (Han & Nam, 2011). Additionally, Han and Nam (2011) proposed a different method to find the shoulder point in the 3D body model. This method will be used in this study and introduced later.

To establish standard landmarks, the horizontal plane crossing the line from the front neck point to the navel and dividing the left and right sides of the body was set as the median plane. Eight standard landmarks were selected in this study: the left and right lateral waist, left and right lateral shoulder, axillary level at mid-spine, mid-axilla level at mid-spine, cervicale, and nipple center point. The omphalion point and the axillary level at mid-spine were employed. The landmarks were defined based on the standard anthropometric measurement method (Yoon et al., 2016).

Kulińska et al. (2022) applied the method proposed by Wang (2005) to locate the anterior and posterior axillary points, and the method by Han and Nam (2011) to find the side neck point and shoulder point. This significantly aids in creating morphological contours for positioning garments in 3D and, in some cases, detecting specific anthropometric points such as the armpits, sides of the neck, acromion, and the back of the neck (7th cervical) when these points are not identified during scanning. Furthermore, the anthropometric ratios applied to this scanned body follow female proportional standards. Some primary contours correlate directly with stature, while secondary contours are defined relative to the primary contours. The stature value from the scanner measurement

was used to initialize the anthropometric rules and derive an initial version of the morphological contours (Kulińska et al., 2022).

Chi et al. (2022) presented the positions of 10 human feature points marked on each subject by professional surveyors based on skeletal landmarks and the extracted measurement features before scanning. Additionally, combining views from three angles, these points were annotated on the human model by mapping their spatial relationships (Chi et al., 2022).

In this study, the seven feature point extraction method adopted mainly relies on actual human body measurements to locate corresponding points on the body surface. To determine the front axillary point, back axillary point, and underarm point, a combination of anthropometric data and Wang's method is employed. For identifying the shoulder point, the approach developed by Han is referenced. Furthermore, inspired by Kulińska et al. (2022), who preserved human body proportions using actual measurements, this study adjusted the calculated values of each key point based on regression relationships among major body parts across various body types. This approach ensures that proportional relationships between body parts remain consistent.

Hence, once the processed 3D body model is obtained, landmarking the feature points on the model is conducted using Control X 2020, applying three techniques: perpendicular-based, slice-based, and outline-based methods (Yan & Kuzmichev, 2020).

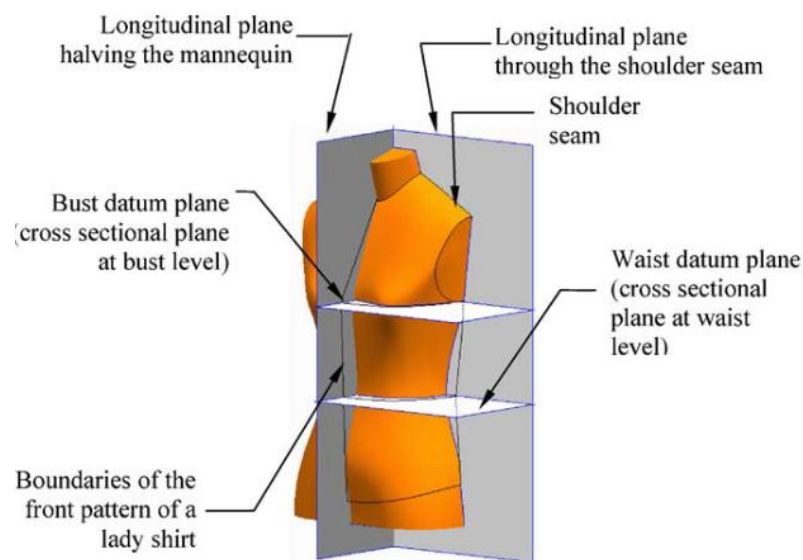
The software Control X 2020 was selected because its accuracy can be controlled within 0.5 mm mean error in landmarking compared with manual methods (Alemany et al., 2022).

MATLAB R2024 is then employed to extract the coordinates of all points on the 3D body model, allowing the identified landmarks to be output as coordinate data. This process enables the 3D body model with annotated landmarks to be exported, saved, and further processed by other software, thus overcoming the limitations of many existing 3D body modeling systems (Chi et al., 2022).

Step Four. Following the principle of the traditional 3D-to-2D real garment draping method (Hong et al., 2017a), the first and important issue in establishing the surface model is to identify the position of the feature points and curves on the 3D body model, which is based on an anthropometry-driven modeling approach, allowing for the development of base block patterns corresponding to various figure types, grounded in the fit models of the clustered groups (H. K. Song & Ashdown, 2012). Therefore, according to the feature points and the anatomical features of the torso, such as chest protrusion, abdominal protrusion, scapular protrusion, gluteal protrusion, shoulder contours, and waist concavity, the feature curves are drawn on the surface of the 3D body model following an anthropometric definition.

After defining the feature curves on the body model, the next step is to use the feature points and feature curves to segment the body into major components: upper limbs,

lower limbs, and torso. The torso is further divided into multiple regions based on the convex and concave surfaces of the body. To enable virtual representation, datum planes aligned with the feature curves are introduced to assist in body segmentation. The concept of using datum planes originates from Au and Ma (2010), who proposed that such planes can be embedded into the body model and serve as sketch planes for designing garment patterns (Au & Ma, 2010), as illustrated in Figure 3.7.



Sources: Au & Ma, 2010

Figure 3.7: Datum Planes

After segmenting the human body, the surface of each region is fitted using the surface fitting tools in CATIA V5 to create a complete 3D surface model of the body. The 3D body surface model, constructed based on feature points and feature curves, is utilized to generate 2D surface patches via reverse engineering software (Alemany et al., 2022).

This 3D model provides the essential conditions for garment fit and the basis for high-quality 2D pattern generation. Subsequently, the flattening method is then employed to transform the 3D body surface model into a 2D body pieces, strictly adhering to the principles of classical 2D pattern design, using the flattening tools within CATIA V5. The software CATIA is a 3D reverse engineering software widely adopted in 3D CAD workflows in industries, particularly in sectors such as aerospace, automotive, and manufacturing. However, there are high costs for the licensing fees and training requirements for certified operators.

By conducting a comparative analysis of the dimensional changes in 2D surface patches derived from different body types through flattening, a quantitative relationship between body shape and block dimensions can be determined which leads to the theoretical understanding of the size, shape and pattern.

Step Five. Based on the 2D surface patches generated from flattening, ease allowances are incorporated into each part accordingly. The determination of ease allowances in this study is mainly based on existing researches. The existing studies on the optimal ease allowance and quantitative evaluations of ease provide a reference for the ease allowance design of the pattern block in this study. Some studies argue that the minimum surface length variation caused by human movement represents the optimal ease allowance needed for clothing (Gill & Hayes, 2012). Others define the optimal ease allowance as the subjective satisfaction of the wearer regarding garment fit, substantiating

this through empirical evidence. For instance, Park and Lee (2013) demonstrated that for a men's formal jacket, an ease allowance of 13.2 cm in the chest circumference yielded the best outcome in motion adaptability evaluation, whereas 9.5 cm was optimal for appearance evaluation (Park & Lee, 2013). Another approach involves using consumer sensory evaluations to assess preferred ease allowances across different sizing options. Kim et al. (2019) estimated preferred ease allowances for jackets as follows: 5.17–8.25 cm for chest circumference, 6.90–2.09 cm for chest–waist difference, –3.82 to 1.34 cm for chest–hip difference, 1.58–5.86 cm for upper arm circumference, –1.80 to 1.95 cm for bi-shoulder length, and 0.406–0.425 for the ratio of jacket length to stature (Kim et al., 2019). As this study focuses on the fit between human body shape and pattern, the design of ease allowance in this research mainly considers the basic ease, excluding the ease for style.

Based on the ease allowance and the regression models of body measurements under different body shapes, the parametric computation models for the dimensions of each component of the pattern block can be established, ultimately enabling the generation of a parametric pattern block for menswear in CAD.

Step Six. The men's shirt basic patterns for different body shapes were subsequently generated in CAD based on the different body shapes of waist and hip. After that, personalized patterns for various body shapes can be generated efficiently based on the quantified relationship between body shape and the basic pattern by selecting the

corresponding parametric models. This allows for the rapid calculation of body-part-specific dimensions and the realization of fit-customized pattern generation.

3.4 Garment Fit Validation (Objective Three)

Lin and Wang (2016) proposed an innovative clothing fit evaluation approach for virtual try-on using a 3D human model dressed with virtual garments according to the model's body shape. The clothing patterns are designed and subsequently sewn around a human figure. Different clothing sizes were tested to fit onto a human body to ensure a satisfactory fit. Representations of several different-sized clothing items were compared between an actual human body and a virtual model to evaluate the virtual try-on clothing fit. The clothing fit of specified sizes was evaluated quantitatively by calculating the vacant space area between the garment and the human body. The vacant space measure is used to perform real and virtual body fit evaluations (Lin & Wang, 2016).

Dabolina et al. (2018) employed virtual try-on to evaluate the ease of the jacket. Colour analysis was used where dark blue shows a too-loose garment and bright red indicates a too-tight garment. White shows appropriate fit, light blue shows loosened fabric, and yellow shows stretched fabric. Gaps between jacket and body show spatial ease; one represents free movements, the other illustrates a bad fit. As all six test persons fit the sizing chart, ill fit is caused only if a person's measurements are extreme or extreme values in the indifference interval (Dabolina et al., 2018). Lapkovska (2022) designed a method for the evaluation of anthropometric fit and ergonomics of clothing by using interviews,

surveys, and tests of ergonomics (Lapkovska, 2022). Liu et al. (2023) proposed an intelligent fit evaluation technique to predict clothing fit. The mathematical relationship model between clothing fit levels and indexes reflecting the clothing fit levels was constructed by using decision tree C4.5 algorithm. Then, two experiments were carried out to collect input and output training data. After learning from the collected data, the proposed model can predict clothing fit accurately (Liu et al., 2023). In this method, the clothing pressures collected from real try-on and virtual try-on were obtained first.

Existing literature on fit evaluation suggests that virtual fitting can serve as an effective method for assessing garment fit. Therefore, in this study, the virtual fitting method was employed to evaluate the fit performance of garment patterns, as it eliminates subjective bias caused by individual consumer preferences. A comparative analysis approach was adopted to validate the fit of garment patterns. Using a real human body model, virtual fittings were conducted for both the ready-to-wear pattern and the personalized pattern generated in this study. By comparing the fitting outcomes, the superior fit performance of the personalized pattern proposed in this study was demonstrated. Figure 3.8 presents details of the method to address the third research objective.

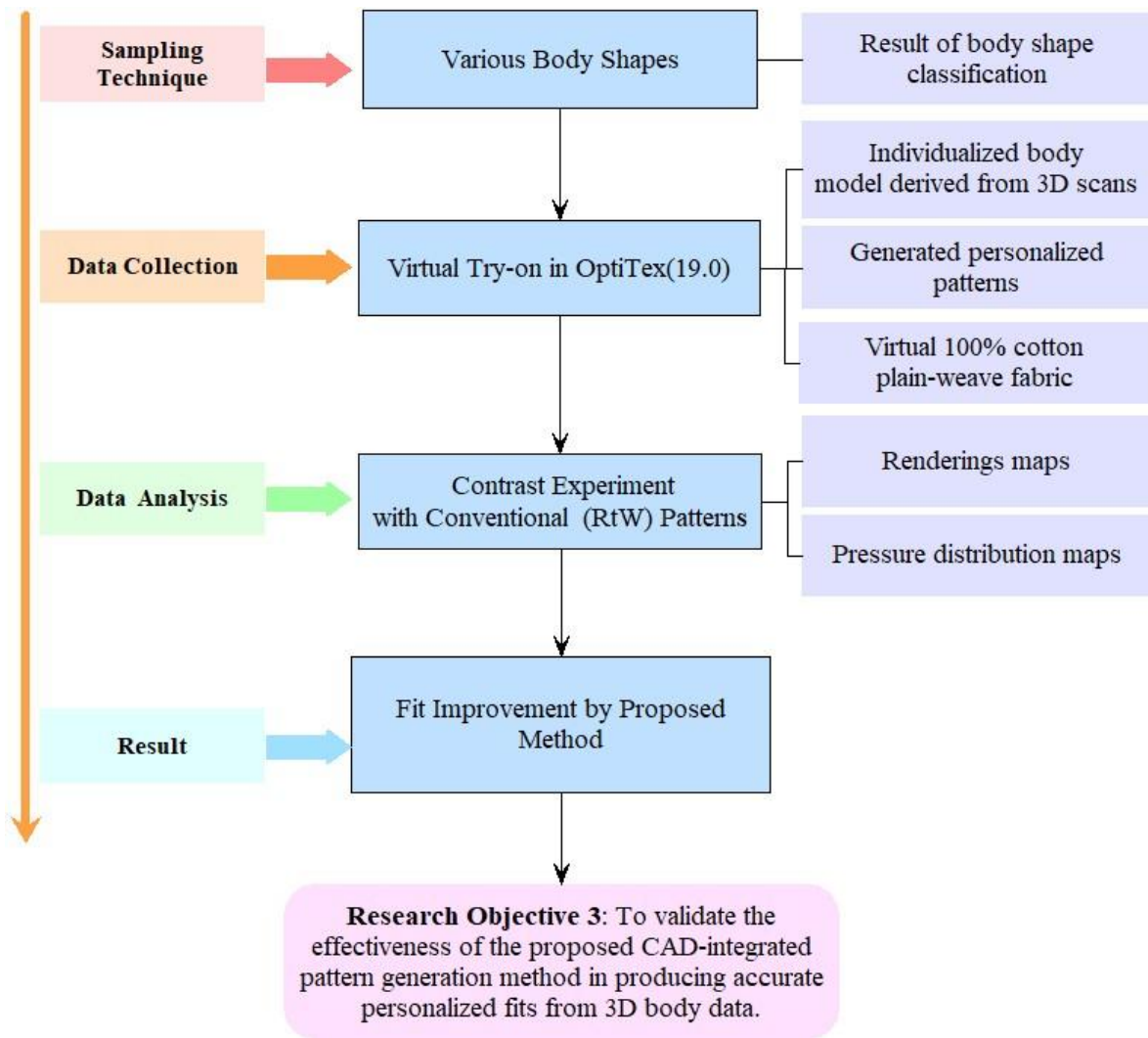


Figure 3.8: Quantitative Method for Research Objective Three

To evaluate the fit of the shirt bodice patterns, virtual fitting experiments were undertaken in OptiTex 3D (version 19.0) using a physics-based simulation engine with a default convergence threshold of 0.01 mm. The simulations employed individualized body models (Scanatars) derived from 3D scans (.obj format), processed with mesh denoising to minimize distortions. The patterns, drafted in Richpeace CAD, were assembled using

industrial-standard seam allowances (1 cm) and stitch type (plain seam). A virtual 100% cotton plain-weave fabric (thickness: 0.1 cm, weight: 15 g/m², bending rigidity: 0.24 μ Nm (X); 0.15 μ Nm (Y), shear stiffness: 755 gf/cm) embedded in the system was applied.

The virtual fitting process generated visual renderings and pressure distribution maps, which were examined using a combined subjective and objective approach. First, sensory evaluation was applied in visual renderings to assess the fitting effects of both the personalized and ready-to-wear patterns, focusing on aspects such as wrinkling, closeness of fit, and silhouette. The specific criteria for subjective evaluation of the fit of men's shirts are as follows.

i. Overall silhouette. The visual renderings exhibit a uniform smoothness across the front, side and back, devoid of any discernible wrinkles or bulges.

ii. Closeness of fit. The tightness of the garment at the chest, waist, hip, shoulder and back, collar and armhole is appropriate, avoiding the formation of wrinkles and bulges caused by improper looseness. It is imperative that the side seams remain vertical.

iii. Wrinkling. It is imperative that the key points and structural lines of the pattern correspond to the body's feature points and lines, thereby ensuring that wrinkles caused by imbalance in proportion are avoided. For instance, the nape line formed by the back neck point, side neck point, and front neck point of the human body should correspond to the collar line of the pattern. It is imperative that the chest circumference line, waist

circumference line, and hip circumference line of the human body correspond to the chest line, waist line, and hip line of the pattern. In the event of a discrepancy between the anterior and posterior chest lines, this can result in an irregularity in the alignment of the front and back pieces, which can lead to the formation of wrinkles. The shoulder line of the human body should correspond to the shoulder seam of the pattern. Should the shoulder seam be positioned excessively forward or backward, this will result in the formation of wrinkles at the shoulder, back, and armhole, among other areas.

Subsequently, objective evaluation was based on a comparative analysis of pressure value maps generated in OptiTex. The pressure values between the garment and the body in various regions within the 3D simulation environment were displayed in both colour gradients and numerical ranges. This provided a visual representation of garment deformation caused by external pressure. As the pressure value decreases, the colour tends to shift towards a darker shade of blue. An increase in pressure value results in a shift towards a darker shade of red. When the pressure value is situated within the median position, the resultant colour will be green. Given that the ready-wear pattern and the personalised patterns used for comparison are of the same size and possess an identical chest girth allowance, it can be concluded that the pressure value can directly reflect the tightness of each part of the pattern. In accordance with the requirements for the fitting of the men's shirt, it is imperative that the chest, hip, shoulder, back, neckline and armhole line maintain an appropriate degree of tightness. A reduction in pressure results in an

enhancement of comfort. Consequently, when comparing the pressure values, on the basis of the fit of the overall visual effect, if the pressure values at the chest, hip, shoulder, neckline and armhole line are relatively small, it is considered that the fit is relatively well. Concurrently, these pressure values can also be extracted and archived to support future research.

Finally, a comparative analysis was carried out to verify the improvement in fit achieved through fit customization, based on the redesigned sizing system and the proposed patternmaking method developed in this study.

3.5 Chapter Summary

In conclusion, a mixed-methods approach was employed in this study to support data collection and analysis. The overall research methodology consists of three phases:

Phase One. The methodology for achieving the first objective adopts a qualitative approach to investigate the current implementation and challenges of advanced technologies in apparel enterprises implementing FC. In addition, it explores the key factors influencing garment fit from the perspective of garment technologists.

Phase Two. The methodology for the second objective employs quantitative methods to conduct body shape classification and examine the quantitative relationships among body shape, body size, and fit. A 3D-to-2D surface flattening technique is then used to unfold the 3D human body model. Quantitative analysis is applied to study the

relationship between body types and basic block patterns, which supports the generation of parametric base patterns. Based on the established statistical relationship between body shape and pattern, a method for the rapid creation of personalized patterns is developed.

Phase Three. To achieve the third objective, virtual fitting technology and comparative analysis are used to evaluate the fit performance of garment patterns. A thorough evaluation combining sensory assessment and pressure-based analysis was conducted to compare the personalized patterns proposed in this study with conventional ready-to-wear patterns. This process verifies the improved fit achieved through the proposed method.

CHAPTER 4

INVESTIGATION OF FIT CUSTOMIZATION

4.1 Introduction

This chapter presents the results and findings of data collection from the first objectives. The qualitative research methods employed in this study encompass interviews and case studies. The analysis of the results from both data sets is undertaken to address the first research objective, namely, "To investigate the garment fit factors and the integration of advanced technologies in menswear production processes."

The technologies currently utilized for FC in practical production settings is derived through a meticulous analysis of the case study data outcomes while the factors that influence garment fit in FC is derived from the analysis of the interview data outcomes. Consequently, this chapter is structured into two phases, each aligned with a specific objective. Furthermore, the results of the data analysis will be discussed directly after each phase of analysis.

4.2 Case Study: Implementation of Fit Customization

4.2.1 Data Analysis

Company P realizes FC through the production process from size measurement, basic pattern generation, and personalized pattern adjustment. The strategy employed in each process incorporate the latest technological advancements. In size measurement, a

personalized customization platform is provided to consumers to select styles and fabrics for consumer-customized apparel. On-site manual measurement services like video tutorials offered by the platform are available to assist with measurements. Furthermore, photo measurement is trial in offline shop. The garment order is generated with information about categories, customers, craftsmanship, sizes, and prices in a consolidated format. The platform has the capacity to interact with multiple systems, including enterprise resource planning (ERP), intelligent design systems, and warehouse management systems (WMS). The intelligent design system generates basic patterns based on standard measurements. Subsequently, these patterns undergo automatic adjustment according to the actual sizes and body features of the wearer.

Manufacturing Execution Systems (MES) and RFID cards are used throughout the manufacturing process. Advanced planning and scheduling systems (APS) are employed for automatic layout and automatic cutting beds for high-precision cutting. The use of RFID numerical control systems and intelligent hanging systems enables the realization of flexible and intelligent mixed-flow sewing production. The manufacturing process is characterized by its flexibility, which is seen in the sequential progression from automatic layout and cutting to sewing, followed by quality control and inspection, and ending with packaging and shipping from the warehouse.

Company C adopts the primary production process including initial communication, design proposals, on-site measurement, manufacturing, client fitting,

feedback, and ensuring customer satisfaction for consumer-customized apparel. Regarding production technology, significant innovations and upgrades have been made to various techniques, including sleeve, collar, lining, and shoulder construction. The company has achieved intelligent analysis and processing of human body measurements, allowing smart pattern adjustments for personalized body types.

The company has developed a Product Lifecycle Management (PLM) system, integrating design, construction, materials, production, and sales information for intelligent management. During manufacturing, advanced technologies such as cutting bed assignment systems, projection-based compound cutting, RFID numerical control systems, intelligent hanging systems, and intelligent warehousing are employed to achieve flexible and intelligent mixed-flow production for various types of clothing. When combined with measurements, production processes, and 5G technology, these systems meet the customized requirements of individual customers by offering a personalized pattern and package.

Thorough examination of the investigative records regarding the production processes of the aforementioned enterprises shows that both companies implemented the FC paradigm earlier and actively employed advanced technologies to improve smart manufacturing during the implementation process. Table 4.1 offers a summary of the advanced technologies used in the production process of the two companies for comparative analysis.

Table 4.1: Technologies Utilized in the Production Process of the Two Companies

Production stage	Company P	Company C
Anthropometry	Video tutorials, Manual measurement, Photo measurement	Manual measurement, 3D body scanning
Pattern-making	CAD	CAD
Cutting	APS, Automatic cutting, RFID, Manufacturing execution system	Cutting bed assignment systems, Automatic cutting, RFID, Product lifecycle management
Sewing	Mixed-flow production, RFID, Intelligent hanging systems	Mixed-flow production, RFID, Intelligent hanging systems
Warehouse	WMS	WMS

4.2.2 Results and Discussion

The implementation of advanced technologies has led to advancements in the digitalization and intelligence levels of FC production. A comparative analysis reveals the use of these technologies in the production process, as illustrated in Figure 4.1. Their success offers insights into FC best practices that emphasize metrics such as levels of digitalized production, production scalability and integration into existing workflows, while there may exist survivorship bias so that their market dominance may limit generalizability to smaller firms.

The technologies employed for the control of product quality and production efficiency in the cutting, sewing, and warehousing stages have been implemented extensively, resulting in significant technological advancements. In the domain of cutting processes, the integration of automatic cutting beds has led to a notable improvement in the precision of fabric cutting. Intelligent Hanging Production Systems have been shown to improve production flow, increase efficiency, support customized production, and meet the production requirements of different products. These systems have been proven to substantially enhance the flexibility and accuracy of production. Radio-frequency identification (RFID) and barcode tracking systems are utilized to monitor and manage the movement of materials and garments throughout the production process. Integrated Supply Chain Management Systems are essential for the real-time tracking and management of materials, orders, and production schedules.

Nevertheless, in the pattern design stages, the implementation of intelligent pattern adjustment technology has resulted in considerable improvements in production efficiency. However, the level of intelligence in body measurement and human data processing varies across the company. While manual measurement techniques remain common, 3D body scanning and photo measurement are in the initial phases of implementation. Furthermore, 3D CAD and virtual fitting systems are employed less frequently in both companies. A major limitation concerns the misalignment between scanner-defined anatomical landmarks and those used in industry practice. This discrepancy between digitally acquired

and manually obtained measurements reduces the practical utility of 3D body scanning in current workflows. Consequently, despite extensive research on 3D scanning, 3D pattern-making, virtual fitting, and other e-commerce technologies, such as clothing recommendation systems for fit customization, in academic circles, their practical application in enterprise production remains limited.

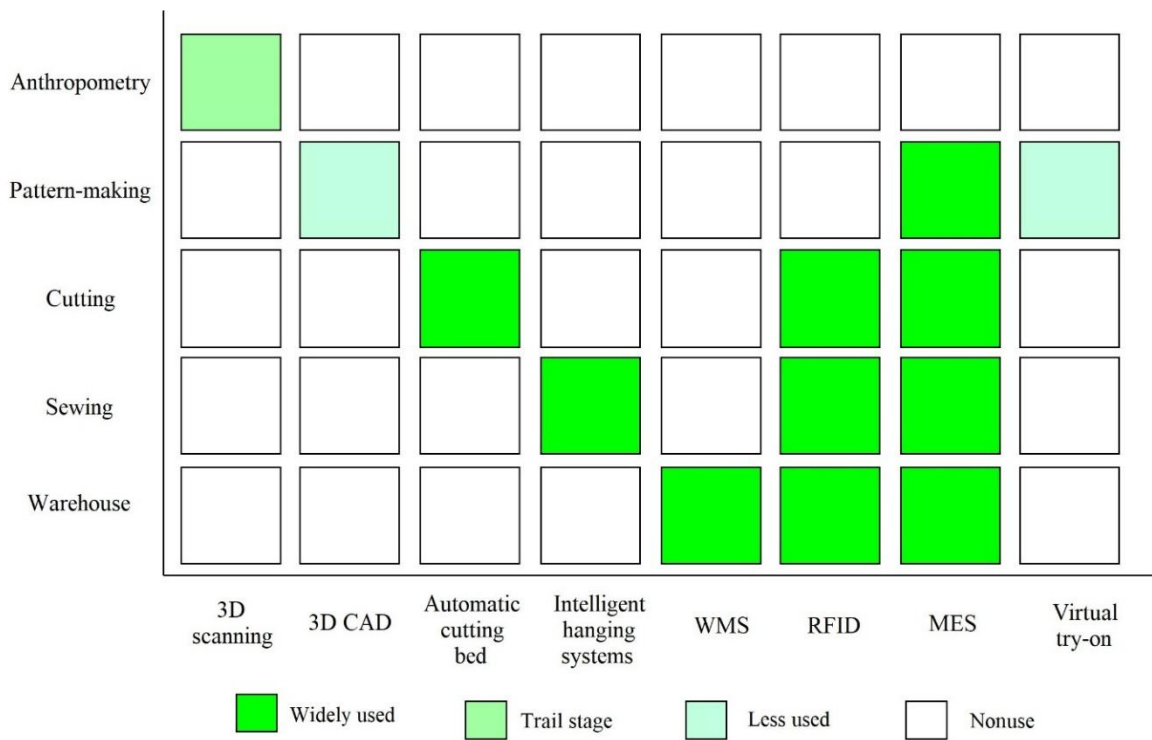


Figure 4.1: The Extent of the Use of Technologies in the Production Process

The adoption of 3D pattern-making technologies has yet to attain widespread industrial acceptance. Despite the introduction of 3D pattern-making technologies designed to improve ease of use, manufacturers retain some caution regarding their accuracy and

their ability to comply with FC requirements. Conversely, pattern designers possess expertise in advanced CAD platforms, which have been shown to produce considerable improvements in precision and efficiency for automated pattern adjustment, thereby ensuring the fit of the pattern.

Virtual fitting systems have yet to be exploited to their full potential. This situation can be attributed primarily to the tendency of contemporary 3D fitting software to produce virtual drape and fit profiles that differ from the behavior of real-world garments. The observed difference between the behavior of virtual garments and their real-world equivalents can be explained by two main factors. Firstly, the human body shapes generated by 3D garment fitting software significantly differ from actual human body shapes. Secondly, the properties of certain fabrics deviate from those of authentic materials. Consequently, the fit corrections suggested by these systems offer limited practical value for pattern development. Nevertheless, the rendering of garment silhouettes in three dimensions indicates the potential for virtual fitting to function as a supplementary visualization tool.

Therefore, the limitations of 3D technology are not only technical restrictions like the observed discrepancy between virtual and real garments, but also constrained by the compatibility, trialability, and observability in the existing production mode. Here, 3D fitting software struggles with compatibility, its outputs do not correspond with industry-standard measurement landmarks, and trialability, as few factories can test it at

scale. Hence, it not only requires that the existing production mode has the capability to flexibly handle multi-dimensional data both from manual measurement and 3D technology, but also demands the consistency and standardization in technical standards. Doing like this will upgrade conversion path of the data flow and enhance the integration between technologies. Additionally, manual methods persist because they embed tacit knowledge that digital tools cannot yet replicate. While academic studies promote 3D scanning and 3D CAD (Ashdown, 2014; Gupta, 2020), their industrial uptake remains low because they fail to meet the relative advantage threshold for workers accustomed to physical prototypes.

4.3 Interviews

4.3.1 Coding and Analysis

Table 4.2 provides a detailed overview of the coding process for all keywords. Finally, the data underwent statistical analysis to determine the factors that affect the fit and the challenges encountered during practical production.

Table 4.2: Open Coding Process

Data Extra (Interview)	Frequency	Initial Coding	Secondary Categories	Primary Categories	Theme	RO1 Componet Addressed
<p>...When taking measurements, it is important to first observe whether the customer has any distinctive body features, such as a prominent chest or a hunched back... The body structure, such as a hunched back, sloping shoulders, or a large belly, needs to be noted when measuring body dimensions...</p>	8	Body shape		Manual measurement	Body measurement	Garment fit factors

Table 4.2 continued

<p>The factors affecting body measurements mainly include the person's posture while standing. The body should stand naturally, as the position of the shoulders, back, and even items in pockets can influence the measurements... When measuring the body, it should be done according to standard procedures, ensuring the customer stands in a natural and upright position... The standing posture and whether the breathing is in a natural state should also be maintained...</p>	7	Standing posture				
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Table 4.2 continued

<p>... There is a standard procedure for operations. For example, when measuring the chest circumference, the tape must be horizontal... The measurement method, attention to detail, and the operator's habits... For instance, when measuring the chest circumference, the tape should be level with the pectoral area, following the body's contour...</p>	<p>4</p>	<p>Operational standardizati on</p>				
<p>... However, different measurers may have variations in determining this point... It requires a combination of tools and a keen eye... Often, measurement data cannot fully express the details, and sometimes it is based on experience to convert observations into data...</p>	<p>8</p>	<p>Anatomy knowledge</p>				

Table 4.2 continued

<p>... Currently, the primary research direction is 3D scanning technology. Its biggest drawback is that it cannot be easily taken out and used practically; it is only suitable for research... The advantage of 3D scanning is its ability to capture the external dimensions of the human body. However, its greatest limitation is the inability to accurately determine several specific points...</p>	<p>2</p>	<p>3D scanning</p>		<p>3D body scanning</p>		
<p>... Some companies use photo-based body measurement...</p>	<p>1</p>	<p>Photo-based body measurement</p>		<p>Photo measurement</p>		

Table 4.2 continued

<p>... It is not enough to only consider height and weight; it is also necessary to see a person's overall body shape in order to determine their specifications...</p>	<p>10</p>	<p>Body shape</p>				
<p>... When the dimensions are fixed, the process is mainly based on the style... Different styles require different fit ease... First, determine the style, followed by the basic fit ease... The fit ease is also the most crucial factor affecting the fit... Additionally, the occasion and style should dictate the corresponding measurements...</p>	<p>22</p>	<p>Style</p>	<p>Fit ease</p>	<p>Garment specification</p>	<p>Pattern</p>	

Table 4.2 continued

<p>The thickness, elasticity, and material of the fabric have a significant impact... Factors affecting the fit include the fabric and the matching of the lining with the fabric... The primary consideration is the fabric, especially when creating the first sample, where the elasticity and shrinkage of the fabric need to be evaluated...</p>	<p>12</p>	<p>Fabric</p>				
<p>...Additionally, there are the customers' fit preferences (whether they prefer fitted or loose clothing)... Communication with the customers is also necessary, understanding their dressing habits, and so on... People's demands for fit vary from person to person...</p>	<p>14</p>	<p>Fit preference</p>				

Table 4.2 continued

<p>The design concept and the feeling the designer wants to convey are very important... people's thoughts and perceptions about clothing, their sense of beauty, and their feeling for style... It's like the experienced tailor in a clothing store who can tell what kind of clothes will suit you just by looking at you... The pattern cannot be made entirely according to the human body's exact shape, as doing so would make the clothing clearly highlight any flaws when worn...</p>	10	Fit aesthetic				
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Table 4.2 continued

...Body height and bust size are the two most fundamental criteria...	4	Body size	Sizing system		
The sizing system should mainly focus on the classification of body types...If it's customized, it will depend on your body type...	4	Body shape			
...Following the national standard series 5.4, industry standards, and clothing category standards... Basically, all are in accordance with national standard regulations...	6	National size standards			
...Grading will lead to significant fit bottleneck issues...	3	Grading		Grading	

Table 4.2 continued

<p>...Garment construction also has a significant impact, especially in suit tailoring... The adaptability and comfort actually come down to the issues of pattern and craftsmanship... The sewing techniques used also affect the fit...</p>	<p>14</p>	<p>Sewing techniques</p>		<p>Garment construction</p>		
<p>...Pattern-making methods often use the basic pattern method... Initially, a standard body template is created, and then adjustments are made for specific body types based on this standard template... The pattern-making process is starting with a basic pattern... Each company has different requirements for the size of the basic pattern...</p>	<p>9</p>	<p>Basic pattern</p>		<p>Basic pattern</p>		

Table 4.2 continued

<p>...For customization, we use a fit sample, adjustments are then made based on this fit sample... Since everyone's body shape and size are different, we use the fit sample to meet our specific requirements...</p>	<p>3</p>	<p>Fit sample</p>		<p>Size categorization</p>		
<p>... the actual measured body dimensions are assigned to corresponding size...First, measure the dimensions, then, category the height and weight...</p>	<p>5</p>	<p>Body size</p>				
<p>...For example, someone's body height is 172 cm, we would categorize them as 170 cm if he is thin. This still needs to be determined based on factors such as body type, height, and weight...</p>	<p>3</p>	<p>Body shape</p>				

Table 4.2 continued

<p>If it's a fit garment, there will be a significant disparity in the fit when wearing it if the difference exceeds 2cm...It also depends on the style. For example, the hem is ribbed....</p>	<p>3</p>	<p>Style</p>				
<p>...First, the basic sample is made, and adjustments are made to each part based on the fitting effect, ensuring a better fit in the future... For customization, it involves fitting sessions, usually with a basic sample... For unique body types, we have a fitting process, typically starting with a basic sample to fit the dummy...</p>	<p>4</p>	<p>Fitting process</p>		<p>Prototype fitting</p>		

Table 4.2 continued

<p>...For experienced pattern makers, they generally have a rough idea in their minds... It all comes down to the experience of both the pattern maker and the measurer... Pattern making often relies heavily on visual judgment, which is quite subjective... The rules of variation are based on experience rather than body measurements... It relies on aesthetic sense and years of experience...</p>	<p>6</p>	<p>Experience</p>		<p>Patternmaking experience</p>		
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Table 4.2 continued

<p>...In reality, it all boils down to the issue of labor... The labor force is not getting younger, and there are fewer young workers willing to enter this industry... In the factory labor sector, there is aging, with older workers unable to continue, and younger ones unwilling to join...</p>	<p>7</p>	<p>Labor</p>		<p>Aging workforce</p>		
<p>...Although there are many templates and automation technologies now, many aspects still cannot replace manual craftsmanship, such as trimming, ironing, shrinking, stretching, and so on. These are aspects where automated equipment cannot effectively standardize the process...</p>	<p>2</p>	<p>Inheritance of handcrafting techniques</p>		<p>Technology inheritance and innovation</p>	<p>Issues in men's wear production</p>	<p>Technical challenges</p>

Table 4.2 continued

<p>...Innovations in materials or craftsmanship... Digitalization is very timely and more suitable for small-scale production... Optimizing the technical issues encountered in production...</p>	<p>9</p>	<p>Innovation in fabrics and techniques</p>				
<p>...Once many patterns are finalized, there isn't much that needs to be changed, except for various collar styles. In such cases, could modularization be implemented?... Breaking down a piece of clothing into components, with each component related to a specific process...</p>	<p>3</p>	<p>Modular production of patterns</p>				
<p>...Popularizing awareness of style and aesthetics...</p>	<p>1</p>	<p>Aesthetics perception</p>		<p>Popularization of aesthetic perception</p>		

Table 4.2 continued

<p>...We currently don't use 3D body models because their practicality isn't great; if used in production, efficiency wouldn't be very high... Currently, it's not applicable to the production process; it's mainly used for display purposes... Its line variations cannot be used for production; it's all design-oriented, not practical for production... It's cumbersome to use if not familiar with new software... It still requires experimentation; it may take time to adapt...</p>	<p>17</p>	<p>Inapplicability</p>		<p>Application of 3D technology</p>		
<p>3D pattern making is definitely more intuitive...3D technology might be more convenient when it comes to the pattern adjustment...</p>	<p>4</p>	<p>Intuitiveness</p>				

- **Factors Influencing Fit**

A qualitative analysis was conducted on the interview content to identify the factors affecting the fit in FC. The keywords that exerted a significant influence on the concept of fit were identified by applying coding and content analysis. Additionally, the reference points for each level of code were established. Using these reference points, the influence weights of each factor affecting the fit and their relationships were confirmed.

The supporting frequency of each keyword within each coding level was calculated based on the number of reference points linked with that level of coding. The relative importance of each keyword affecting fit was determined by calculating its proportion among all keywords, based on its supporting frequencies. The two primary factors influencing garment fit are the proportional distribution of these keywords, body measurement, and pattern-making. These key factors, alongside the specific sub-factors affecting each, are illustrated in Figure 4.2. The sankey diagram produced by Application Chiplot clearly illustrates the influencing factors across multiple hierarchical levels, as well as the magnitude of impact associated with each factor.

As illustrated in Figure 4.2, the factors influencing the fit in FC are body measurement and pattern. Many sub-factors influence body measurement and patterns, a topic that is discussed in detail below.

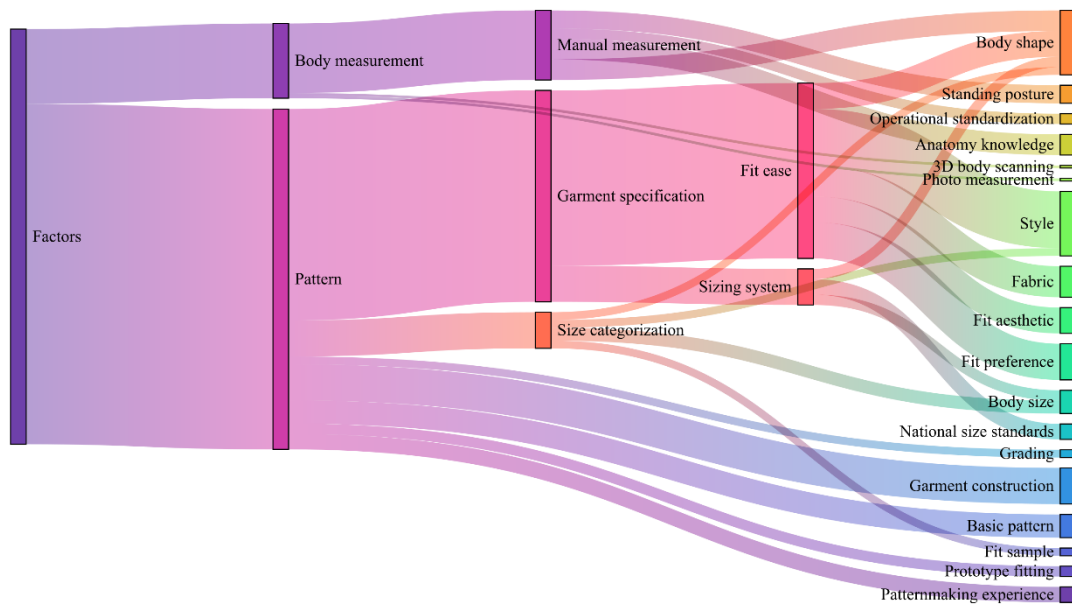


Figure 4.2: Sankey Diagram of Factors Affecting the Fit

Body Measurement

The primary factor influencing the fit of a garment is body measurement. As demonstrated in Figure 4.2, manual measurement remains the predominant approach for acquiring body dimensions, despite the existence of technologies such as 3D scanning and photo measurement. These technologies are currently used by only a limited number of companies. During the body measurement process, the subject's posture and body type, as well as the measurer's adherence to standard procedures, significantly impact the accuracy of the body data, particularly the measurer's understanding of body types. Consequently, identifying the reference points for body measurement and extracting body surface data according to different body types are the most critical issues in body measurement.

Pattern-Garment Specification

As illustrated in Figure 4.2, the fit of garment patterns is primarily influenced by several key factors, including garment specifications, size categorization, garment construction, basic patterns, grading, and pattern-making experience. It is evident that the garment specification exerts the greatest influence on the fit of the pattern. The sizing system and fit ease are the most prominent factors that contribute to garment specifications.

Initially, regarding the sizing system, it is important to note that body size and shape are essential in establishing the sizing system, which serves as the foundational element for garment specifications. Enterprises can establish their own standards in accordance with market demand and national sizing standards. Presently, the implementation of the sizing system is predominantly observed in garment production and end sales, focusing on enterprises operating within the clothing industry. However, consumers have limited knowledge of the sizing system, and few can match their body type with the appropriate clothing size, leading to difficulties in selecting well-fitting garments.

Secondly, the most significant and variable factor affecting garment specifications is fit ease. The ease of a garment directly affects its fit, comfort, and aesthetic appeal. As demonstrated in Figure 4.3, statistical evidence indicates that the primary factors

influencing the design of garments intended for a specific fit are the style of the garment, the fabric used, the body shape of the wearer, the fit preferences, and the company's fit aesthetic. The finding challenges linear sizing paradigms. Hence, fit ease is not merely a technical calculation but a cultural negotiation. Cross-cultural studies (e.g., Zakaria & Ruznan, 2020) reveal that Chinese consumers prioritize ‘modest’ ease (masking body contours) compared to Western ‘fitted’ silhouettes. This cultural preference may explain why ‘fit aesthetic’ emphasizes ‘optimizing’ proportions over anatomical precision. Similarly, generational divides emerge: younger interviewees referenced ‘streetwear-inspired’ looseness, whereas older technicians adhered to traditional tailoring norms. Such tensions suggest that FC must consider shifting aesthetic paradigms.

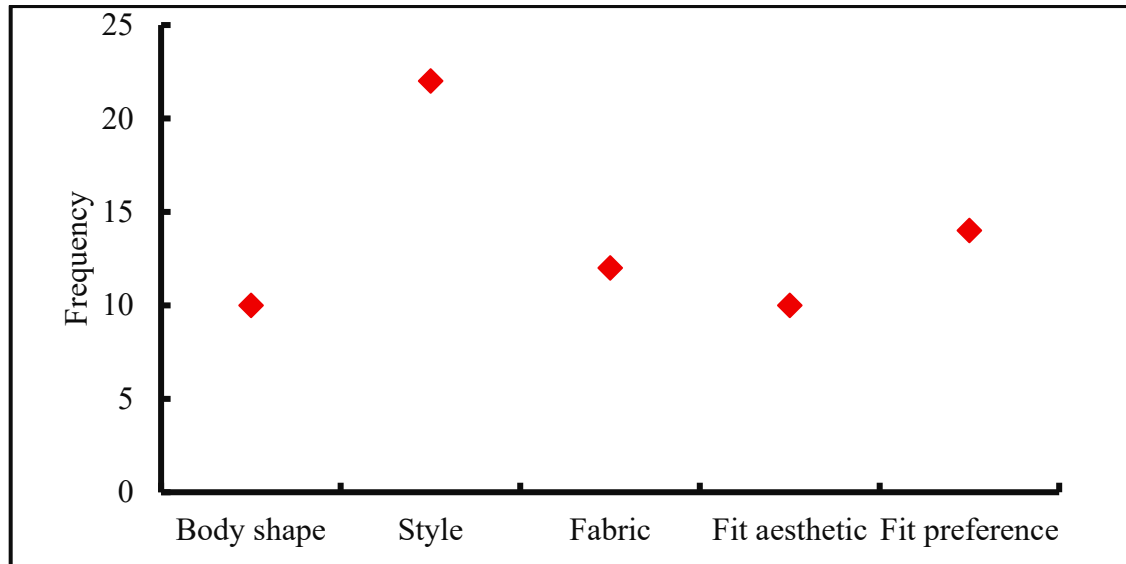


Figure 4.3: Hierarchical Influences on Fit Ease

Garment style represents the most immediate and influential factor in determining fit ease, as each style requires a specific ease allowance to achieve its intended silhouette

and aesthetic qualities. Furthermore, fabric properties, including elasticity, shrinkage, thickness, and compatibility with trims and accessories, also play a critical role in ease allowance design, as these characteristics directly affect the structural behavior of the garment and its pattern construction. Variations in body shape further complicate the process of determining appropriate ease allowances. This is partly because pattern design aims not merely to replicate the body's dimensions but to optimize and refine its visual appearance, masking potential imperfections rather than highlighting them. Body shape is arguably the most complex variable, as individuals with identical chest circumferences may require significantly different allowances due to variations in other dimensions, such as arm girth, which consequently affect chest and shoulder ease requirements. Additionally, consumer perceptions of fit and style are highly subjective and may not always correspond with the brand's fit standards or design intentions.

Therefore, the design of fit ease must result from a comprehensive consideration of fabric behavior, individual body morphology, consumer expectations, and aesthetic principles, to achieve both functional comfort and stylistic coherence.

Pattern- Size Categorization

Size categorization represents a critical phase in fit customization, significantly affecting pattern fit. During this process, companies adopt various approaches depending on garment style and body morphology. A widely employed method involves categorizing

sizes for standard body types based on body measurements and morphology, typically aligned with national sizing standards. To improve efficiency, many companies have developed proprietary software systems to automate the size categorization process. In contrast, for individuals with non-standard body shapes, size categorization often depends on using fit samples to determine the most suitable size classification. The accuracy and validity of size categorization play a crucial role in determining pattern fit quality. Figure 4.4 illustrates the multifaceted factors influencing size categorization, which is influenced not only by objective data such as body measurements and body shape, but also by the effects of style characteristics and fit sample performance, both of which are further shaped by aesthetics and individual preferences.

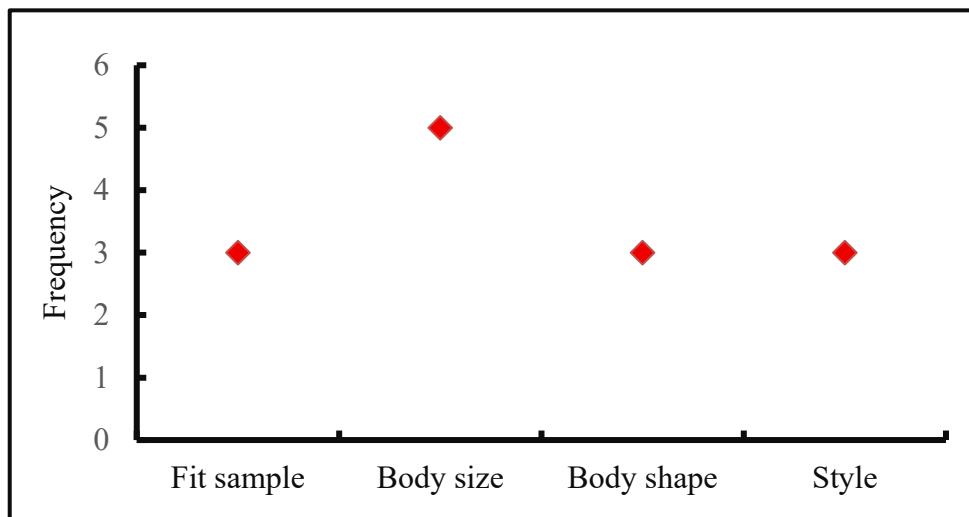


Figure 4.4: Hierarchical Influences on Size Categorization

Pattern- Garment Construction

Garment construction refers to the techniques employed in the sewing process, including pressing, shaping, and ironing. The execution of these techniques requires a high level of skill and experience. Through the series of processes involved, the garment pattern's comfort and fit are substantially improved. During the production process, the use of templates has effectively reduced the complexities associated with sewing methods and enhanced the quality of the final product. However, it is essential to acknowledge that manual techniques, despite advancements in machinery, remain indispensable in this context. These techniques result from years of accumulated professional knowledge and experience by craftsmen. However, due to the aging workforce, the transmission of these techniques to future generations faces various challenges.

Pattern- Basic Patterns

Basic patterns are widely used in FC. This method supports the rapid generation of customized patterns by altering precise measurements according to a standard template. The utilization of fundamental patterns has been shown to improve efficiency and accuracy, making it particularly suitable for application in FC production models. However, since each company holds a distinct market position, its fundamental patterns vary, consequently producing different levels of fit.

Pattern- Grading

Grading constitutes an essential production step in manufacturing group-customized apparel, with the potential to affect the fit of the pattern. A greater number of sizes in the grading process is associated with an increased risk of pattern inaccuracies. Furthermore, in specific areas such as the armholes and neckline, grading can produce imprecise measurements, resulting in poor fit. The grade rule constitutes a critical element within the grading process. An inadequate grade rule design may increase production costs or reduce pattern accuracy.

Pattern- Prototype Fitting

Prototype fitting has been identified as the most common and effective method for adjusting pattern fit within companies. For unique body types, companies often use mannequins to fit prototype garments made from muslin, thereby refining the pattern. Despite the adoption of 3D fitting technology by some companies, discrepancies remain between digital body models and actual production needs, hindering its widespread use in the production process. Prototype fitting has been demonstrated to be the most effective approach for improving the quality of patterns.

- **Issues in Actual Production**

The primary challenges encountered in practical production can be categorized into four distinct aspects: As shown in Table 4.2, the following factors are involved: the aging workforce, technology inheritance and innovation, the popularization of aesthetic

perception, and the use of 3D technology.

As illustrated in Table 4.4, the aging workforce and the inheritance and innovation of techniques are two major concerns for technicians. In the context of an aging workforce, the preservation of traditional handcraft techniques is a pressing concern, as these methods represent a significant part of the industry's heritage. The transfer of these skills to the next generation poses a universal challenge within the sector. The aging workforce crisis reflects deeper systemic issues in labor valuation. This elucidates the underlying reasons why the inheritance of handcraft techniques remains an uncertain process. In contradistinction to the CAD training, tailoring expertise eludes such systematic instruction. Interviews revealed that older workers linked declining interest to precarious wages, underscoring how FC's technological progress may inadvertently erode the craftsmanship it relies upon for high-end customization.

Concurrently, innovation in fabrics and techniques is a primary focus. The ability to master the physical and chemical properties of textiles is instrumental in ensuring precise control over garment dimensions and patterns. In terms of technological innovation, the optimization of technical problems encountered in production and the advancement of processes are of paramount importance. Additionally, there is a necessity for the comprehensive improvement of digital and automation technologies to support the intelligence of the entire production process. Furthermore, the dissemination of aesthetic perception is important for pattern makers.

When discussing the application of 3D technology, two divergent viewpoints emerge. The prevailing opinion among researchers is that 3D technology is not suitable for practical applications due to several factors. These include inaccuracies in body measurements during 3D scanning, incompatibility with other production systems, discrepancies between virtual models and real body shapes in 3D fitting systems, and inadequate simulation of fabric behavior. These limitations render it impractical for actual production. A minority of respondents expressed a favorable view of the visual clarity of 3D pattern making, though they acknowledged the necessity of time to adapt to the new technology. Consequently, the applicability and compatibility of digital technology remain the most salient issues.

4.3.2 Results and Discussion

Through in-depth interviews with apparel professionals and detailed analysis of the interview data, it was determined that the fit of apparel is primarily influenced by body measurements and pattern, which are, in turn, affected by various factors, including apparel styles and fabrics, body shape, fit aesthetics, and production technology. The preceding data analysis is herein summarized in Figure 4.5, which outlines the factors affecting garment fit and the technical requirements.

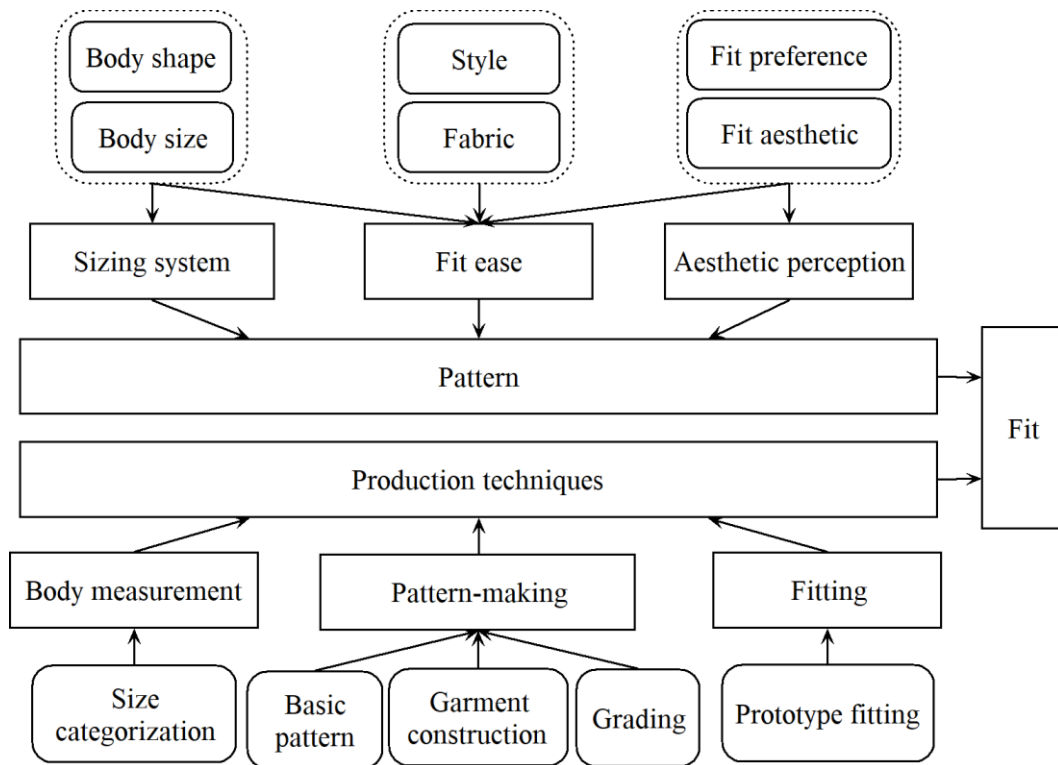


Figure 4.5: Summary of Factors Affecting Garment Fit

The application of 3D technology and technology inheritance and innovation, and the aging workforce additionally are major issues in actual production, which was also substantiated by previous case study investigations. Hence, for these technologies to be effective, they must provide technological accuracy, functionality, authenticity, practicality, and convenience. Moreover, aesthetic perception is connected to embodiment theory (Entwistle, N. J., 2000), which examines how clothing mediates body perception and cultural ideals of fit.

Although there are numerous studies on fit preferences (Ashdown, 2014;

Hernández et al., 2018), body shape (Pandarum et al., 2020; Zakaria & Ruznan, 2020), and fit ease (Hidellaarachchi et al., 2018; Park et al., 2017), the investigation in this study reveals that the following issues still persist in actual enterprise production, presenting potential directions for future research.

i. Body measurements are essential for garment fit. The most important factor in guaranteeing data accuracy, whether via manual measurement or non-contact anthropometry, is a thorough understanding of human anatomy and the precise identification of important body measurement locations. In practice, locating the seventh cervical vertebra point, shoulder endpoints, armpit points, and crotch points has proven to be quite difficult with non-contact measurement. Furthermore, the 3D body models obtained by 3D body scanners are not suitable for direct use in fitting or pattern-making. Another dilemma that requires resolution is the ease of processing 3D body models and their compatibility with real-world production patterns.

ii. The sizing system is among the key elements. Body size and shape serve as the foundation for sizing systems. Developing detailed standards and methods for body type classification appropriate for pattern structure processing is crucial for establishing a size system for clothing companies. To resolve fit difficulties with the neckline and armhole during grading, greater emphasis should be placed on the morphology of the neck and shoulder-arm junction. Additionally, the overall coordination of the upper and lower body based on aesthetic principles, as well as occupation and age, should be considered in the

sizing system. It is necessary to adopt a reasonable standard and method in size design to balance production and market demands. Moreover, by assigning body measurements to the proper garment specifications, the sizing system forms the basis for size categorization, which has a significant impact on fit. This approach to size categorization may assist customers in selecting the appropriate garment size.

iii. Although fit ease is important for clothing patterns, the amount of ease added varies according to several factors, including body type, style, fabric, and fit aesthetics. The goal of clothing is to enhance the human body rather than emphasize its imperfections. Clothing firms primarily do this by designing ease allowances based on the aesthetic judgment and experience of technicians. Therefore, a quantitative study on the relationships among style, fit aesthetics, fabric, body shape, and consumer preferences should be conducted further to provide a theoretical foundation for the design of garment fit ease, aiming to improve fit aesthetics and accommodate a broader range of body types.

iv. The technology that generates personalized patterns based on basic patterns is widely used in companies. However, the pattern's inclusivity, which is difficult to quantify in actual production, is determined by the variation between patterns of special body types and fundamental patterns. The theoretical approaches for individualized pattern generation based on fundamental patterns require further investigation. Furthermore, although 3D pattern-making technology has not yet been applied in practical production, it still needs to

be verified for accuracy and suitability for FC based on research on 3D body models, fabric properties, and fit ease.

v. Fitting is an important method to improve the fit of clothing. For mannequin fittings, accurately producing human body models can considerably enhance fitting accuracy. Additionally, for virtual fitting technology, the creation of 3D human models suitable for different age groups and populations, as well as the realistic simulation of various physical and chemical properties of fabrics, are key factors influencing the applicability of fitting software in industrial production. This has consistently been a major focus and challenge in research.

4.4 Chapter Summary

FC is a critical point in the implementation of MC. There has always been an emphasis on how to manage FC and enhance its implementation in a flexible and efficient manner using advanced technologies. This study investigated two Chinese apparel industries that have successfully implemented MC and interviewed clothing technical professionals. By analyzing the survey data, the study demonstrates how advanced technologies support the implementation of FC and identifies the factors affecting FC during the production process from the perspective of professionals.

This chapter's findings, from the technological gaps in 3D adoption (Objective 1) to the multifactorial influences on fit (Objective 2), collectively address RQ1. The

promising strategy of 3D-based sizing systems emerges not as a silver bullet but as a contingent solution: it bridges measurement-pattern gaps yet depends on resolving the socio-technical barriers identified in Sections 4.2–4.3. This tension sets the stage for Chapter 5’s quantitative testing of pattern accuracy from the 3D human body.

The key details are summarized as follows:

i. The Current Status of Existing Technology Utilization

In defining FC, FC is increasingly conceptualized as the level of flexibility offered to customers, encompassing physical fit and functional performance. Therefore, the adoption of advanced technologies plays a crucial role in improving both the efficiency and flexibility of FC implementation. According to the findings of this study, technologies are being increasingly integrated into apparel production processes to support more effective and adaptive FC practices. Notable improvements have been made in the application of technology for quality control and production efficiency, particularly in the cutting, sewing, and warehousing stages. Technologies such as RFID and barcode tracking systems are employed to monitor and manage the flow of materials and garments throughout the production process.

However, the use of technologies such as 3D body scanning, 3D pattern design, and virtual fitting remains limited in the stages of body data acquisition and pattern development. This is largely due to the complexity of human body morphology and fabric

properties, the low interoperability between 3D body processing and pattern-making technologies, and the limited integration of these technologies with current FC models. Consequently, further research and development are required to achieve a transformative technological advance, from body measurement to pattern generation to fitting simulation. Once these technological barriers are overcome, the cost and waste associated with physical fitting processes will be substantially reduced, and FC will be promoted as a genuinely sustainable and eco-friendly production approach.

ii. Factors Influencing Garment Fit

Through in-depth analysis and discussion of interview data, it is found that the pattern is the most direct factor affecting garment fit. The pattern itself is influenced by multiple elements, including the sizing system, fit ease, and fit aesthetics. Within the current FC models, the design of the basic pattern is fundamental. Therefore, key considerations in basic pattern construction include: the rational classification of body types, the optimization of sizing systems, and the incorporation of garment style and fit aesthetics into the design of ease allowance.

At the body measurement stage, the identification of anatomical landmarks and accurate dimensional measurement based on these key points is critical. During the sizing system design stage, scientifically grounded body-type classifications must be established based on key anthropometric indicators. For fit ease design, factors such as style, fit

aesthetics, fabric characteristics, and individual body shape should be carefully considered when developing the ease of the basic pattern.

Although the application of virtual fitting technologies is currently limited in apparel companies, primarily due to discrepancies between virtual human models and real body shapes, as well as between simulated and actual fabric properties, technical professionals in the industry remain optimistic about the potential of 3D pattern design and virtual fitting technologies. Once current technical bottlenecks are addressed, the integration of 3D body-based pattern design and virtual fitting is expected to bring about a transformative improvement in both garment fit and production practices.

The findings contribute to the practical understanding of FC implementation from body measurement to pattern-making procedures through real manufacturing in the apparel industry. On the one hand, it highlights the challenges still faced in the implementation of FC in the clothing industry. On the other hand, a promising strategy for enhancing FC practices has clearly emerged: designing sizing systems based on body type classification, generating basic patterns from 3D body models, developing personalized patterns derived from these basic templates, and ultimately conducting virtual fittings based on real human bodies. This investigation lays a solid foundation for subsequent quantitative research.

CHAPTER 5

PERSONALIZED PATTERN GENERATION

5.1 Introduction

This chapter presents a quantitative analysis of body measurements and discusses the findings related to the second research objective: (i) classifying body shapes and examining the relationship between body size, shape, and fit, and (ii) investigating the association between body shape and patterns to develop a parametric personalized pattern generation approach based on pattern blocks derived from 3D body models.

This chapter is structured into two sections. The first section focuses on the result of body shape classification, which employs 3D body scanning and statistical modeling to establish a data-driven body shape classification framework. The second section addresses the pattern blocks creation based on 3D body model and the parametric personalized slim fit men's shirt patterns generation for individuals with distinct body shapes based on pattern blocks.

This chapter provides a practical solution for the second research objective through quantitative analysis, and is also the core of this research for solving problem that how to incorporate 3D body data collected from 3D body scanning into patternmaking procedures to improve fit in MC.

5.2 Body Type Classification

5.2.1 Analysis of the Body Measurements

To analyze body measurements and classify body shapes, the following analytical steps will be undertaken. To ensure the normal distribution of each body measurement, outliers were detected and eliminated from the dataset covering 42 body measurements as a preliminary data-cleaning step. First, a descriptive analysis will be performed to provide an overview of the basic characteristics of the anthropometric data, including measures such as the mean, standard deviation, maximum, and minimum values. Next, correlation analysis will be conducted to examine the relationships between variables, serving as a basis for subsequent regression analysis. Following this, factor analysis will be used to identify latent variables that account for specific variations in body morphology. Based on the extracted factors, the K-means clustering method will be employed to classify body shapes and establish a body type database. An F-test will be applied to assess the validity of the clustering results; classifications will be considered statistically significant when the p-value is less than 0.05. Finally, regression analysis will be used to predict the proportional relationships among different body regions based on the classified body types.

- **Descriptive Analysis**

Descriptive analysis of 42 body measurements (Table 5.1) revealed that the average body height was 175.1964 cm, and the average chest circumference was 92.12145 cm,

indicating the general body size of the sample population. The mean values of key body measurements were used as the basis for developing the standard size.

In addition, there was significant variability in chest girth (G1), waist girth (G2), and body height (L1) with standard deviations of 7.7 cm, 7.4 cm, and 6.85 cm, respectively. This underscores the challenge of achieving a uniform fit across populations and justifies the need for body shape classification. Notably, the low variability in neck base width (W12) suggests it could serve as a stable reference for pattern adjustments. In contrast, the high variability in abdominal girth (G5) highlights the necessity of adaptive dart placement in pattern blocks.

- **Correlation Analysis**

After the descriptive analysis, a correlation analysis was conducted, as shown in the tables. Pearson correlation coefficients ranging from 0.6 to 1.0 indicate a strong relationship, those between 0.4 and 0.6 indicate a moderate relationship, and those below 0.4 are considered weak correlations. Tables 5.2, 5.3, 5.4 and 5.5 present strong correlations (Pearson coefficient > 0.6) among height-related, girth-related, and width-related measurements.

An analysis of Table 5.2 reveals that the height of the seventh cervical vertebra (L2), the bust point height (L3), arm length (L6), height of shoulder blades (L11), the front neck point height (L13), and upper arm length (L18) are strongly correlated with body

height (L1); however, they are not strongly associated with the anterior or posterior torso morphology. Hence, incorporating such correlations into parametric models could improve the quick response by automatically calculating the dimensions relative to body height.

Hip height (L5), knee height (L8), and abdominal prominence height (L15) are strongly correlated with waist height (L4) and the waist-to-height ratio (R1). Back waist curvature height (L12) and crotch height (L7) are strongly correlated with waist height (L4). The inclusion of R1 thus plays a significant role in enhancing the fit of lower-body garments.

The back length (L14) shows the strongest correlation with back waist length (L10) as shown in Table 5.3. It is also strongly correlated with cervical vertebra height (L2), body height (L1), and the length from the horizontal position of the back armpit point to the waistline (L20). Likewise, front waist length (L21) demonstrates stronger correlations with the side neck point to the bust point (L17) and the front center to the waistline (L22) than other height-related measurements. This indicates that these measurements, in addition to being influenced by body height, are more significantly affected by the shape of the anterior and posterior upper body. Therefore, incorporating an analysis of the front and back upper body shapes into size design can contribute to improved fit of upper-body garment patterns.

Table 5.1: Descriptive Analysis for the Body Measurements

No.	Labels	Mean	Standard Deviation	Variance	Skewness		Kurtosis	
					Statistics	Standard Error	Statistics	Standard Error
1	L1	175.1964	6.851001	46.93621	0.280069	0.121269	0.012203	0.241951
2	L2	148.5734	6.278635	39.42126	0.275975	0.121417	-0.05105	0.242246
3	L3	126.242	5.511614	30.37789	0.214621	0.121567	0.090286	0.242543
4	L4	108.3231	4.920045	24.20684	0.201137	0.121567	-0.03575	0.242543
5	L5	86.63395	4.53464	20.56296	0.208466	0.121717	-0.11451	0.242841
6	L6	58.53554	3.439816	11.83234	0.088968	0.121417	-0.05506	0.242246
7	L7	75.73795	4.439519	19.70933	0.164393	0.121567	0.299155	0.242543
8	L8	46.17787	2.415908	5.836613	0.209286	0.121717	-0.11515	0.242841
9	L10	44.81376	2.271189	5.1583	0.084845	0.121269	-0.26741	0.241951
10	L11	132.5632	6.730545	45.30024	0.119524	0.12112	0.308084	0.241656
11	L12	101.0665	4.837684	23.40319	0.131413	0.121567	-0.01312	0.242543
12	L13	142.7794	6.057623	36.69479	0.215759	0.121417	-0.06909	0.242246
13	L14	41.3361	1.947865	3.794177	0.128455	0.121269	-0.37611	0.241951
14	L15	101.2951	5.037205	25.37344	0.256219	0.121717	0.019169	0.242841

Table 5.1 continued

15	L17	26.50077	2.015194	4.061008	0.154817	0.121567	0.186844	0.242543
16	L18	33.72691	1.858187	3.452859	-0.23154	0.120825	0.427313	0.24107
17	L19	22.87602	2.229975	4.972791	-0.06552	0.121567	-0.21343	0.242543
18	L20	22.82274	2.140011	4.579647	-0.01917	0.121867	-0.0344	0.24314
19	L21	45.31578	2.519028	6.3455	0.161547	0.125657	-0.03625	0.250662
20	L22	36.04586	2.365421	5.595219	0.175805	0.120972	-0.09931	0.241363
21	W1	41.33396	2.576499	6.638345	0.007624	0.12217	-0.26065	0.243741
22	W2	35.84072	3.059527	9.360704	0.352563	0.121717	0.333789	0.242841
23	W3	42.0338	3.355303	11.25806	0.138338	0.121417	0.31654	0.242246
24	W4	35.59542	4.385178	19.22979	0.293849	0.121567	0.678966	0.242543
25	W5	14.06249	1.178043	1.387784	0.042849	0.121717	0.038944	0.242841
26	W6	10.68597	1.392258	1.938382	0.358055	0.121717	0.00147	0.242841
27	W12	13.01171	0.903542	0.816388	0.138248	0.121269	-0.08141	0.241951
28	W13	19.6371	1.514587	2.293973	0.257136	0.121717	0.293105	0.242841
29	G1	92.12145	7.7007	59.30078	0.280363	0.122019	0.190999	0.24344
30	G2	76.72579	7.423107	55.10251	0.398231	0.122783	0.079863	0.244957

Table 5.1 continued

31	G3	94.95325	5.766782	33.25577	0.109348	0.12217	0.058671	0.243741
32	G4	41.17646	2.168809	4.703732	0.189485	0.122019	-0.09903	0.24344
33	G5	80.68608	7.873279	61.98852	0.471927	0.122475	0.20876	0.244347
34	G6	82.15719	4.769507	22.7482	0.247998	0.122322	0.273768	0.244043
35	G7	53.59739	4.518872	20.4202	0.11484	0.122322	-0.05541	0.244043
36	G8	36.83783	2.43452	5.926889	0.15691	0.122629	0.193756	0.244651
37	G9	27.17715	2.614575	6.836	0.18105	0.121567	0.012208	0.242543
38	G10	83.51282	6.409727	41.0846	0.341536	0.123092	0.216539	0.245572
39	A1	24.89424	3.862964	14.92249	-0.15869	0.121417	-0.09687	0.242246
40	A4	17.70796	3.800449	14.44341	-0.08439	0.121417	0.32417	0.242246
41	D11	7.692979	2.231335	4.978855	0.033841	0.121867	-0.00947	0.24314
42	R1	0.61845	0.008992	8.09E-05	-0.42517	0.121417	1.169444	0.242246

An analysis of Table 5.4 shows that among the girth measurements, bust girth (G1) is strongly correlated with all other girth dimensions except for neck base girth (G4). In addition, the correlation analysis revealed that shoulder width (W1) and bust girth (G1) exhibit a strong positive relationship ($r = 0.72$), indicating that broader shoulders often accompany larger chest circumferences. This finding challenges traditional pattern-making assumptions, which treat these dimensions independently. For FC applications, integrating such correlations into parametric models could improve torso fit by automatically scaling shoulder width in relation to chest girth.

The neck base girth (G4) shows a strong correlation with the lateral neck point distance (W12), and also correlates strongly with waist girth (G2), hip girth (G3), abdominal girth (G5), mid-hip girth (G10), and upper arm girth (G9)—all of which are closely related to body fat distribution.

Abdominal girth (G5) strongly correlates with waist girth (G2), and the distance between the vertical planes passing through the abdominal prominence and the front neck point (D11) shows the strongest correlation with waist width (W4). This suggests that variations in waist circumference can effectively reflect the shape of the abdominal area.

Back width (W2) shows good correlations with shoulder width (W1), bust girth (G1), and upper arm girth (G9). This indicates that back width is not only influenced by chest circumference, as assumed in traditional methods, but is also affected by arm girth

and shoulder width. Incorporating these two factors into pattern adjustments can further improve the fit of garments in the shoulder and chest areas.

Conversely, the two angular terms, A1 and A4, exhibit weak correlations with all other measurements. Therefore, they are not included in Tables 5.2, 5.3, 5.4 and 5.5. The weak correlation between angular measurements (A1, A4) and linear dimensions suggests that posture-related adjustments such as shoulder slope should be addressed separately in pattern fitting.

Table 5.2: Correlation Analysis of the Hight (a)

Pearson r	L1	L2	L3	L4	L5	L6	L7	L8	L10	L11
L1	1	0.985**	0.943**	0.950**	0.875**	0.717**	0.852**	0.875**	0.702**	0.871**
L2	0.985**	1	0.956**	0.962**	0.894**	0.713**	0.867**	0.894**	0.735**	0.878**
L3	0.943**	0.956**	1	0.973**	0.886**	0.671**	0.854**	0.886**	0.606**	0.845**
L4	0.950**	0.962**	0.973**	1	0.962**	0.708**	0.891**	0.962**		0.843**
L5	0.875**	0.894**	0.886**	0.962**	1	0.699**	0.877**	1.000**		0.772**
L6	0.717**	0.713**	0.671**	0.708**	0.699**	1	0.665**	0.699**		
L7	0.852**	0.867**	0.854**	0.891**	0.877**	0.665**	1	0.877**		0.797**
L8	0.875**	0.894**	0.886**	0.962**	1.000**	0.699**	0.877**	1		0.772**
L10	0.702**	0.735**	0.606**						1	0.619**
L11	0.871**	0.878**	0.845**	0.843**	0.772**		0.797**	0.772**	0.619**	1
L12	0.895**	0.905**	0.880**	0.911**	0.882**	0.676**	0.949**	0.882**		0.830**
L13	0.963**	0.965**	0.947**	0.950**	0.879**	0.679**	0.819**	0.879**	0.657**	0.859**
L14	0.729**	0.757**	0.621**						0.946**	0.626**
L15	0.827**	0.844**	0.842**	0.920**	0.964**	0.667**	0.825**	0.964**		0.708**
L18	0.800**	0.793**	0.738**	0.753**	0.708**	0.698**	0.666**	0.708**	0.633**	0.675**

Table 5.2 continued

L19									0.669**	
L20									0.720**	
L21	0.622**	0.621**								
R1				0.621**	0.673**				0.673**	

Table 5.3: Correlation Analysis of the Hight (b)

Pearson r	L12	L13	L14	L15	L17	L18	L19	L20	L21	L22
L1	0.895**	0.963**	0.729**	0.827**		0.800**			0.622**	
L2	0.905**	0.965**	0.757**	0.844**		0.793**			0.621**	
L3	0.880**	0.947**	0.621**	0.842**		0.738**				
L4	0.911**	0.950**		0.920**		0.753**				
L5	0.882**	0.879**		0.964**		0.708**				
L6	0.676**	0.679**		0.667**		0.698**				
L7	0.949**	0.819**		0.825**		0.666**				
L8	0.882**	0.879**		0.964**		0.708**				

Table 5.3 continued

L10		0.657**	0.946**			0.633**	0.669**	0.720**		
L11	0.830**	0.859**	0.626**	0.708**		0.675**				
L12	1	0.867**		0.817**		0.706**				
L13	0.867**	1	0.689**	0.834**		0.750**			0.680**	0.622**
L14		0.689**	1			0.634**	0.654**	0.726**	0.647**	
L15	0.817**	0.834**		1		0.674**				
L17					1				0.823**	0.659**
L18	0.706**	0.750**	0.634**	0.674**		1				
L19			0.654**				1	0.929**		
L20			0.726**				0.929**	1		
L21		0.680**	0.647**		0.823**				1	0.877**
L22		0.622**			0.659**				0.877**	1
R1				0.645**						
W1									0.612**	
G3					0.646**				0.631**	
G5					0.644**					

Table 5.3 continued

G6									0.636**	
G10					0.637**					

Table 5.4: Correlation Analysis of the Girth

Pearson r	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	D11
L17			0.646**		0.644**					0.637**	
L21			0.631**			0.636**					
W1	0.722**	0.655**	0.654**	0.638**	0.661**	0.604**	0.633**		0.701**	0.624**	
W2	0.657**								0.665**		
W4											0.585**
W6	0.839**	0.736**	0.712**		0.717**		0.764**	0.611**	0.782**	0.661**	
W12				0.763**					0.608**		
W13	0.837**	0.718**	0.680**		0.713**	0.648**	0.694**		0.719**	0.640**	
G1	1	0.754**	0.705**		0.747**	0.631**	0.754**	0.629**	0.765**	0.656**	
G2	0.754**	1	0.835**	0.653**	0.966**		0.826**	0.745**	0.724**	0.900**	

Table 5.4 continued

G3	0.705**	0.835**	1	0.648**	0.888**	0.681**	0.896**	0.779**	0.738**	0.914**	
G4		0.653**	0.648**	1	0.659**				0.609**	0.635**	
G5	0.747**	0.966**	0.888**	0.659**	1	0.640**	0.851**	0.775**	0.720**	0.951**	
G6	0.631**		0.681**		0.640**	1	0.636**	0.648**	0.606**		
G7	0.754**	0.826**	0.896**		0.851**	0.636**	1	0.803**	0.796**	0.823**	
G8	0.629**	0.745**	0.779**		0.775**	0.648**	0.803**	1	0.648**	0.747**	
G9	0.765**	0.724**	0.738**	0.609**	0.720**	0.606**	0.796**	0.648**	1	0.668**	
G10	0.656**	0.900**	0.914**	0.635**	0.951**		0.823**	0.747**	0.668**	1	
D11											1

Table 5.5: Correlation Analysis of the Width

Pearson r	W1	W2	W3	W4	W5	W6	W12	W13
L21	0.612**		0.582**					
W1	1	0.680**			0.761**		0.610**	0.755**
W2	0.680**	1						0.639**

Table 5.5 continued

W3			1	0.656**				
W4			0.656**	1				
W5	0.761**				1			
W6						1		0.706**
W12	0.610**						1	
W13	0.755**	0.639**				0.706**		1
G1	0.722**	0.657**	0.591**			0.839**		0.837**
G2	0.655**					0.736**		0.718**
G3	0.654**					0.712**		0.680**
G4	0.638**						0.763**	
G5	0.661**					0.717**		0.713**
G6	0.604**							0.648**
G7	0.633**					0.764**		0.694**
G8						0.611**		
G9	0.701**	0.665**				0.782**	0.608**	0.719**
G10	0.624**					0.661**		0.640**

- **Factor Analysis**

Firstly, the obtained data were verified by a Kaiser-Meyer-Olkin (KMO) test and a Bartlett test. As shown in Table 5.6, the KMO value is greater than 0.8, and the p-value for the Bartlett's test is less than 0.1, indicating suitability for factor analysis.

Table 5.6: KMO and Bartlett's Test

KMO Measure of Sampling Adequacy		0.896
Bartlett's Test of Sphericity	Approximate Chi-square	30636.433
	Degrees of Freedom	861
	Significance	0.000

The total variance explanation is conducted to prepare for the factor analysis. The cumulative variance contribution rate of the first eight components is 85.5%, as indicated by the total variance explanation table 5.7. After analyzing the rotated component matrix, as shown in Table 5.8, summaries of eight factors can be obtained, as shown in Table 5.9: height factor, girth factor, back torso length above the waist, waist and abdomen, front torso length above the waist, shoulder width, shoulder tilt degree, and hip bulge. Based on the interpretation of total variance, it is evident that the first five elements account for 75.78301% of the cumulative explanation, particularly the height and girth factors, accounting for about 56% of the cumulative explanation.

Consequently, the primary category of human body shape is represented by the height and girth factors, while the secondary category is represented by the waist and abdomen, and the front and back torso length above the waist. The third category includes shoulder width, shoulder tilt degree, and hip bulge.

Classification variables for each index are determined based on the analysis of each factor. In the first indicators, height is identified as the classification variable of the height factor, and bust girth is identified as the classification variable of the girth factor. Through descriptive analysis, it is shown that the average height value is 175 cm, and the average bust girth value is 92 cm. Based on this, the interval for height is set at 5 cm, and the interval for bust girth is set at 4 cm. For example, the height “175” indicates that the height value range is greater than or equal to 173 cm and less than 178 cm. Bust girth “92” means that the bust girth value range is greater than or equal to 90 and less than 94.

For waist and abdomen morphological factors, abdominal bulge and waist width are the primary components. According to the definition of abdominal bulge, abdominal bulge reflects the degree of protrusion relative to the front neck point, and abdominal girth has a strong correlation with waist girth. Waist and abdomen morphological factors describe the relationship between the bust and the waist, abdomen, and buttocks. To better represent the upper body contour in terms of bust, waist, and hip girths, bust–waist difference and hip–bust difference were utilized as classification variables for waist and abdominal morphology.

Table 5.7: Total Variance Explanation

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Cumulative	Percentage of Variance	Cumulative %	Cumulative	Percentage of Variance	Cumulative %	Cumulative	Percentage of Variance	Cumulative %
1	17.3027	41.19691	41.19691	17.3027	41.19691	41.19691	12.22693	29.11173	29.11173
2	8.893633	21.17532	62.37222	8.893633	21.17532	62.37222	11.32756	26.97038	56.08211
3	2.906912	6.921218	69.29344	2.906912	6.921218	69.29344	3.854396	9.177134	65.25925
4	1.96406	4.676333	73.96978	1.96406	4.676333	73.96978	2.221186	5.288538	70.54778
5	1.350923	3.216484	77.18626	1.350923	3.216484	77.18626	2.198793	5.235222	75.78301
6	1.297779	3.08995	80.27621	1.297779	3.08995	80.27621	1.491011	3.550026	79.33303
7	1.141725	2.718392	82.9946	1.141725	2.718392	82.9946	1.308007	3.114301	82.44733
8	1.052575	2.506132	85.50073	1.052575	2.506132	85.50073	1.282428	3.053399	85.50073

Table 5.8: The Rotated Component Matrix a

	Component							
	1	2	3	4	5	6	7	8
L8	0.969824251							
L5	0.969812869							
L4	0.968806776							
L7	0.948443966							
L15	0.942407841							
L12	0.93105912							
L3	0.921486288							
L2	0.90832589							
L1	0.893705929							
L13	0.886565421							
L11	0.825939888							
L6	0.787143975							
L18	0.748299764							
R1	0.687142838							

Table 5.8 continued

G1		0.88763287						
W6		0.87439543						
G2		0.86261848						
G7		0.85609708						
G3		0.85414955						
G5		0.85050725						
W13		0.83490838						
G9		0.83365205						
G10		0.82196458						
G4		0.75774311						
G8		0.73778355						
W1		0.70876914				0.589307		
W12		0.70420518						
W2		0.7020282						
G6		0.68827936						
L17		0.58189027						

Table 5.8 continued

L20			0.882118928					
L19			0.849523406					
L10			0.742175099					
L14			0.73832462					
W4				0.83053909				
D11				0.657129984				
L22					0.779088			
L21		0.53173921			0.63803			
W3								
W5						0.825504		
A1							0.923351	
A4								0.855557
Extraction method: Principal Component Analysis.								
Rotation method: Varimax with Kaiser Normalization.								
a. Rotation Converged in 7 Iterations.								

Table 5.9: Factor Analysis

Categories	Factors	Components
Primary Indicator	Height	L8, L5, L4, L7, L15, L12, L3, L2, L1, L13, L11, L6, L18, R1
	Girth	G1, W6, G2, G7, G3, G5, W13, G9, G10, G4, G8, W1, W12, W2, G6, L17, L21
Secondary Indicator	Back Torso Length above the Waist	L20, L19, L10, L14
	Waist and Abdomen	D11, W4
	Front Torso Length above the Waist	L22, L21
Tertiary Indicator	Shoulder Width	W1, W5
	Shoulder Tilt Degree	A1
	Hip Bulge	A4

The back torso length above the waist factor includes the primary components, such as neck to waist center back, neck to waist back, and across back width (armpit level) to waist. For the front torso length above the waist factor, the main components are neck to waist front and neck to waist centre front. It is evident that these two factors mainly reflect two aspects: first, whether the upper body posture tends toward a protruding chest or a hunchbacked shape; and second, the length of the upper torso. Regarding the first aspect, combined with clothing pattern design, the difference between FWL and BWL was used to capture the variation in chest and back curvature and was applied as a classification variable for the "front torso length above the waist" factor. For the second aspect, the ratio of waist height to total height (R1) was introduced to indicate the upper torso length and was also applied as a classification variable for this factor.

Regarding the shoulder width factor, the concept of the ratio of shoulder width to height is introduced and used as the classification variable for the shoulder width morphological factor. For the shoulder tilt degree and hip bulge factors, the shoulder angle and the hip angle were separately employed as classification variables for each factor.

Through the above analysis, it can be observed that height and bust girth are regarded as the primary characteristics of body type, accounting for 56% of the variance. Bust-waist difference, hip-bust difference, BWF-FWL difference, and waist-to-height ratio are considered secondary characteristics, as shown in Table 5.10. These secondary factors were prioritized in the subsequent K-means clustering to ensure body types reflected dominant morphological trends. For instance, the 'waist and abdomen' factor (D1, D10)

guided segmentation of apple-shaped versus hourglass silhouettes. Shoulder-height ratio (R2), shoulder angle (A1), and hip angle (A4) are regarded as tertiary characteristics, allowing finer distinctions within clusters. This hierarchical approach aligns with FC needs, where primary and secondary dimensions drive block selection, and tertiary features refine fit.

Table 5.10: Characteristics of Body Type Classification

Categories	Factors	Lables
Primary Dimensions	Height	L1
	Girth	G1
Secondary Dimensions	Waist and Abdomen	D1
		D10
	Front and Back Torso Length above the Waist	D5
		R1
Tertiary Dimensions	Shoulder Width	R2
	Shoulder Tilt Degree	A1
	Hip Bulge	A4

- **Cluster Analysis**

Next, the values of these features are used as classification variables to perform K-means cluster analysis on the entire sample, and the cluster category with the highest classification accuracy is adopted through comparative analysis of multiple clustering results. The significance test of ANOVA is presented in Table 5.11. The optimal clustering categories and clustering centers of each classification variable are displayed in Table 5.12.

Table 5.11: Significance Test

ANOVA						
Lables	Clustering		Error		F	Significance
	Mean Square	Degrees of Freedom	Mean Square	Degrees of Freedom		
D1	1870.172	4	1.698	399	1101.466	0.000
D10	3621.724	2	3.749	398	965.946	0.000
D5	826.310	2	1.026	375	805.318	0.000
R1	0.013	2	0.000	401	753.763	0.000
R2	0.037	2	0.000	393	954.232	0.000
A1	2445.919	2	2.798	401	874.224	0.000
A4	2302.819	2	3.030	401	759.989	0.000

Table 5.12: Cluster Center and Propotion

Lables	I		II		III		IV		V	
	Cluster Center	Proportion	Cluster Center	Proportion	Cluster Center	Proportion	Cluster Center	Proportion	Cluster Center	Proportion
D1	5.4435	4.0000	18.7848	25.5000	10.8931	28.2000	23.1084	9.9000	14.8310	32.4000
D10	7.3838	36.2000	2.0432	42.6000	-4.1507	21.2000				
D5	1.5670	40.7000	-4.3176	16.9000	-1.1316	42.3000				
R1	0.6276	34.9000	0.6169	46.5000	0.6051	18.6000				
R2	0.2388	47.2000	0.2199	33.8000	0.2585	18.9000				
A1	19.7157	24.0000	24.8961	48.8000	29.4575	27.2000				
A4	12.9431	26.5000	17.7012	43.8000	21.9666	29.7000				

- **Regression Analysis**

Regression analysis was conducted for each classification variable. First, body measurements related to each classification variable were identified based on the correlation analysis results. As shown previously, among height-related measurements, cervical vertebra height (L2), bust point height (L3), front neck point height (L13), and arm length (L6) correlate strongly only with body height (L1), indicating these dimensions are primarily determined by overall height. Thus, they were assigned to the classification variable body height for regression analysis. Waist height (L4), hip height (L5), and crotch height (L7) show strong correlations with lower body proportions, particularly waist height, and were thus included under the classification variable waist-to-height ratio (R1) for regression analysis.

For upper body length measurements, back length (L14), back waist length (L10), and the lengths from the armpit points to the waistline (L19 and L20) show strong correlations with upper torso length. In addition, back width (W2) is strongly associated with bust girth (G1) and shoulder width (W1), and chest width (W3) is well correlated with back waist length (L21) and bust girth. Therefore, these measurements were grouped under the classification variable difference between front and back waist lengths (D5) for regression analysis.

Among girth-related measurements, armhole width (W6) and bust point distance (W13) correlate only with bust girth (G1) and were analyzed under the bust girth (G1)

classification variable. Waist girth (G2), neck base girth (G4), and abdominal girth (G5) show stronger correlations with waist girth, while lateral neck point distance (W12) correlates strongly with G4. These were included under the bust–waist difference (D1) classification variable for regression analysis. Similarly, hip girth (G3), upper thigh girth (G7), knee girth (G8), and upper arm girth (G9) correlate more strongly with hip girth and were grouped under the hip–bust difference (D10) classification variable for regression. Table 5.13 presents all body measurements analyzed under each classification variable in the regression analysis.

Table 5.13: Body Measurements for Regression

Factors	Classification Variables	Body Measurements
Height	L1	L2, L3, L6, L11, L13, L18
Girth	G1	W6, W13
Waist and Abdomen	D1	G2, G4, G5, W12
	D10	G3, G7, G8, G9
Front and Back Torso Length above the Waist	D5	L14, L10, L19, L20, W2, W3
	R1	L4, L5, L7, L8, L12, L15
Shoulder Width	R2	W1
Shoulder Tilt Degree	A1	A1
Hip Bulge	A4	A4

The linear regression equation is fitted to the corresponding dependent variable by

the classification variable. The regression model between each dependent variable and the independent variable is constructed as shown in Table 5.14, 5.15 and 5.16. Through the regression model, the body measurement can be estimated for different body types, and the interval for each body measurement can also be determined.

Table 5.14: Regression Model for Primary Dimensions

Levels	Classification Index	Regression Model	R-squared
Primary Dimensions	L1	$L2=0.912 \times L1 - 11.076$	0.97
		$L3=0.766 \times L1 - 7.94$	0.89
		$L6=0.364 \times L1 - 5.132$	0.514
		$L11=0.849 \times L1 - 16.218$	0.759
		$L13=0.86 \times L1 - 7.881$	0.928
		$L18=0.212 \times L1 - 3.527$	0.64
	G1	$W6=0.15 \times G1 - 3.124$	0.704
		$W13=0.161 \times G1 + 4.777$	0.7

According to the sample distribution of each category of D1 in Table 5.12, Categories I and IV have relatively small proportions. Therefore, regression analysis was not conducted for these two categories. Only Categories II, III, and V, which have larger sample proportions, were included in the regression analysis.

The regression model demonstrates a good fit through the equation test and residual analysis. Through equation testing and residual analysis, the R-squared values for length (L6), neck base girth (G4), back width (W2), chest width (W3), and the distance from the posterior axillary point to the waistline (L20) are below 0.6. The R-squared values for all other body parts are above 0.6. These results suggest that the overall regression performance is satisfactory.

Additionally, shoulder slope is categorized into three types: flat shoulder, normal shoulder, and sloping shoulder, which is not included in the following tables due to their irrelevance. A shoulder slope of 24.9 degrees represents a medium (normal) shoulder slope according to the results of the cluster analysis. To enable more precise design of fitted garment patterns, flat shoulders are further preset as three levels: 16–17 degrees, 18–19 degrees, and 20–21 degrees. Similarly, a slope of 29.46 degrees indicates a sloping shoulder, which is also preset as three levels: 25–26 degrees, 27–28 degrees, and 29–30 degrees.

While the regression models achieved high R^2 values for key dimensions such as 0.97 for cervical height prediction, their generalizability may be limited by sample demographics like age 18–24. Cross-validation with broader populations is advised to ensure scalability. Additionally, the models assume linear relationships, which may not hold for extreme body types. Future research could explore machine learning methods to capture non-linear interactions, particularly for angular measurements like shoulder slope (A1), where human perception of fit may not align with geometric approximations.

Finally, based on the results of the body shape analysis, the body dimensions will be divided into different grades depending on the significance of the influencing fitness factors. The regression equations can also be applied for body type prediction.

Table 5.15: Regression Model for Secondary Dimensions

Levels	Classification Index	Regression Model	R-squared	Regression Model	R-squared
Secondary Dimensions	D1=18.785	$G2=0.979 \times G1 - 16.884$	0.974	$G5=0.969 \times G2 + 6.329$	0.922
		$G4=0.08 \times L1 + 0.198 \times G1 + 8.23$	0.538	$W12=0.327 \times G4 - 0.394$	0.663
	D1=10.893	$G2=0.989 \times G1 - 9.931$	0.961	$G5=1.057 \times G2 - 0.666$	0.933
		$G4=0.034 \times L1 + 0.201 \times G1 + 17.601$	0.525	$W12=0.355 \times G4 - 1.747$	0.668
	D1=14.831	$G2=0.993 \times G1 - 14.243$	0.974	$G5=1.033 \times G2 + 1.286$	0.935
		$G4=0.103 \times L1 + 0.158 \times G1 + 8.636$	0.465	$W12=0.287 \times G4 + 1.136$	0.522
	D10=7.384	$G3=0.91 \times G1 + 15.302$	0.851	$G7=0.731 \times G3 - 16.762$	0.837
				$G8=0.428 \times G7 + 14.039$	0.645
				$G9=0.166 \times G1 + 0.197 \times G3 - 7.129$	0.709
	D10=2.0432	$G3=0.917 \times G1 + 9.746$	0.938	$G7=0.746 \times G3 - 16.954$	0.863
				$G8=0.431 \times G7 + 13.612$	0.68
				$G9=0.219 \times G1 + 0.12 \times G3 - 4.52$	0.646

Table 5.15 continued

	D10=-4.1507	G3=0.852×G1+10.527	0.866	G7=0.664×G3-8.386	0.824
				G8=0.434×G7+13.563	0.546
				G9=0.26×G1+0.055×G3-2.408	0.689
	D5=1.567	L14=0.532×L1-0.446L4-3.051	0.724	L10=1.052×L14+1.686	0.9
				L20=0.759×L14-8.373	0.547
				L19=1.017×L20-0.498	0.849
		W2=0.133×G1+0.445×W1+5.178	0.401		
		W3=0.296×G1+14.195	0.379		
	D5=-4.318	L14=0.624×L1-0.597L4-3.976	0.692	L10=1.081×L14-0.48	0.898
L20=0.94×L14-16.039				0.541	
L19=0.993×L20+0.657				0.888	
W2=0.075×G1+0.622×W1+3.022		0.405			
W3=0.272×G1+17.051		0.324			

Table 5.15 continued

	D5=-1.13	L14=0.533×L1-0.463L4-2.127	0.682	L10=1.067×L14+0.6	0.916
				L20=0.727×L14-7.358	0.485
				L19=0.939×L20+1.438	0.858
		W2=0.228×G1+0.283×W1+2.886	0.534		
		W3=0.212×G1+22.492	0.287		

Table 5.16: Regression Model for Tertiary Dimensions

Levels	Classification Index	Regression Model	R-squared	Regression Model	R-squared
Tertiary Dimensions	R1=0.628	L4=0.638×L1-1.873	0.975	L5=0.827×L4-2.225	0.916
				L7=0.78×L4-8.434	0.748
				L8=0.441×L4-1.225	0.916
				L12=0.897×L4+3.872	0.826
				L15=0.854×L4+9.518	0.778

Table 5.16 continued

	R1=0.617	L4=0.64×L1-4.091	0.984	L5=0.836×L4-4.195	0.921
				L7=0.767×L4-7.293	0.735
				L8=0.445×L4-2.209	0.921
				L12=0.924×L4+1.117	0.801
				L15=0.907×L4+2.743	0.86
	R1=0.605	L4=0.629×L1-4.163	0.933	L5=0.804×L4-1.423	0.824
				L7=0.762×L4-7.381	0.7
				L8=0.429×L4-0.808	0.824
				L12=0.839×L4+9.936	0.729
				L15=0.878×L4+5.348	0.753
	R2=0.239	W1=0.177×L1+0.074×G1+3.868	0.747		
	R2=0.22	W1=0.175×L1+0.074×G1+1.398	0.663		
	R2=0.259	W1=0.139×L1+0.076×G1+12.805	0.571		

5.2.2 Results and Discussion

This chapter conducts a quantitative analysis of body data from male university students aged 18–24. The analysis examines the overall proportionality between the upper and lower body in terms of height, girth, width, and angle measurements. To capture these proportional relationships, the waist height-to-body height ratio (R1) and a variable representing abdominal morphology (D11) are introduced. Based on the analysis, seven body shape classification variables are identified: D1 (chest-to-waist difference), D10 (hip-to-chest difference), D5 (front-to-back waist length difference), R1 (waist height-to-body height ratio), R2 (shoulder width-to-body height ratio), A1 (shoulder slope angle), and A4 (hip protrusion angle). Among them, D1, D10, and D5 are designated as the first-level classification variables, while R1, R2, A1, and A4 are designated as the second-level classification variables.

Based on the above body shape classification, the new sizing system is composed of three elements: body height, chest girth, and body type classification.

Body height is used as the vertical dimension, and chest circumference as the girth dimension. The standard reference size of the intermediate body type is defined as a body height of 175 cm and a chest circumference of 92 cm.

The classification system consists of two levels for the upper body shape. The first level of body type classification is determined by a combination of D1 and D5, which

represent key morphological differences, as shown in Table 5.17 which provides a statistical summary of 15 body types derived from the combination of D1 and D5, among which six body types have proportions exceeding 10%. The second level of body type classification is determined by R1, R2, D10, and A1 as the detailed body features as shown in Table 5.18.

Table 5.17: Body Types of Primary Dimensions

D5 \ D1	I (%)	II (%)	III (%)	IV (%)	V (%)
I	1.628	10.3785	11.4774	4.0293	13.1868
II	0.676	4.3095	4.7658	1.6731	5.4756
III	1.692	10.7865	11.9286	4.1877	13.7052

Table 5.18: Fine-grained Body Types of Secondary Dimensions

Sub-type	I (%)	II (%)	III (%)
R1	34.9	46.5	18.6
R2	47.2	33.8	18.9
D10	36.2	42.6	21.2
A1	24	48.8	27.2

The classification system also contains two levels for the lower body shape. The first-level classification relies on D1 and D10, which represent the bust–waist difference and hip–bust difference, respectively. From these values, the hip–waist difference (DHW) for each body type can be computed. The proportion of each body type and its corresponding hip–waist difference is presented in Table 5.19. The second-level classification depends on R1 and A4, which serve as detailed indicators of lower body characteristics. The distribution of body types at this level is shown in Table 5.20.

Based on the correlations between body shape classifications and various body measurements, regression analysis was performed to establish regression models for different body dimensions. These models quantitatively represent the relationships among body measurements, body shapes, and garment fit, thereby providing a data-based foundation for the design of basic garment patterns. Moreover, the regression models can be employed to predict body size specifications, which, although not included in the scope of the present study, represent a promising avenue for future research.

In summary, this study not only emphasizes the key factors affecting human body shape through detailed body type classification but also highlights the importance of achieving proportional balance between the upper and lower body. It enables an in-depth examination of the relationships among body measurements, body shape, and garment fit. Furthermore, the multi-level classification system allows for flexible implementation of fit modification at varying levels, tailored to different body types.

Table 5.19: Body Types of Primary Dimensions

D1 D10	I		II		III		IV		V	
	D _{HW} (cm)	Proportion (%)	D _{HW} (cm)	Proportion (%)	D _{HW} (cm)	Proportion (%)	D _{HW} (cm)	Proportion (%)	D _{HW} (cm)	Proportion (%)
I	12.82728	1.448	26.16868	9.231	18.2769	10.2084	30.49224	3.5838	22.2148	11.7288
II	7.486668	1.704	20.82806	10.863	12.93628	12.0132	25.15163	4.2174	16.87419	13.8024
III	1.29275	0.848	14.63415	5.406	6.742365	5.9784	18.95771	2.0988	10.68027	6.8688

Table 5.20: Fine-grained Body Types of Secondary Dimensions

Sub-type	I (%)	II (%)	III (%)
R1	34.9	46.5	18.6
A4	26.5	43.8	29.7

5.3 Landmark of Feature Points on 3D Body Model

In this study, for the purpose of subsequent research, body types with relatively large proportions, as identified in Table 5.17, were selected as representative categories for the design of upper garment patterns. Three body types with a height of 175 cm, chest circumference of 92 cm, Type II-I (proportion: 10.3785%), Type III-III (proportion: 11.9286%), and Type V-I (proportion: 13.1868%), were chosen as the foundational human figures for 3D body surface reconstruction to create a standard basic block pattern. Table 5.21 presents the characteristics of the body shapes for the three selected foundational figures.

Table 5.21: The Characteristic of the Three Selected Foundational Body Figures

No.	D1	D5	R1	R2	D10	A1	A4
Base Body 1	II	I	II	I	II	I	I
Base Body 2	V	I	II	I	I	III	II
Base Body 3	III	III	II	I	I	III	II

Firstly, the body needed to be aligned and symmetrized, and then the body surface was reconstructed, and the foundational pattern was derived from the reconstructed body surface by using a 2D flattening method. Furthermore, differences in fine-grained body features depending on the secondary dimensions of body type were analyzed. The pattern adjustment rules will be designed to generate patterns for various fine-grained body types through modifications of the foundational pattern.

5.3.1 Posture Alignment of the Human Body

The 3D point cloud data of the human body obtained through scanning often contains noise, outliers, and gaps. The point cloud processing, including unification, denoising, and gap filling, was first done in Geomagic Wrap software to obtain a smooth 3D human body point cloud. Since the human body is not a perfectly symmetrical model and may exhibit asymmetry due to standing posture inclinations, adjustments for alignment and symmetry were performed to enable the reconstruction of a standardized body model and the generation of block patterns.

In Geomagic Wrap, the human model was first mirrored along the coordinate axes, as shown in Figure 5.1 (b), followed by rotation and translation along the Z-axis in the global coordinate system to align the upper body, as depicted in Figure 5.1 (c). Next, unnecessary components such as the arms and head were removed, and the torso was extracted by trimming the body at the hip circumference plane. The aligned torso was then further processed using the YZ plane in the global coordinate system, retaining the left half of the body, which was mirrored to create a symmetrical torso model.

Finally, the symmetrical torso model was compared with the aligned torso model. In actual human bodies, the symmetry between the left and right sides varies among individuals; some exhibit relatively good symmetry, while others display significant asymmetry. Figures 5.2, 5.3, and 5.4 respectively illustrate the results of the symmetrical torso and aligned torso comparison tests conducted on base body 1, 2, and 3.

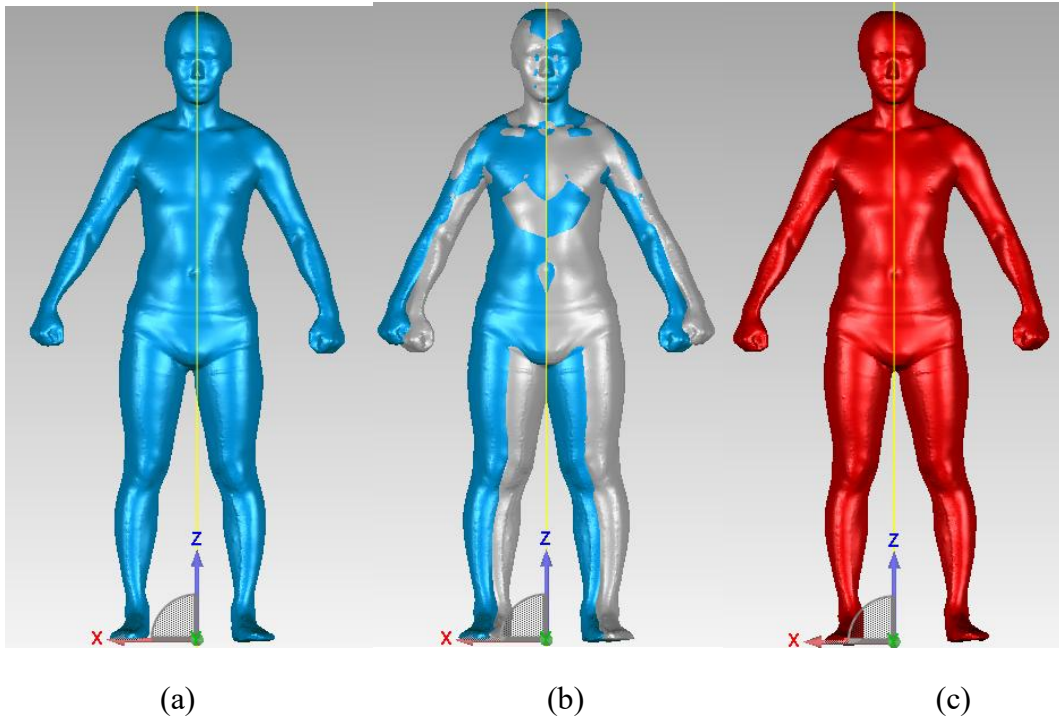


Figure 5.1: Body Alignment

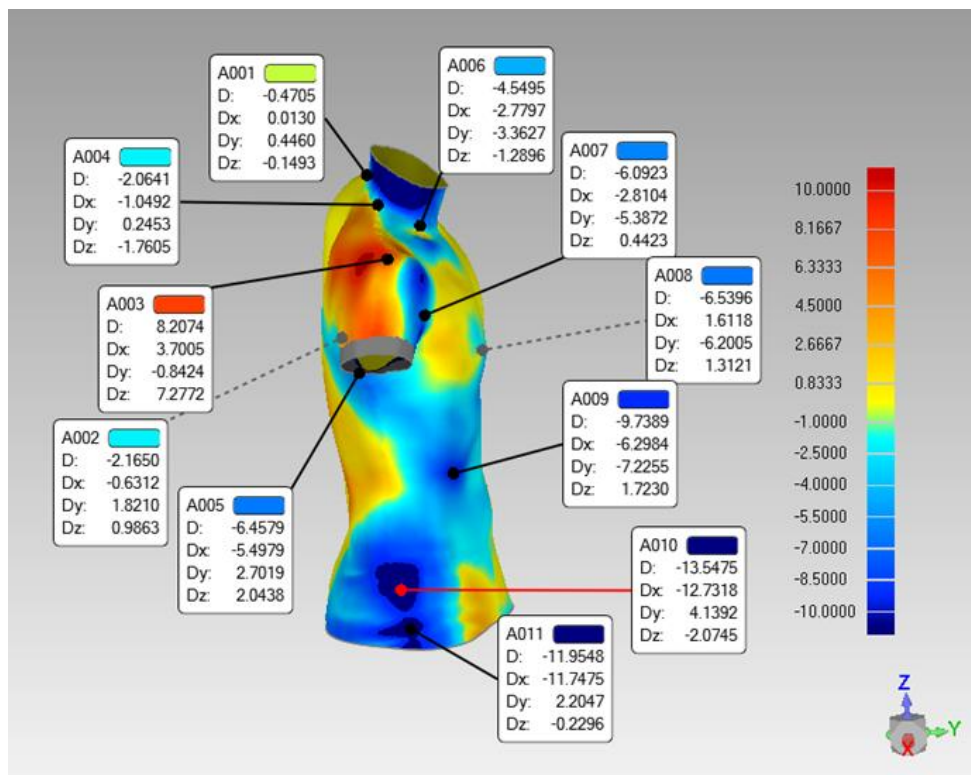


Figure 5.2: Comparison Test of Symmetry Torso and Alignment Torso of Base Body 1

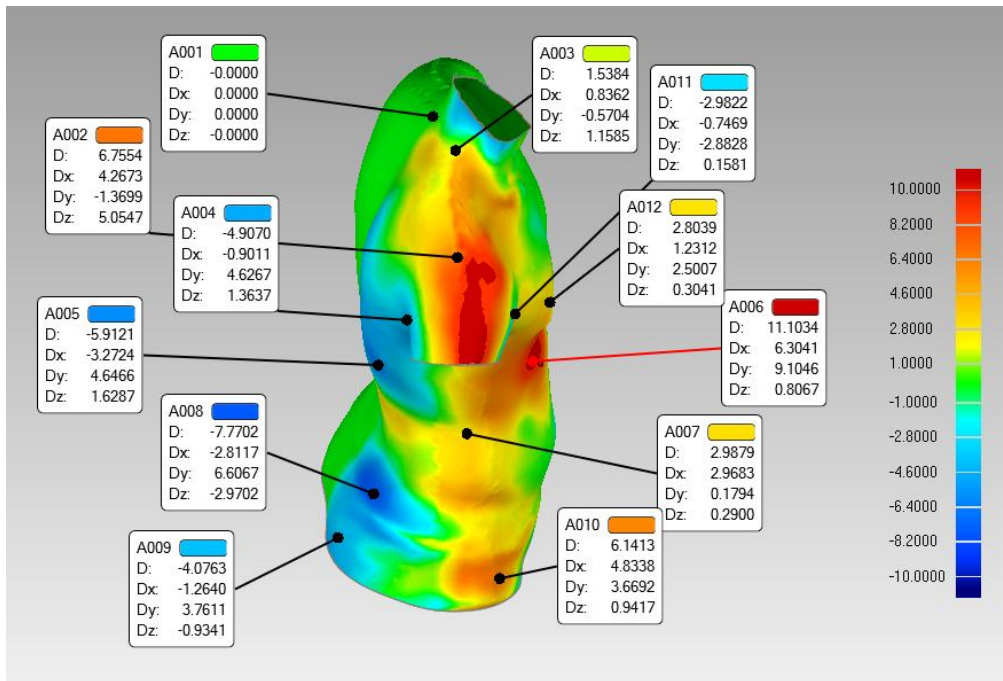


Figure 5.3: Comparison Test of Symmetry Torso and Alignment Torso of Base Body 2

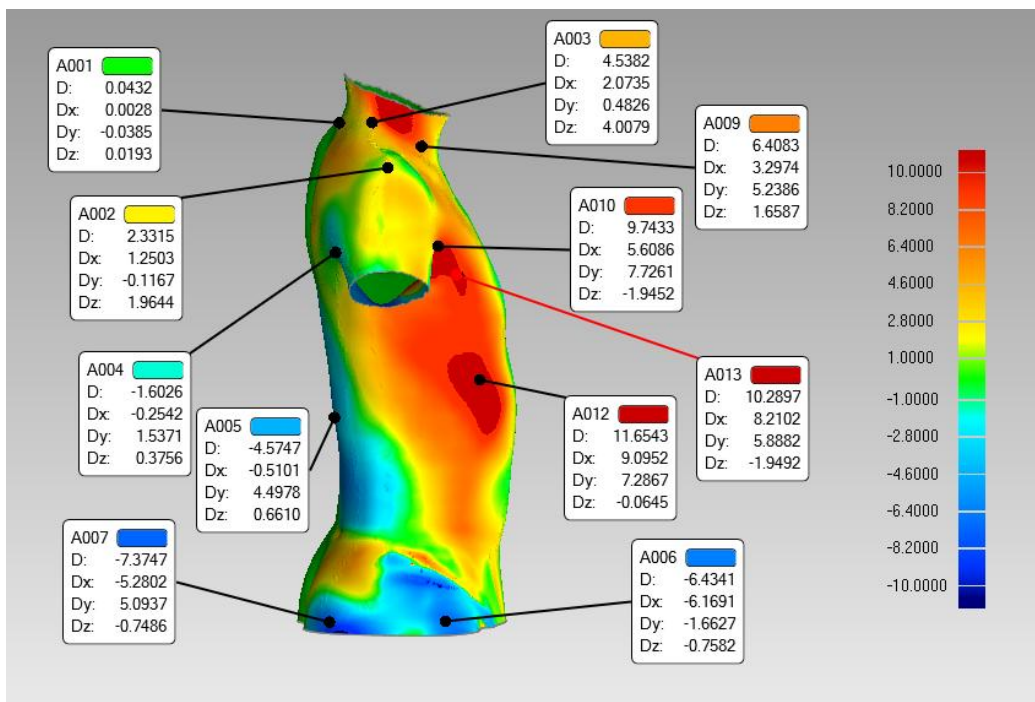


Figure 5.4: Comparison Test of Symmetry Torso and Alignment Torso of Base Body 3

After applying symmetry alignment to the aforementioned three body types, a comparative analysis of differences between the left and right sides was conducted. Among them, the waist exhibited the largest differences in key body parts, as shown in Table 5.22. From the data presented in the table, it can be observed that Base Body 3 demonstrates relatively large deviations at the neck, underarm, chest, and waist regions. Base Body 1 shows relatively large deviations at the shoulder and hip areas, while Base Body 2 displays a significant deviation at the waist.

Table 5.22: Comparative Analysis of the Differences in Symmetry for Torso

No.	Neck (mm)	Shoulder (mm)	Armpits (mm)	Bust (mm)	Waist (mm)	Hip (mm)
Base body 1	-4.5495	8.2074	-2.1650	-6.4579	-9.7389	-13.5475
Base body 2	1.5384	6.7554	-4.9070	2.8039	11.1034	6.1413
Base body 3	6.4083	2.3315	9.7433	10.2897	11.6543	-7.3747

5.3.2 Determination of the Feature Points

The following sections provide a detailed description of the procedures for obtaining each key point.

- **Determination of the Front Neck Point and Back Neck Point**

To determine the front neck point and back neck point, the YZ plane was initially inserted into the symmetrized 3D point cloud of the human body model to obtain the

anterior-posterior symmetry centerline of the model. Subsequently, a plane parallel to the XY plane was established at the height of the front neck point obtained from the 3D scan of the body. The intersection of this plane with the anterior centerline was designated as the front neck point. Similarly, a plane parallel to the XY plane was established at the height corresponding to the posterior neck point obtained from the 3D scan of the body. The intersection of this plane with the posterior centerline was designated as the back neck point. Figure 5.5 illustrates the schematic diagrams of the neck points: (a) shows the posterior neck point, and (b) shows the anterior neck point.

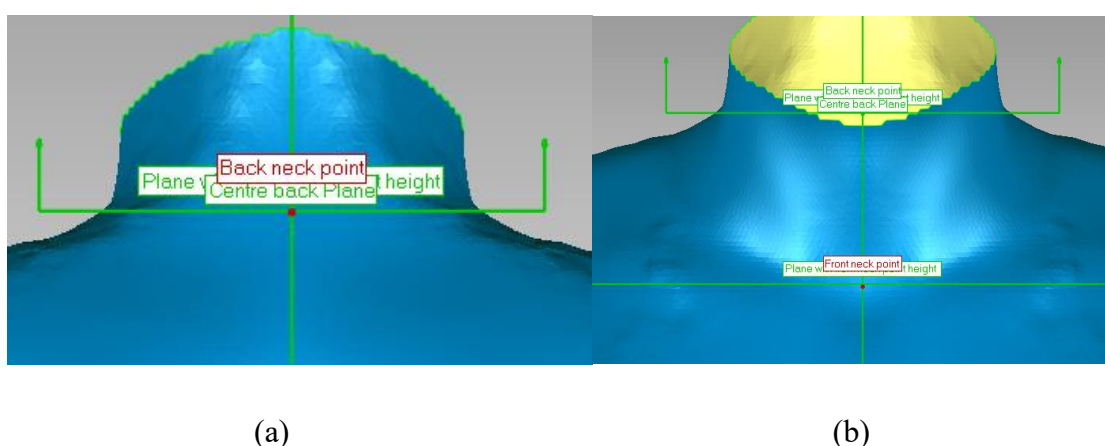


Figure 5.5: Determination of the Front Neck Point and Back Neck Point

- **Determination of the Side Neck Point**

In the literature, the determination of the side neck point primarily involves locating it at the maximum bending location or the extreme point (C. C. L. Wang, 2005) along the front view contour. In this study, the side neck point is identified based on 3D anthropometric data, including waist height, the length from the side neck point to the back

waistline (back waist length), and the distance between the side neck points. First, using the distance between the side neck points obtained from 3D body scans, a plane PL_{snpz} parallel to the YZ plane and passing through each side neck point is constructed. The waistline plane (PL_{wl}) is extracted from the scanned waist height data, and the side neck point is then located on the body surface curve defined by plane PL_{snpz} using the back waist length. Since the computed intersection point may not coincide exactly with a point on the point cloud, a fuzzy matching approach is applied by selecting the point nearest to the theoretical intersection. Figure 5.6 illustrates the schematic diagram for the identification of the lateral neck point.

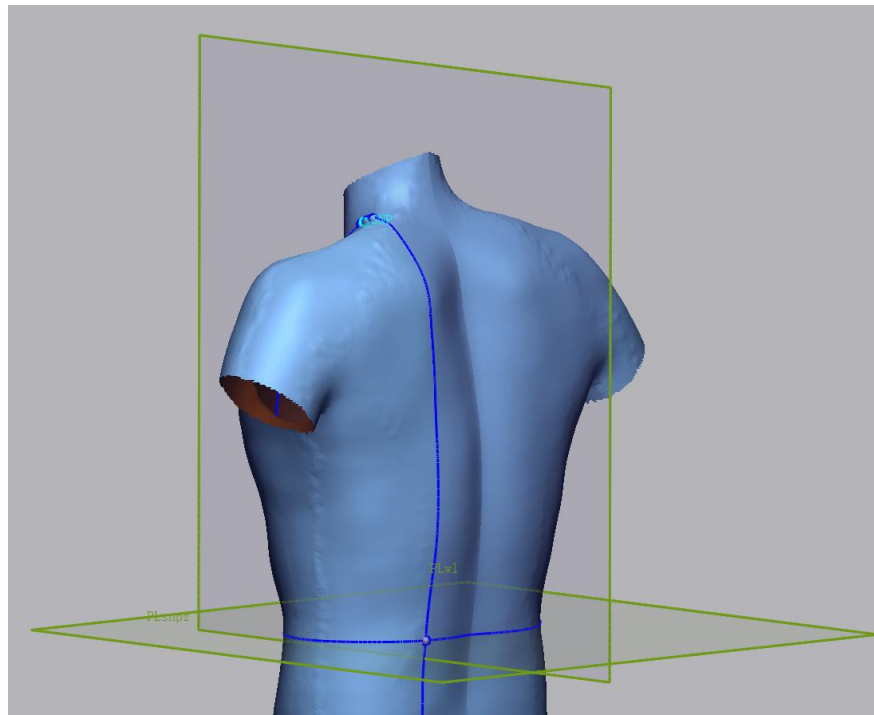
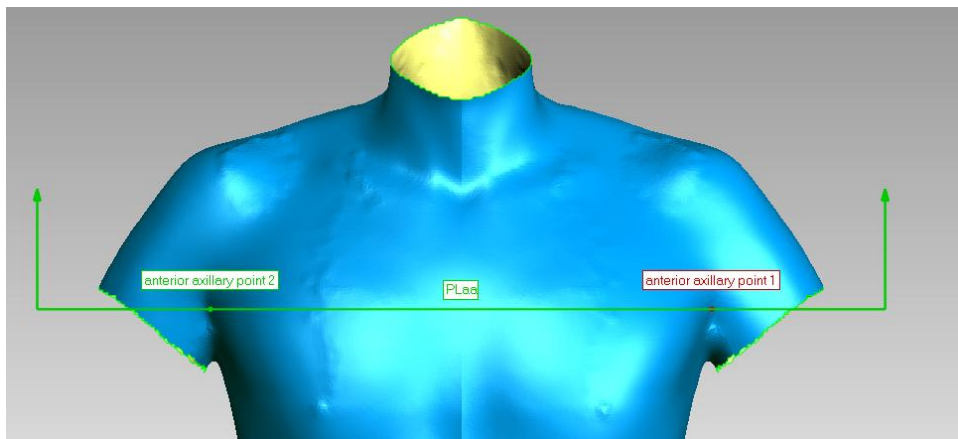


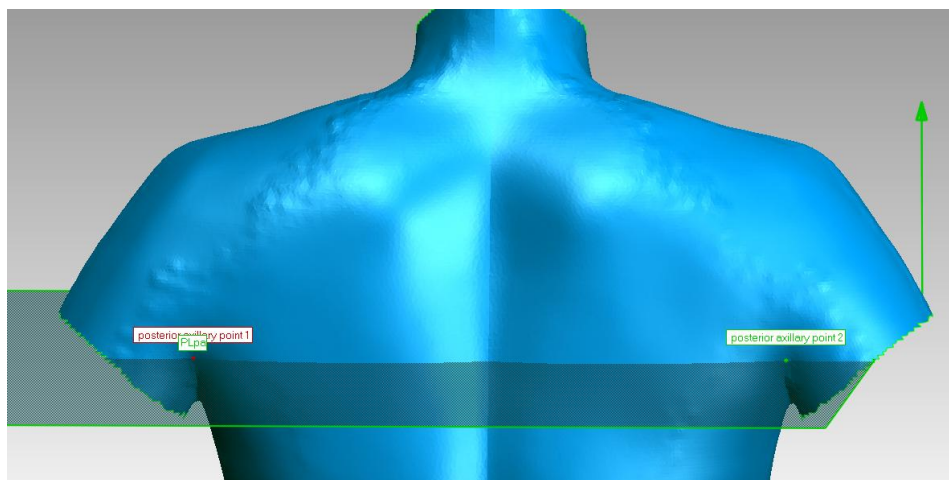
Figure 5.6: Determination of the Side Neck Point

- **Determination of the Anterior Axillary Point, Posterior Axillary Point, and Underarm Point**

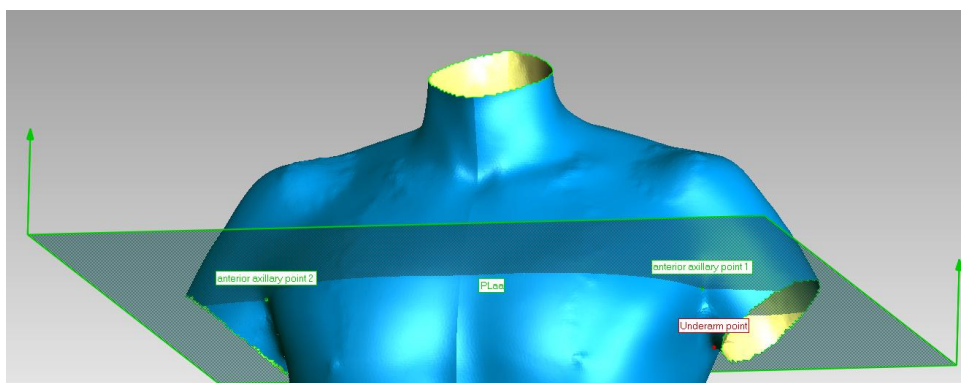
The anterior axillary point is first determined. A plane parallel to the XY plane, denoted as PLa, is created and incrementally moved upward from the chest circumference line to intersect the body. The process continues until the cross-section reveals a clear transition point between the arm and torso. The surface length between the two transition points is measured, and when this length matches the chest width obtained from the 3D body scan, the position of the anterior axillary point is identified, as shown in Figure 5.7(a). The same method is applied to determine the posterior axillary point. The surface length between two transition points on the back is measured, and when this length matches the back width from the 3D body scan, the position of the posterior axillary point is identified, as shown in Figure 5.7(b). Finally, two planes parallel to the XZ plane are created, passing through the anterior and posterior axillary points, respectively. The distance between these two planes represents the arm root width. This arm root width, obtained from the 3D body scan, is used to verify and adjust the positions of the anterior and posterior axillary points. The underarm point is located at the midpoint of the anterior axillary point and the posterior axillary point, as shown in Figure 5.7(c).



(a)



(b)

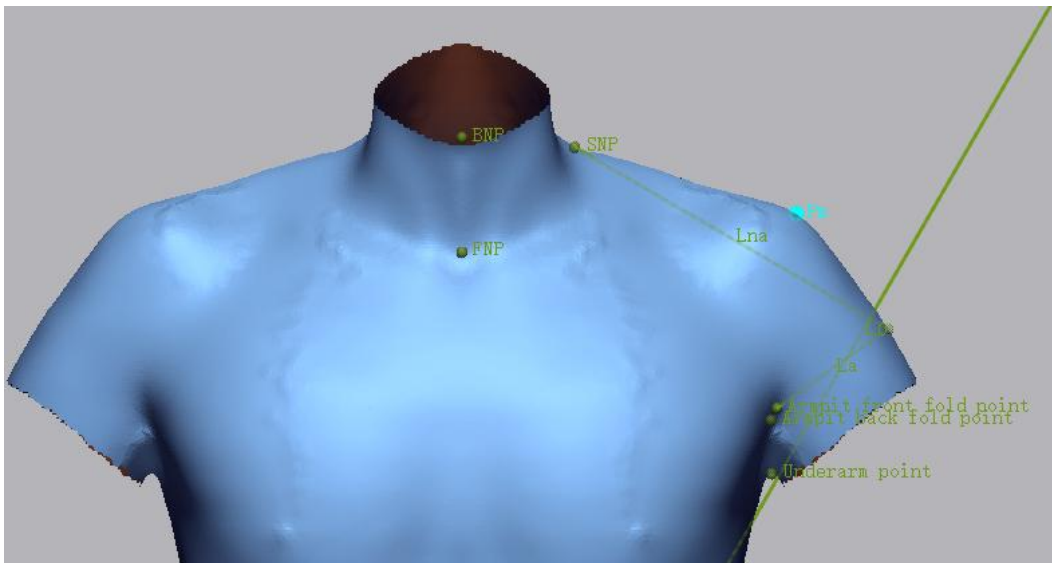


(c)

Figure 5.7: Determination of the Axillary Point and Underarm Point

- **Determination of the Shoulder Point**

Following the method by Han and Nam, the determination of the shoulder point begins with constructing the arm circumference line through the anterior axillary point. A straight line L_{na} is drawn to connect the side neck point and the outermost point of the arm at axilla height. A line perpendicular to L_{na} is then created and moved from the outermost point of the arm. When this line intersects the anterior contour of the shoulder at its maximum length, the intersection point is denoted as P_m , as shown in Figure 5.8(a). P_m is the point at the largest perpendicular distance from the segment connecting the side neck point and the outermost arm point at axilla height.



(a)

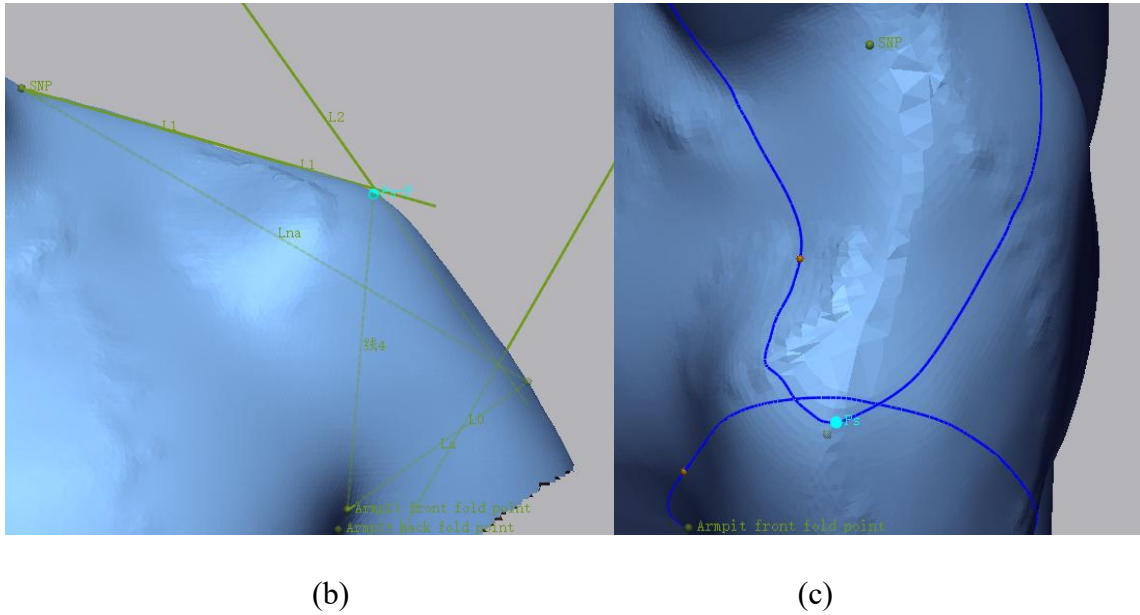


Figure 5.8: Determination of the Shoulder Point

Next, a line parallel to the shoulder line is drawn through the side neck point and labeled L1. A line parallel to the arm axis (the perpendicular line to the arm circumference) is drawn through Pm, and this line is labeled L2. The intersection of L1 and L2 is denoted as Pn. A line L3 is then drawn to connect Pn with the anterior axillary point. The intersection of L3 with the anterior contour of the shoulder is the preliminary shoulder point, labeled Ps-P, as shown in Figure 5.8(b).

The preliminary shoulder point is then refined. A plane PLs passing through the shoulder point is used to slice the body point cloud, and another plane, PLaf, passing through the anterior and posterior axillary points and parallel to the Z-axis, is created. The intersection of PLaf with the cross-section PLs forms a line, which is shifted 10 mm

towards the shoulder point. The shoulder point P_s is adjusted to the intersection of this shifted line with the midpoint of the cross-section, as shown in Figure 5.8(c).

5.4 Pattern Blocks' Generation

5.4.1 Surface Reconstruction and Flattening of the Human Body

In this study, reverse engineering software was used to reconstruct the surface of the scanned 3D human body by employing feature points and feature lines. To enable the generation of the basic upper-body pattern, the human body torso was initially segmented using feature planes. A vertical plane passing through the underarm point was first applied to divide the human body. Subsequently, the forearm was trimmed using a plane defined by the shoulder point, front underarm point, and underarm point. In contrast, the back arm was trimmed using a plane defined by the shoulder point, back underarm point, and underarm point, achieving segmentation of the arms. Next, a plane formed by the back neck point, side neck point, and front neck point was applied to trim the neck region. Finally, the torso was aligned and merged with the point cloud of the left half of the body, as shown in Figure 5.9.

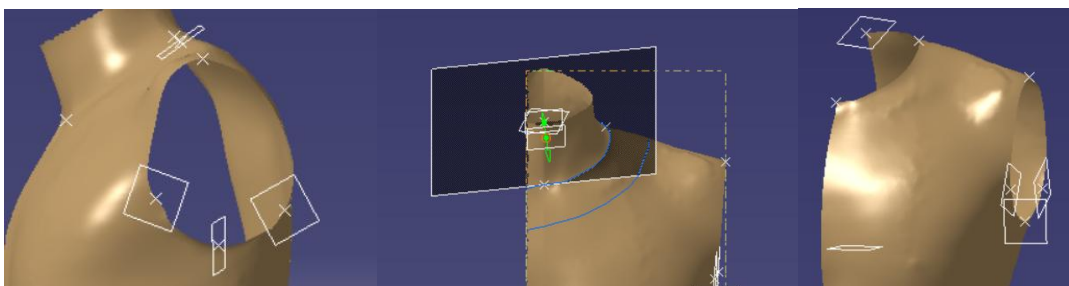


Figure 5.9: The Processing of the Torso

To better fit the curved surface of the human body, dividing the torso into surface regions is necessary. Based on the feature points and the anatomical features of the torso, the torso's surface shape is formed. Accordingly, the following feature lines and planes are used for surface partitioning of the torso, as shown in Figure 5.10: the hip circumference line, abdominal circumference line, waist circumference line, chest circumference line, a horizontal plane at the midpoint between the shoulder point and front axillary point, a horizontal plane at the midpoint between the shoulder point and back axillary point, a curve connecting the side neck point and the shoulder point, a curve connecting the underarm point to the midpoint of the waist circumference line, a curve passing through the midpoints of the waist, abdominal, and hip circumference lines, and a vertical plane located at half the distance of the intermammary line from the front center. Once the feature lines and feature plane were defined, planar sections in the reverse engineering software were used to cut the point cloud, and curves were subsequently generated from the scan.

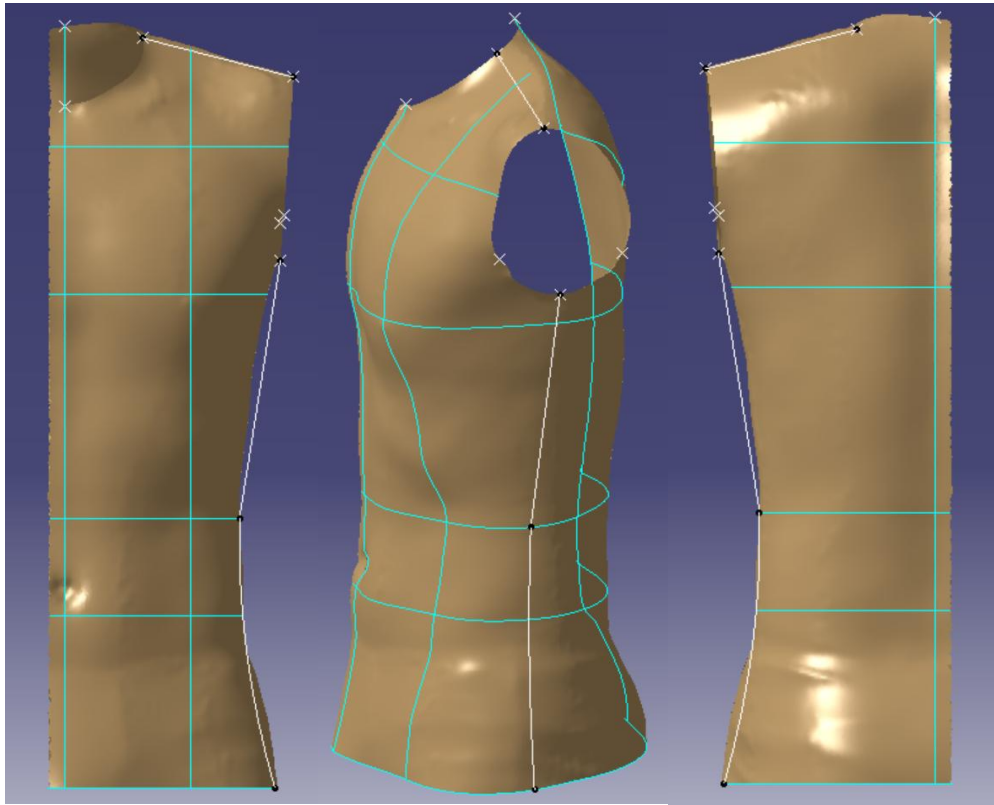


Figure 5.10: Feature Lines and Planes for Body Segmentation

Surface construction is performed based on the defined feature lines. Selected point cloud regions corresponding to the areas of interest are approximated by using the PowerFit method, and the resulting surfaces are segmented according to the feature lines. The fitting tolerance for each surface can be adjusted: a tolerance of 1 mm is applied to the shoulder seam and scapular region of the back panel, while a tolerance of 0.2 mm is used for all other regions. The complete surface fitting for all segmented regions of the human body is presented in Figure 5.11.

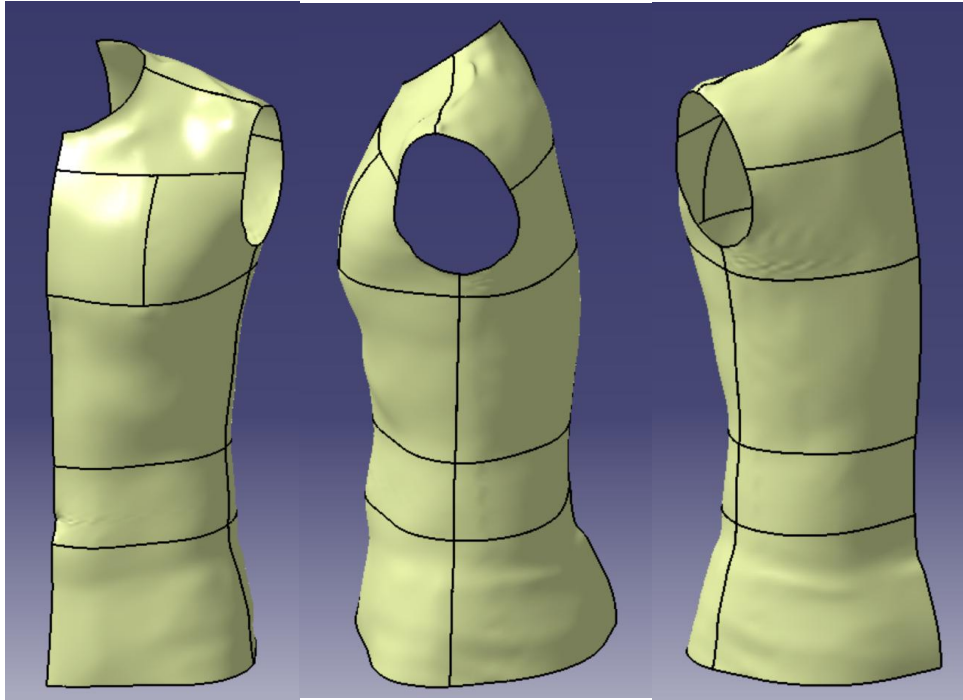


Figure 5.11: Human Body Surface Fitting of Each Segmentation

Finally, deviation analysis was conducted for each surface patch using the Deviation Analysis tool. For base body 1, as shown in Figure 5.12, the results indicate that the greater deviations are primarily located in the area between the shoulder line and scapula on the back panel, with the maximum deviation observed at the shoulder region, reaching -3.46 mm. For base body 2, as shown in Figure 5.13, the results show that the larger deviations are also located in the area between the shoulder line and scapula on the back panel, with the maximum deviation observed at the shoulder region, reaching 3.54 mm. For base body 3, as shown in Figure 5.14, the results reveal that the larger deviations are located in the area between the shoulder line and chest on the front panel, with the maximum deviation observed at this region, reaching 3.51 mm. This deviation falls within

the acceptable range defined by the maximum tolerance standards for garment sizing.

The Unfold Definition tool is utilized to flatten each surface individually, creating 2D unfolded pieces for every body type. Figure 5.15 shows the flattened body surface pattern of Base Body 1; Figure 5.16 presents the flattened body surface pattern of Base Body 2, and Figure 5.17 illustrates the flattened body surface pattern of Base Body 3. These pieces are assembled using the center front line, center back line, and bust line as reference points, indicated by the orange lines in the figures.

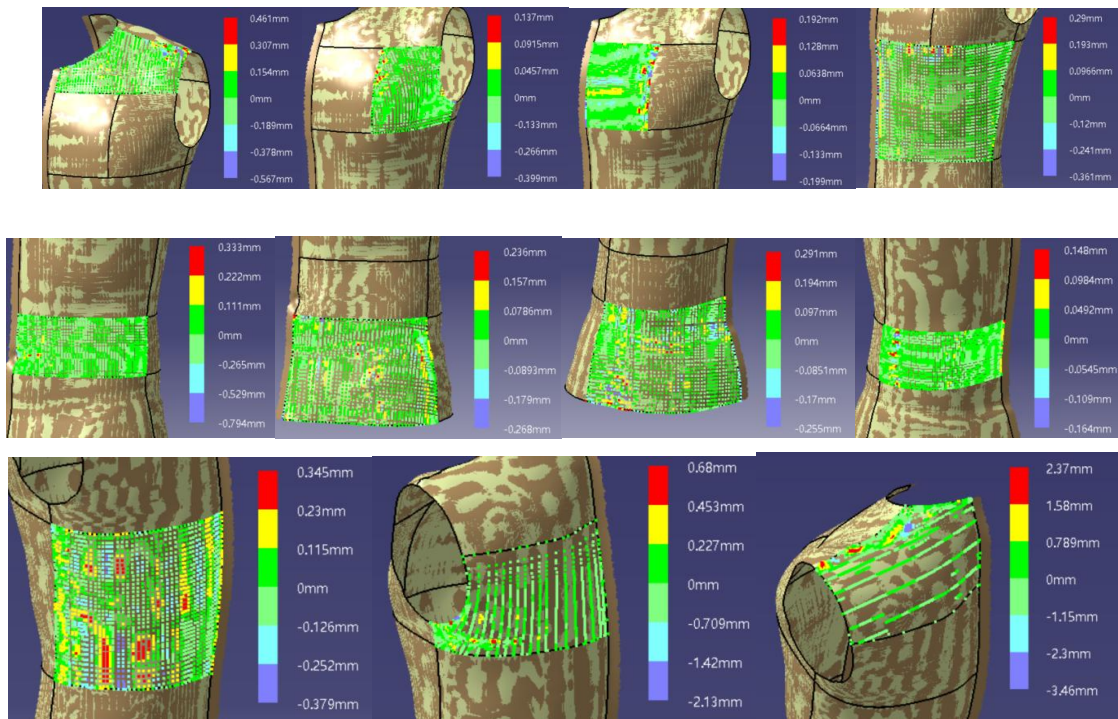


Figure 5.12: Deviation Analysis of Base Body 1

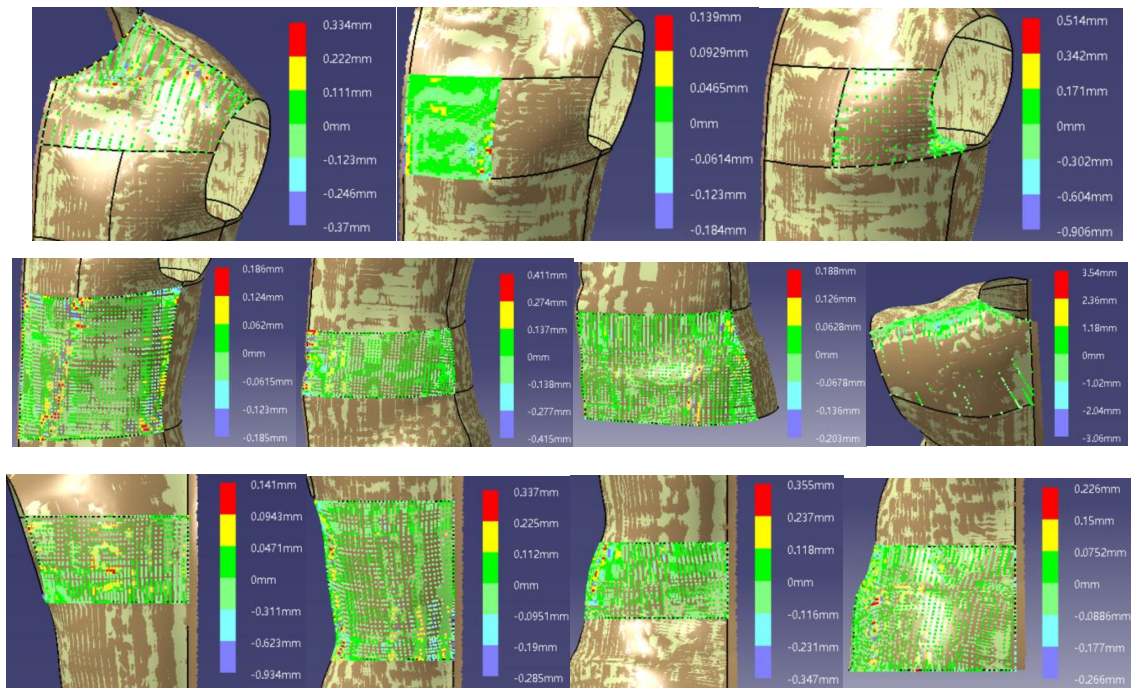


Figure 5.13: Deviation Analysis of Base Body 2

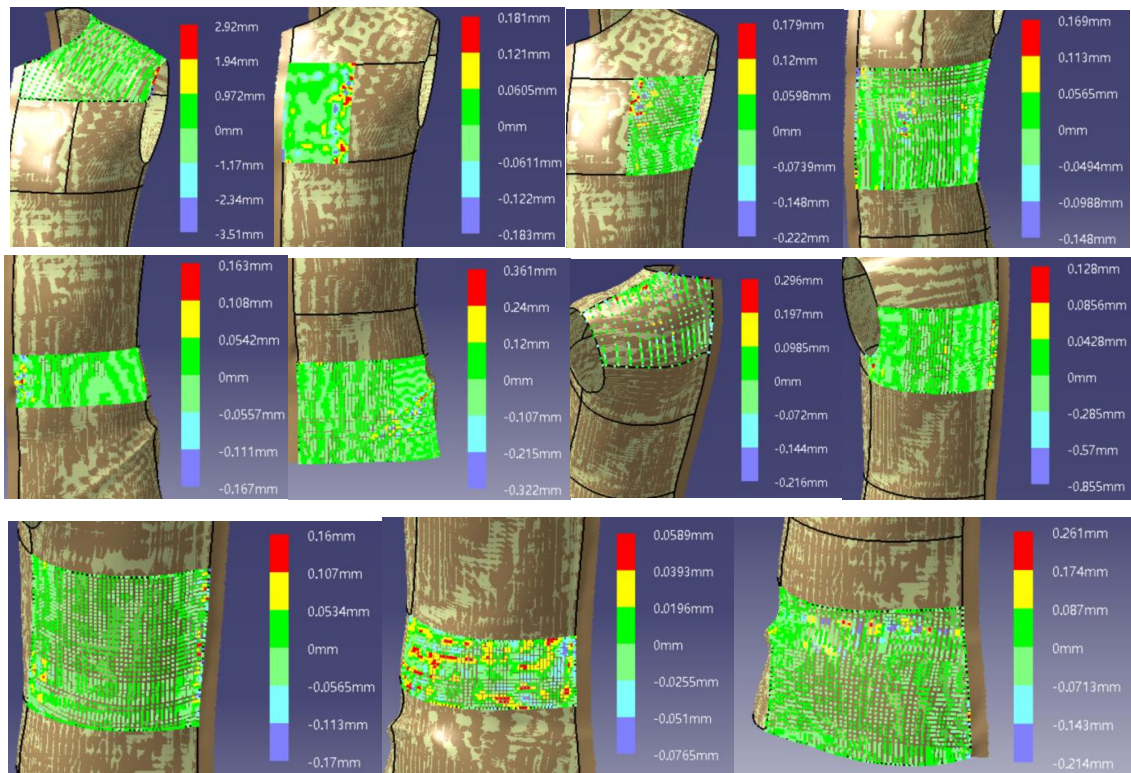


Figure 5.14: Deviation Analysis of Base Body 3

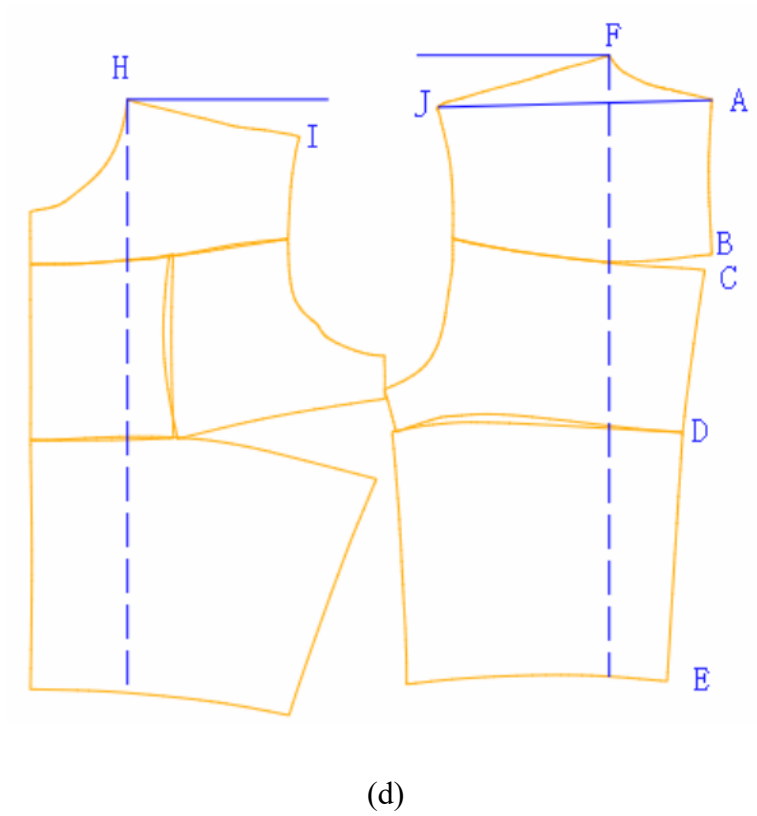
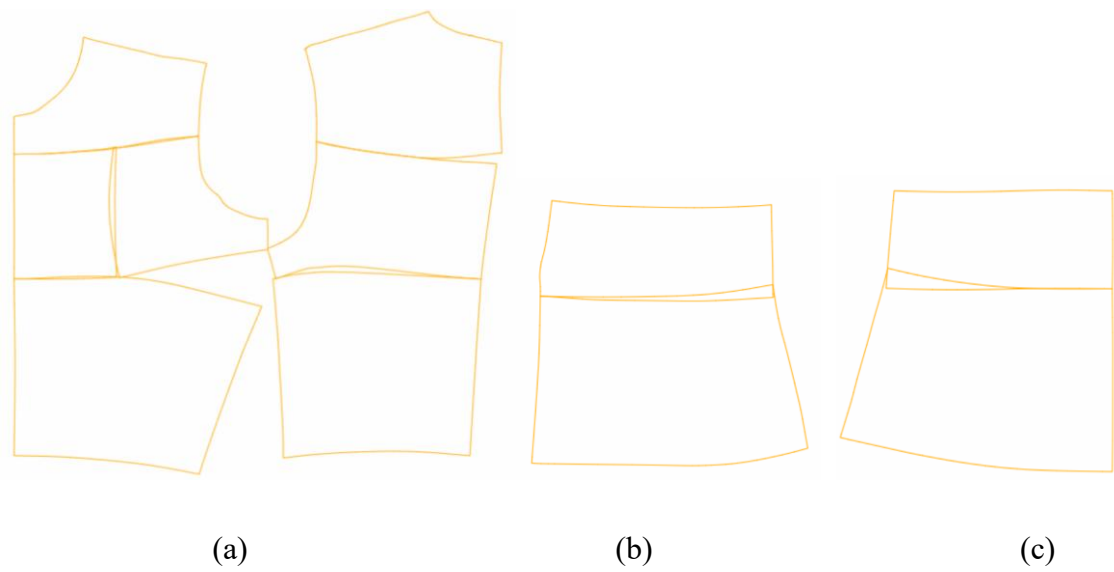


Figure 5.15: Unfolded Pieces of Body Surface of Base body 1

(a. Upper Torso Above the Waistline, b. Front Panel Below the Waistline, c. Back Panel Below the Waistline, d. Measurement Diagram)

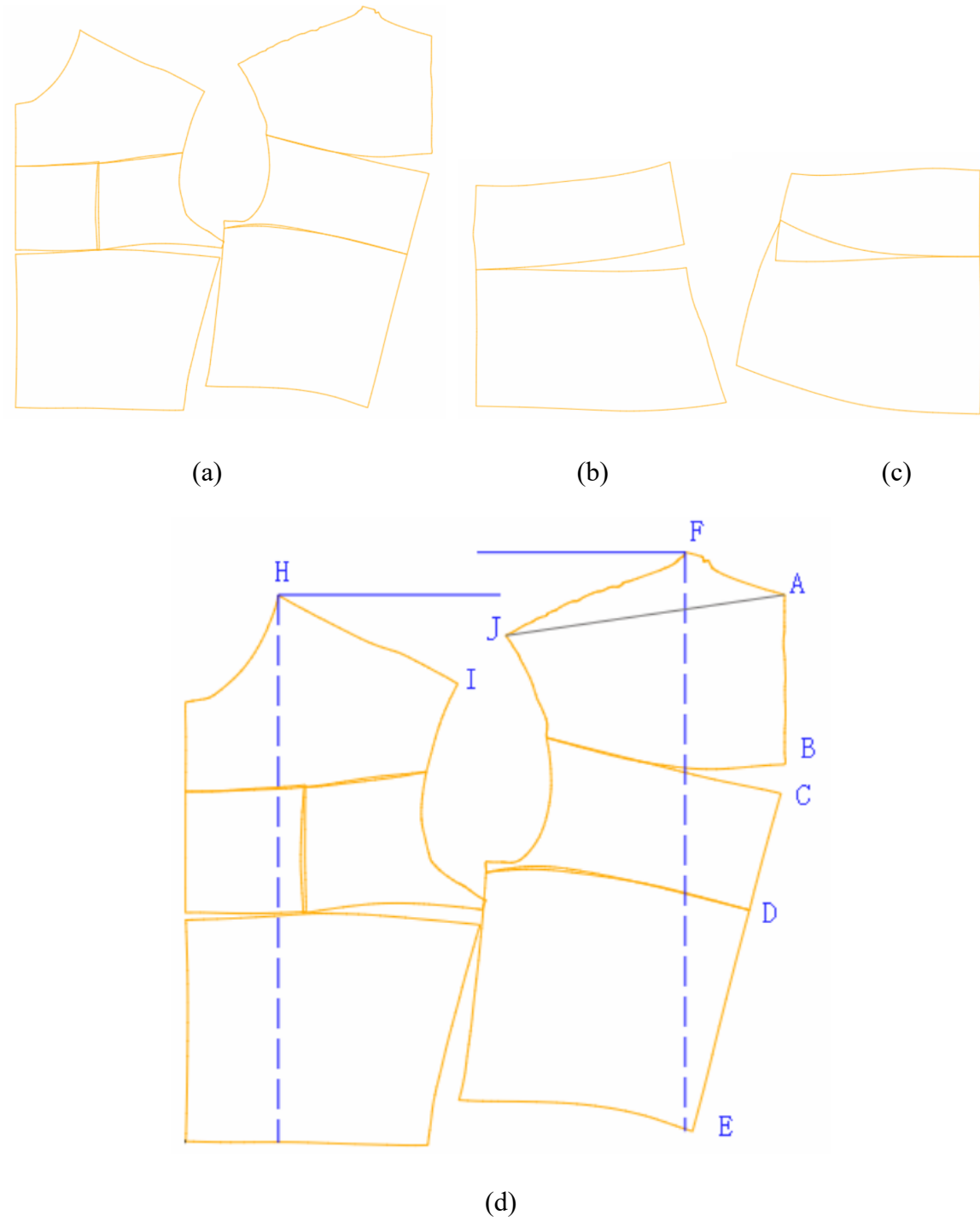


Figure 5.16: Unfolded Pieces of Body Surface of Base body 2

(a. Upper Torso Above the Waistline, b. Front Panel Below the Waistline, c. Back Panel Below the Waistline, d. Measurement Diagram)

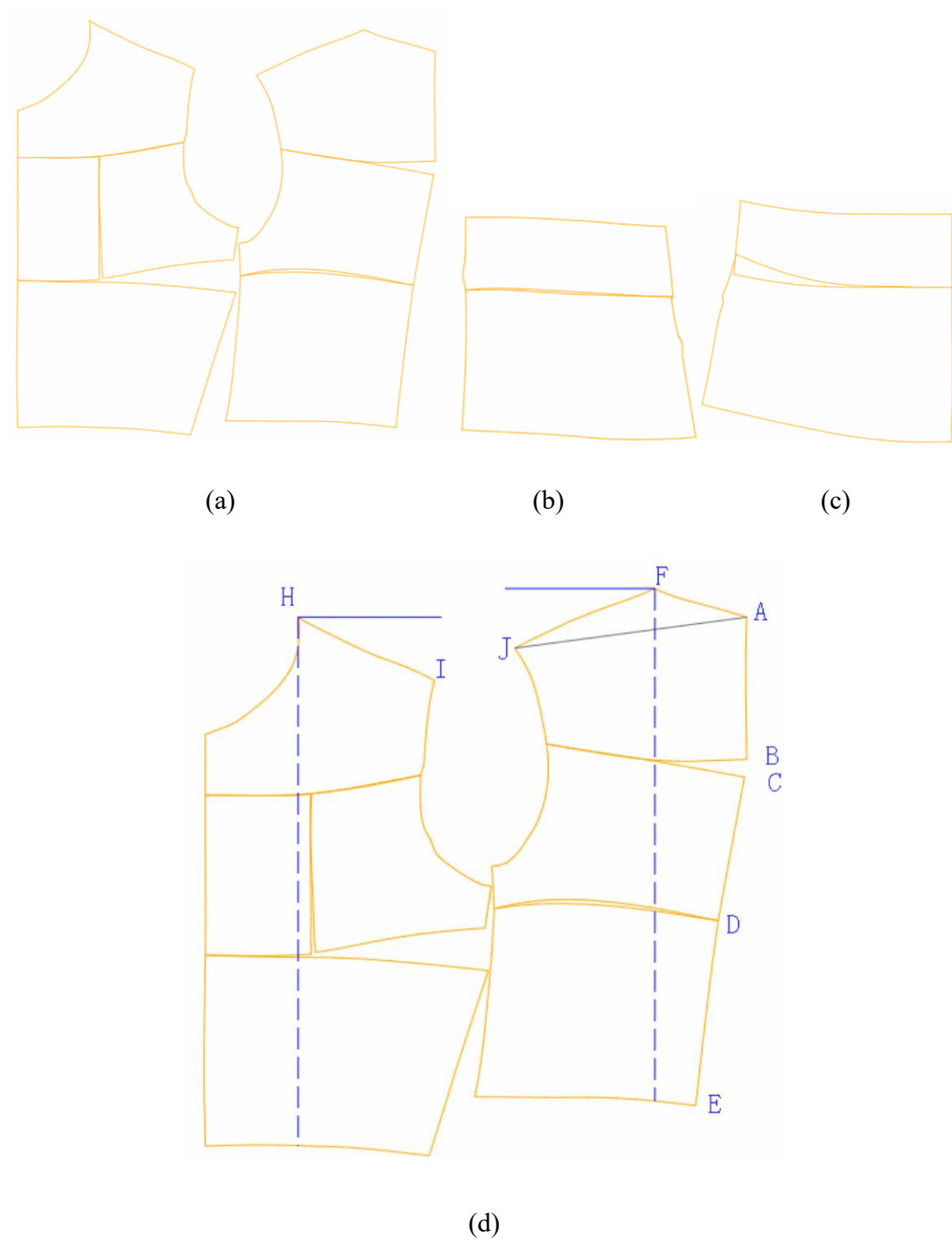


Figure 5.17: Unfolded Pieces of Body Surface of Base body 3

(a. Upper Torso Above the Waistline, b. Front Panel Below the Waistline, c. Back Panel Below the Waistline, d. Measurement Diagram)

Measurements were taken for key dimensions on the flattened surface of the human body. The assembled pattern pieces clearly illustrate the defining characteristics of each body type, aligning with their respective body type categories, as shown in Table 5.23, which presents the main body measurements. In the table, Back Length is calculated as the sum of the segment lengths A–B, C–D, and D–E from the posterior view (part (d)) of the flattened body surfaces shown in Figures 5.15–5.17. Shoulder Width is defined as twice the length of segment A–J. Average Shoulder Slope is calculated as the average of the front and back shoulder angles: the front shoulder angle is the angle between segment H–I and the horizontal line through point H, and the back shoulder angle is the angle between segment F–J and the horizontal line through point F. Front Waist Length is the length of the vertical dashed line dropped from point H to the waistline. Meanwhile, Back Waist Length is the length of the vertical dashed line from point F to the waistline.

Table 5.23: Key Measurement Values of Human Body Surface Unfolded Pieces

Sample	Back Length (cm)	Shoulder Width (cm)	Average Shoulder Slope (cm)	Front Waist Length (cm)	Back Waist Length (cm)
Base body 1	41.25	40	14.62	42.81	45.44
Base body 2	41.05	46.6	25.64	44.51	47.8
Base body 3	43.08	42.6	23.92	48.03	46.95

According to the classification based on D1/D5, the bust-to-waist difference for Base body 1 is 18 cm, for Base body 2 is 14 cm, and for Base body 3 is 10 cm. Between Base body 1 and Base body 2, which share the same D5 value, Base body 1 shows a relatively larger bust-to-waist difference, while Base body 2 shows a smaller one. Consequently, in the flattened pattern, the dart volume at the bust is larger for greater bust-to-waist differences. When comparing the bust dart volume between Base body 2 and Base body 3, although Base body 3 has a smaller bust-to-waist difference, its front waist length exceeds the back waist length, indicating a more prominent chest and straighter back posture. As a result, the bust dart volume for Base body 3 is greater than that of Base body 2. Therefore, for the same bust-to-waist difference, the greater the difference between front and back waist lengths (i.e., the flatter the back), the larger the corresponding bust dart volume will be.

According to the classification based on D5, the back waist length is greater than the front waist length in both Base body 1 and Base body 2, while in Base body 3, the front waist length exceeds the back waist length. The measurement data obtained from the flattened human body surface are consistent with the classification results, indicating that body types with a longer front waist length relative to the back waist length correspond to a prominent chest posture. This significantly affects pattern design, particularly in determining back length, back width, the height difference between the front and back side neck points, and the waistline drop. However, this factor is often overlooked in conventional pattern design practices.

According to the classification based on A1, Base body 1 corresponds to a square-shouldered body type, while Base body 2 and Base body 3 fall under the sloping-shoulder category. This is further supported by the shoulder slope values observed in the flattened human body surface, which align with the body type classification results. The A4 classification indicates that Base body 1 exhibits relatively low gluteal protrusion, whereas Base body 2 and Base body 3 display more pronounced gluteal protrusion. However, the hip-to-waist difference in Base body 2 is greater than that in Base body 3, resulting in a more noticeable surface lift (protrusion) in the flattened human body surface for Base body 2. This suggests that both gluteal protrusion and hip-to-waist difference influence pattern design. Nonetheless, the hip-to-waist difference has a relatively greater effect on upper garment pattern design compared to gluteal protrusion.

5.4.2 Optimization of the Human Body Surface Unfolded Pieces

The modifications of the human body surface unfolded pieces for the three base bodies are conducted individually to provide essential data for constructing basic block patterns. Figure 5.18 illustrates the adjustment process of the flattened pattern for Base Body 1, Figure 5.19 depicts the adjustment process for Base Body 2, and Figure 5.20 presents the adjustment process for Base Body 3.

The process begins with adjusting the bust and scapular dart, as shown in part (a) of Figures 5.18–5.20. Half of the bust dart is transferred to the shoulder seam. In the figures, the dashed lines represent the original contours of the flattened pattern, while the solid

lines indicate the revised contours after dart transfer. Similarly, half of the scapular dart is transferred to the shoulder seam. For Base Body 1, however, no transfer occurs for the scapular dart due to its relatively small size.

Next, the shoulder width is adjusted based on the measured shoulder width. Finally, all sections are redrawn along the modified contour lines after dart transfer to produce the upper-body basic block pattern for each base body, as shown in part (b) of Figures 5.18–5.20. The following conclusions arise from analyzing pattern measurements of the modified human body surface unfolded pieces for the three base bodies:

- Back length is influenced by R1 and the degree of spinal curvature. Therefore, in addition to affecting back length, R1 also plays an important role in determining length proportions between upper and lower garments in tailored designs.

- R2 significantly affects shoulder width; different R2 classifications produce varying calculated shoulder widths.

- D5, with a fixed bust-to-waist difference and constant back neck depth, inversely correlates with the front waistline drop, the smaller the D5 value, the greater the front waistline drop. For Base Body 1 and Base Body 2, the front waistline drop is 1.2 cm, while for Base Body 3 it is 2.4 cm.

- The shoulder slope angle strongly impacts pattern shaping. Further subdivision of sloping and square shoulders enables more precise, body-conforming pattern design.

- Additionally, comparisons among the three patterns show that the more pronounced the spinal curvature, the deeper the back neck depth tends to be, while the front neck depth becomes relatively shallower. The front neck width is generally narrower than the back neck width, and the front neck depth is greater than the front neck width.

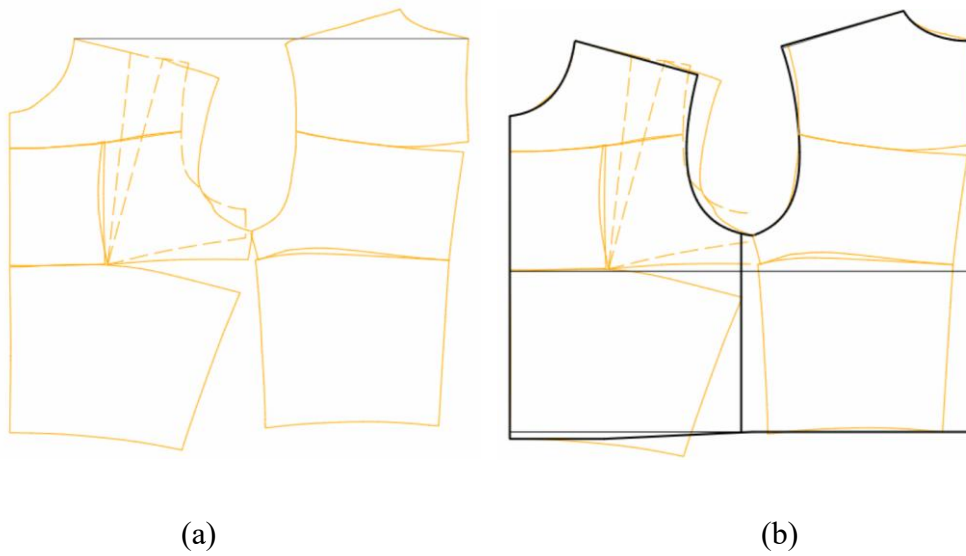


Figure 5.18: Surface Unfolded Pieces Modification of Base Body 1

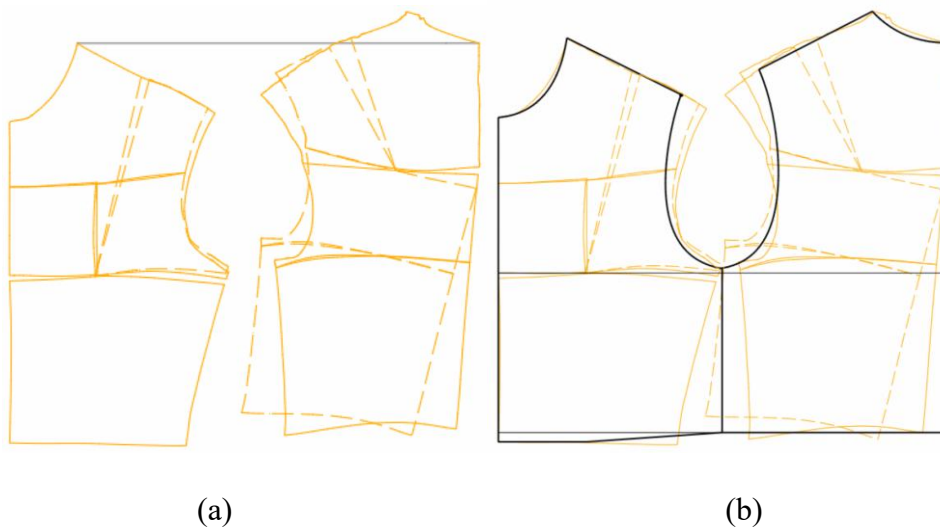


Figure 5.19: Surface Unfolded Pieces Modification of Base Body 2

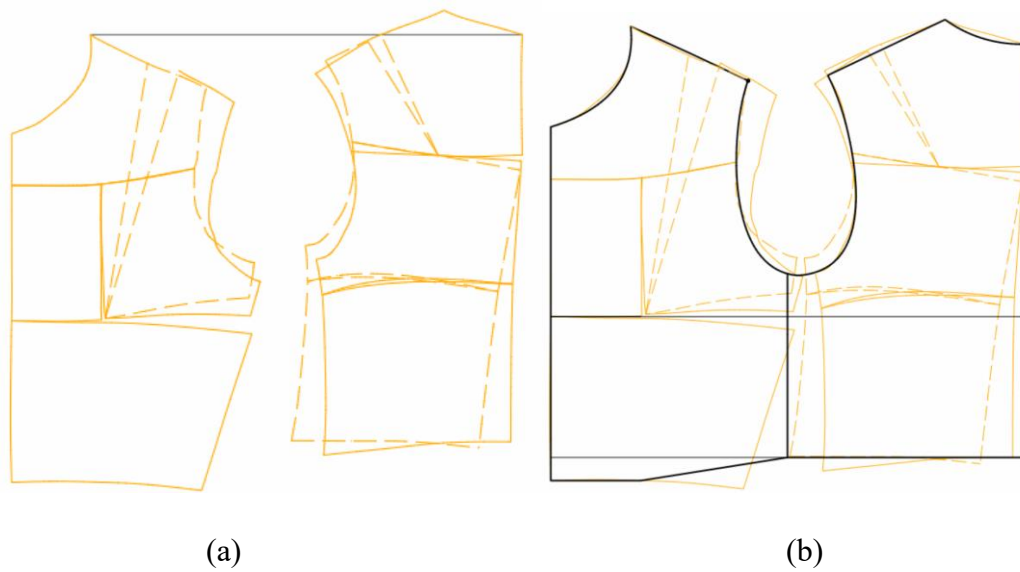


Figure 5.20: Surface Unfolded Pieces Modification of Base Body 3

5.4.3 Basic Ease Allowance Design

As identified in interviews with apparel design professionals in Chapter 4, the main factors influencing ease allowance design include the style of the garment, the fabric used, the body shape of the wearer, fit preferences, and the company's aesthetic standards for fit. Accordingly, in developing the basic upper garment pattern, this study primarily emphasizes the influence of body shape on ease allowance design.

Based on the existing research, the study focuses on ease allowance design for a slim-fit silhouette. The ease allowances for key regions in the basic block pattern are presented in Table 5.24, with detailed explanations provided for each design choice. Firstly, regarding chest ease, referring to both the literature and expert interview findings, an 8 cm ease allowance was applied consistently to all three body types in the slim-fit basic block

pattern. For back length ease, different fit allowances were applied according to the classification of D1; smaller bust–waist differences correspond to greater designed ease.

Table 5.24: Ease Allowance Design of Each Body Type

Body Type	II-I	V-I	III-III
Bust (cm)	8	8	8
Back Length (cm)	0~1	1~2	1~2
Armhole Depth (cm)	0~1	0~1	0~2
Back Neck Width (cm)	2	2	2
Back Width (cm)	1	1	1
Armhole Width (cm)	2	2.5	2.5
Front Waistline Drop (cm)	1.6	1.6	2.4
Shoulder Width (cm)	0	0	0
Shoulder Slope (°)	3	3	3

Similarly, armhole depth ease varies based on D1 classification, with body types showing smaller bust–waist differences receiving slightly increased ease.

The armhole width ease is also influenced by D1: for body types V-I and III-III (with smaller bust–waist differences), an additional ease allowance of up to 0.5 cm was

added compared to type II-I. For back neck width and back width, the same ease values were applied to all three body types.

The front waistline drop was determined based on values observed in the flattened surface patterns of each base body. The shoulder width was kept consistent with the original measurements without any additional ease. As for shoulder slope, due to the connection between the torso and arms, a base level of functional ease was required. Therefore, the same ease value was assigned to shoulder slope across all body types.

5.4.4 Parametric Design of the Basic Block Pattern

Table 5.25 presents the proportional distribution of all samples across various subdivided body types. In D10, Type II, with a hip-bust difference of approximately 2 cm, accounts for the largest proportion, followed by Type I with a hip-bust difference of approximately 7 cm. In R1, Type II, with a waist height-to-body height ratio of approximately 0.617, also shows the highest proportion, followed by Type I with a ratio of about 0.239, indicating a relatively longer lower body. In R2, Type I, with normal shoulder width, constitutes the largest proportion, followed by Type II with narrow shoulder width. In A1, Type II, with a shoulder slope around 24.9, has the highest proportion. Similarly, in A4, Type II, with hip protrusion around 17.7, also accounts for the largest share.

Table 5.25: Proportional Distribution of Subdivided Body Types

Variables	I		II		III	
	Centroid	Proportion (%)	Centroid	Proportion (%)	Centroid	Proportion (%)
D10 (cm)	7.383834	36.2	2.043218	42.6	-4.1507	21.2
R1	0.627632	34.9	0.616895	46.5	0.605086	18.6
R2	0.238754	47.2	0.21991	33.8	0.258515	18.9
A1 (cm)	19.71569	24	24.89607	48.8	29.45749	27.2
A4 (cm)	12.94309	26.5	17.70123	43.8	21.96658	29.7

The body type subdivisions of the three base body models employed in surface flattening are shown in Table 5.26. For Base Body 1, the corresponding D10 falls under Type II, which has the second highest proportion after Type I. Its corresponding A1 belongs to Type I, whose proportion is notably lower than that of Type II. For Base Body 2, A1 corresponds to Type III, which also has a much smaller proportion compared to Type II; similarly, Base Body 3's A1 also falls under Type III. Apart from the cases mentioned above, all other body type classification indicators for the three reference models fall into the most common category.

Table 5.26: Body Type Subdivisions of the Three Base Bodies

Samples	D1	D5	R1	R2	D10	A1	A4
Base Body 1	II	I	II	I	II	I	I

Table 5.26 continued

Base Body 2	III	III	II	I	I	III	II
Base Body 3	V	I	II	I	I	III	II

Therefore, the design of the fundamental patterns is based on the most prevalent categories within each body type subdivision. The specific intermediate body type categories employed for the basic block patterns are listed in Table 5.27. Based on the body type classifications of the three reference body models shown above, the A1 category for each type is assigned to Type II with the highest proportion in shoulder slope. This approach ensures that the basic block patterns corresponding to the three body types can accommodate a wider range of body shapes.

Table 5.27: Subdivided Body Type Categories for Each Basic Block Pattern

Body Type	D1	D5	D10	R1	R2	A1	A4
II-I	II	I	II	II	I	II	I
V-I	V	I	I	II	I	II	II
III-III	III	III	I	II	I	II	II

Based on the subdivided categories of each body type, the corresponding basic block patterns are developed. The first step involves establishing the relationship between human body parts and pattern components, as shown in Table 5.28. According to the table, back length is determined by both overall height and waist height. The depth of the

armhole is calculated using the ratio between armhole depth and back length from the pattern. The back neckline width is defined by the classification of D1, while the back neckline depth is derived from its proportional relationship to the back neckline width, approximately one-third of the latter. Both front neckline width and front neckline depth are determined based on the back neckline width of each body type. The calculation methods for different shoulder widths vary according to the R2 classification.

Table 5.28: Relationship Between Basic Block Measurements and Classification Indicators

Classification Indicators	Anthropometric Measurements	Pattern Measurements
D5	L14	Back Length Armhole Depth
R1	L4	
D1	W12	Back Neck Width Back Neck Depth
	G4	Front Neck Width Front Neck Depth
D5	W2	Back Width /2
R2	W1	
G1	W6	Armhole Width
D10	G9	
D5	D5	Waistline Drop
R2	W1	Shoulder Width
A1	A1	Shoulder Slope

Subsequently, based on the subdivided body type categories, the parametric regression relationships for each component of the basic block patterns are calculated. This process combines the regression models established earlier for different body parts according to classification indicators and the previously defined ease allowances in the basic block pattern design. The resulting parametric relationships for each body type's basic block pattern components are presented in Tables 5.29, 5.30, and 5.31. In these tables, "Equations" represents the parametric design process of each pattern dimension, that is, the value of each pattern dimension was obtained by adding ease allowance (the bolded values in the equations) to the body dimension. "Parametric Relationships" represents the parametric relationship between the body dimensions and the pattern dimensions. Through these parametric relationships, the pattern dimensions can be directly calculated from the body dimensions, thereby enabling the parametric design of the patterns.

Finally, based on the flattened patterns of the three base body models and the parametric relationships and calculated values corresponding to each body component for each body type, the basic block patterns were constructed. The resulting basic block patterns for each body type are shown in Figure 5.21, where (a), (b), and (c) represent the parametric basic block patterns for body types II-I, V-I, and III-III, respectively.

By aligning the back neck points and center back lines of the three basic block patterns, a comparative analysis of their characteristics was conducted, as shown in Figure 5.22. The green line represents the basic block pattern for body type III-III, the red line corresponds to V-I, and the blue line denotes II-I. As illustrated, both body types II-I and

V-I fall under the same D5 category; therefore, the waistline drop is set at 1.6 cm. In contrast, body type III-III falls into a D5 category where the front waist length exceeds the back waist length, resulting in a greater waistline drop of 2.4 cm. In addition, the three body types differ in their D5 classifications, which leads to variations in the horizontal position of the front neckline point relative to the back neckline point. Among them, II-I has the largest bust-to-waist difference at 18 cm, followed by V-I at 14 cm, and III-III at 10 cm. Correspondingly, the horizontal height difference between the front and back neckline points decreases progressively across the three body types. Furthermore, differences in D10 classifications among the three body types are also apparent. Since D10 affects upper arm circumference, it directly influences the amount of ease added to the armhole width in the basic block pattern. Both V-I and III-III fall under Type I for D10, indicating a larger hip-to-bust difference. According to the regression relationships, this results in a relatively larger upper arm circumference, and consequently, greater ease in armhole width for V-I and III-III compared to II-I.

Based on the existing drafting method for slim-fit men's shirt basic block patterns in ready-to-wear (RTW) design, a standard slim-fit shirt pattern was developed for a male body with a height of 175 cm and a chest circumference of 92 cm. This RTW pattern was then compared with the basic block patterns for the three distinct body types, as shown in Figure 5.23. Figure 5.23(a) compares the II-I body type (blue outline) with the RTW pattern (black outline); Figure 5.23(b) compares the V-I body type (red outline) with the RTW pattern; Figure 5.23(c) compares III-III body type (green outline) with RTW pattern.

Table 5.29: Parametric Design of Each Part of Basic Block Pattern for Body Type II-I

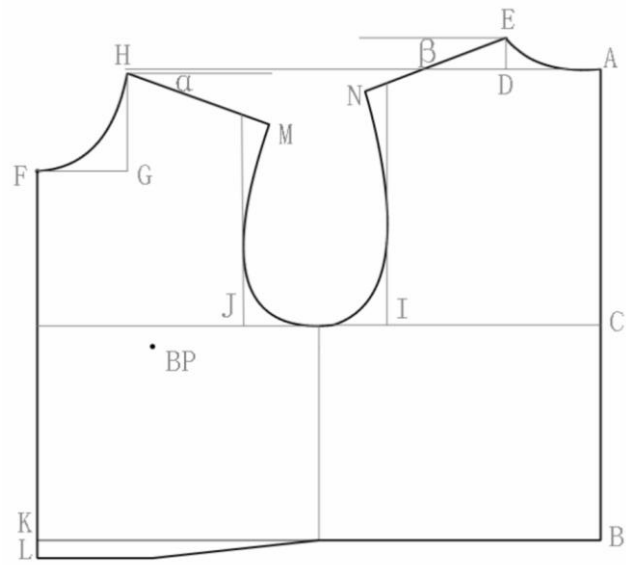
Pattern Dimensions	Equations	Parametric Relationships
Back Length (A~B)	$L14+(0\sim1)$	$0.24656\times L1-1.226+(0\sim1)$
Armhole Depth (A~C)	(Armhole Depth/ Back Length) $+(0\sim1)$	$0.548\times L14+(0\sim1)$
Back Neck Width (A~D)	$W12/2+2$	$0.01308\times L1+0.032373\times G1+1.148105+2$
Back Neck Depth (D~E)	Back Neck Width /3	
Front Neck Width (F~G)	Back Neck Width -0.4	
Front Neck Depth (G~H)	Front Neck Width +0.8	
Back Width /2 (C~I)	$W2/2+1$	$0.0393825\times L1+0.082965\times G1+3.44853+1$
Armhole Width (I~J)	$W6+2$	$0.15\times G1-3.124+2$
Waistline Drop (K~L)	D5	1.6
Shoulder Width (A~N)	$W1/2$	$0.0885\times L1+0.037\times G1+1.934$
Shoulder Slope ($(\alpha+\beta)/2$)	$(\alpha+\beta)/2$	20.5

Table 5.30: Parametric Design of Each Part of Basic Block Pattern for Body Type V-I

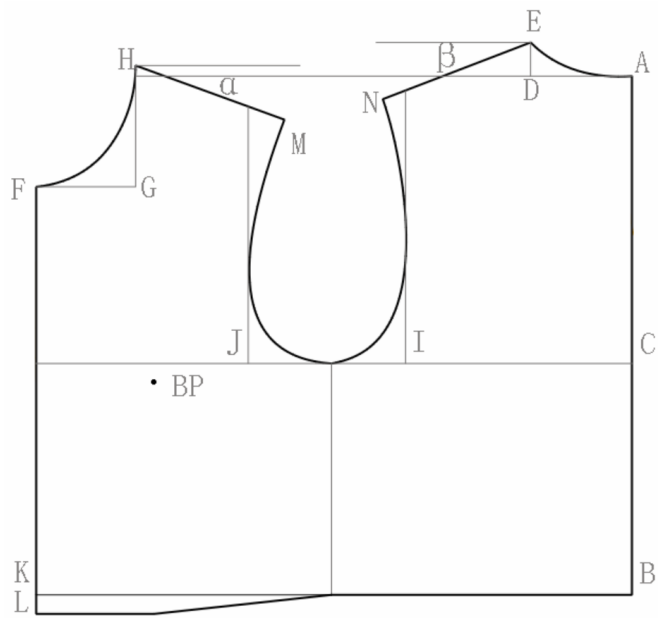
Pattern Dimensions	Equations	Parametric Relationships
Back Length (A~B)	$L14+(1\sim2)$	$L14=0.24656\times L1-1.226+(1\sim2)$
Armhole Depth (A~C)	(Armhole Depth/ Back Length) +(0~1)	$0.55\times L14+(0\sim1)$
Back Neck Width (A~D)	$W12/2+2$	$0.0147805\times L1+0.022673\times G1+1.806766+2$
Back Neck Depth (D~E)	Back Neck Width /3	
Front Neck Width (F~G)	Back Neck Width -0.2	
Front Neck Depth (G~H)	Front Neck Width +1.8	
Back Width /2 (C~I)	$W2/2+1$	$0.0393825\times L1+0.082965\times G1+3.44853+1$
Armhole Width (I~J)	$W6+2.5$	$0.15\times G1-3.124+2.5$
Waistline Drop (K~L)	D5	1.6
Shoulder Width (A~N)	$W1/2$	$0.0885\times L1+0.037\times G1+1.934$
Shoulder Slope ($(\alpha+\beta)/2$)	$(\alpha+\beta)/2$	20.5

Table 5.31: Parametric Design of Each Part of Basic Block Pattern for Body Type III-III

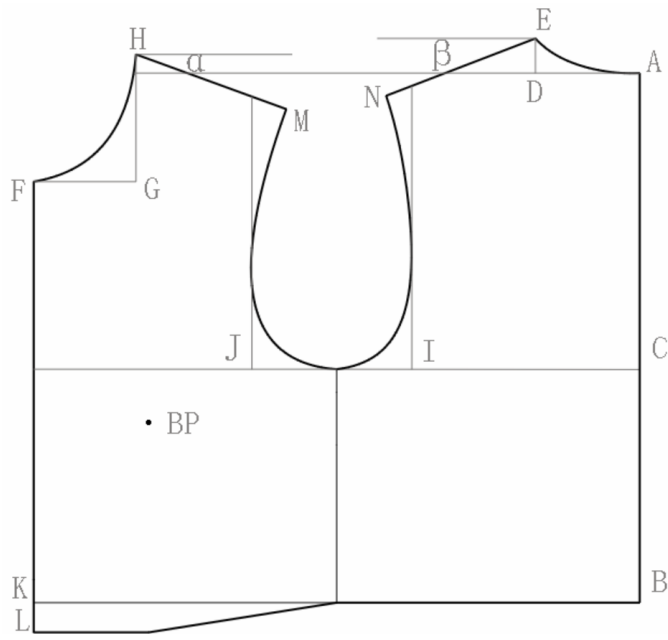
Pattern Dimensions	Equations	Parametric Relationships
Back Length (A~B)	$L14+(1\sim 2)$	$L14=0.23668\times L1-0.23491+(1\sim 2)$
Armhole Depth (A~C)	(Armhole Depth/ Back Length) +(0~2)	$0.55\times L14+(0\sim 2)$
Back Neck Width (A~D)	$W12/2+2$	$0.006035\times L1+0.0356775\times G1+2.2506775+2$
Back Neck Depth (D~E)	Back Neck Width /3	
Front Neck Width (F~G)	Back Neck Width -0.2	
Front Neck Depth (G~H)	Front Neck Width +2	
Back Width /2 (C~I)	$W2/2+1$	$0.0250455\times L1+0.124471\times G1+1.990822+1$
Armhole Width (I~J)	$W6+2.5$	$0.15\times G1-3.124+2.5$
Waistline Drop (K~L)	D5	2.4
Shoulder Width (A~N)	$W1/2$	$0.0885\times L1+0.037\times G1+1.934$
Shoulder Slope ($(\alpha+\beta)/2$)	$(\alpha+\beta)/2$	20.5



(a) Type II-I



(b) Type V-I



(c) Type III-III

Figure 5.21: Parametric Basic Block Patterns

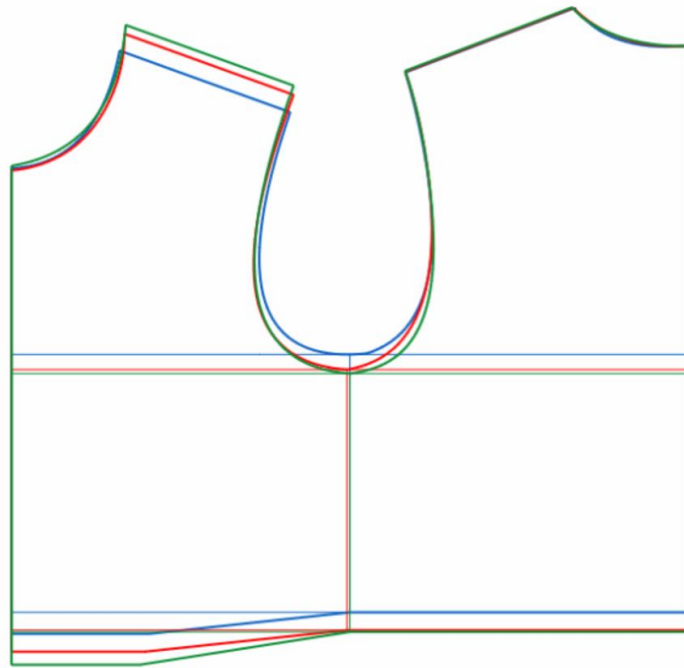


Figure 5.22: Basic Block Pattern Comparison of the Three Body Types

From Figure 5.23(a), it can be observed that the RTW pattern is most similar to the II-I body type pattern, making it suitable for body shapes where the back waist length is greater than the front waist length. The center back length of the RTW pattern is slightly longer. In Figure 5.23(b), since body type V-I has a smaller bust–waist difference than II-I, the pattern shows relatively greater ease in armhole depth and front waist length. As shown in Figure 5.23(c), for body type III-III, where the front waist length exceeds the back waist length, the RTW pattern differs substantially from the custom pattern in the upper front section above the bust line. Additionally, due to a smaller bust–waist difference than the other two body types, the armhole depth is relatively larger. Overall, the basic block patterns generated based on the body type classification method proposed in this study more accurately reflect the morphological characteristics of different body types compared to the standard RTW pattern.

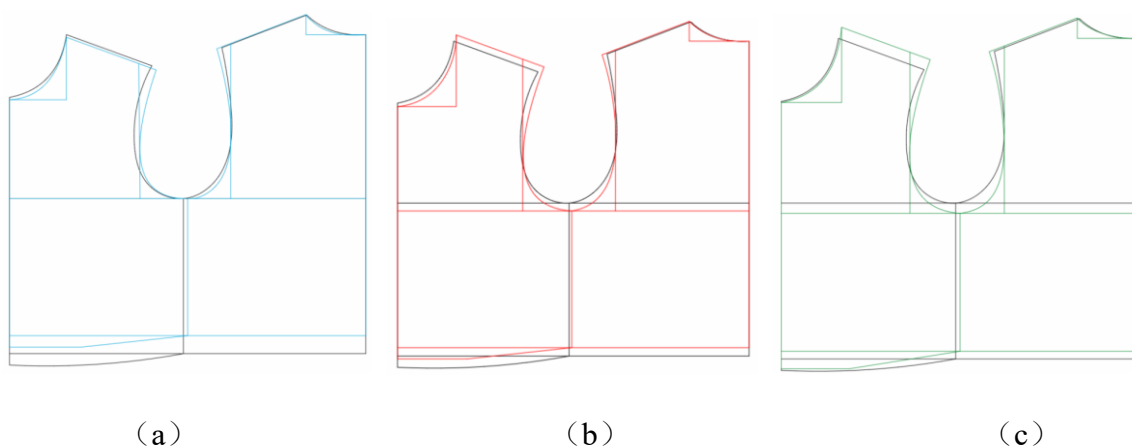


Figure 5.23: Basic Block Pattern Comparison with Ready-wear Pattern

5.5 Personalized Pattern Generation for Men's Shirt

5.5.1 Slim Fitted Basic Patterns of Men's Shirt

Based on the previously constructed upper-body basic block patterns for each body type, fitted shirt basic patterns were developed. First, the length from the waistline to the hipline was added to the upper-body pattern. This value was calculated by the difference between waist height and hip height obtained from the regression model. Next, the waist and hip measurements were adjusted according to the classification of each body type's bust-to-waist difference (D1) and hip-to-bust difference (D10), respectively.

As shown in Figure 5.24, (a) presents the shirt basic pattern for body type II-I (represented by the blue outline in (d)), (b) shows the shirt basic pattern for body type V-I (red outline in (d)), (c) displays the shirt basic pattern for body type III-III (green outline in (d)), and (d) provides a comparative view of the shirt basic patterns for all three body types.

For Type II-I, the D1 classification corresponds to an 18 cm bust-to-waist difference, and the D10 value is 2 cm. Accordingly, the side seams at the waistline on both the front and back pieces were taken in by 1.6 cm, and 0.5 cm was added at the hipline on both the front and back pieces. The side seam was then redrawn to create the fitted shirt basic pattern for Type II-I.

For Type V-I, with a D1 of 14 cm and a D10 of 7 cm, the side seams at the waistline on the front and back pieces were taken in by 1.2 cm, and 1.75 cm was added at

the hipline on both pieces. The side seam was then redrawn to form the fitted shirt basic pattern for Type V-I.

Similarly, for Type III-III, with a D1 of 10 cm and a D10 of 7 cm, the side seams at the waistline were taken in by 0.8 cm, and 1.75 cm was added at the hipline. The side seam was redrawn to obtain the fitted shirt basic pattern for Type III-III.

Figure 5.25 presents a comparison between the customized basic shirt patterns and the ready-to-wear (RTW) basic shirt pattern. Figure 5.25(a) compares the shirt basic pattern for body type II-I with the RTW pattern, Figure 5.25(b) compares the pattern for body type V-I with the RTW pattern, and Figure 5.25(c) compares the pattern for body type III-III with the RTW pattern. The pattern differences above the waistline are consistent with those observed in the basic upper garment pattern comparisons. The focus here is on the differences at and below the waistline.

Due to the variation in D1 classification across body types, different waist ease allowances were incorporated in the shirt pattern designs. The waist ease in the RTW pattern closely aligns with that of body type V-I. For body type III-III, which has a smaller bust–waist difference, the waist ease is relatively larger than that of the RTW pattern. Similarly, the hip ease allowance also varies because each body type falls under a different D10 classification. Compared to the RTW pattern, all three body types exhibit larger hip ease allowances, better accommodating variations in lower body shape.

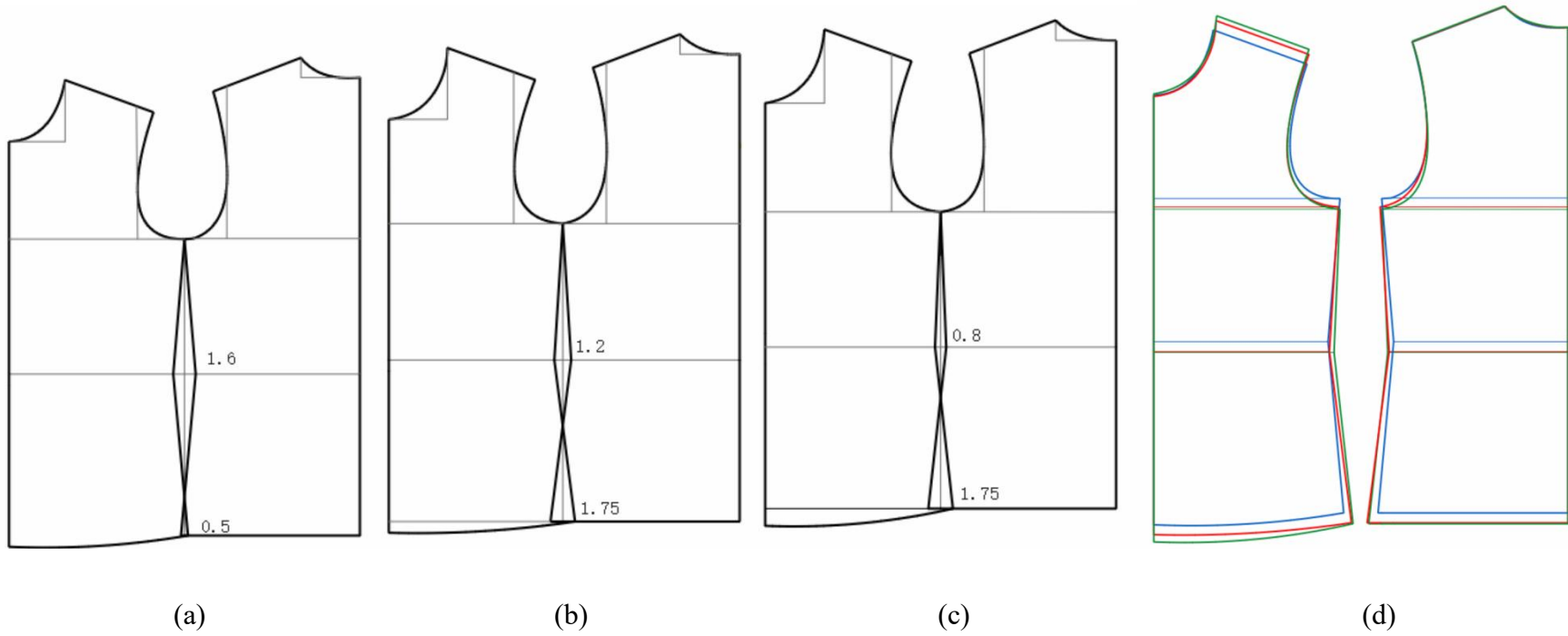


Figure 5.24: Shirt Basic Patterns for the Three Body Types

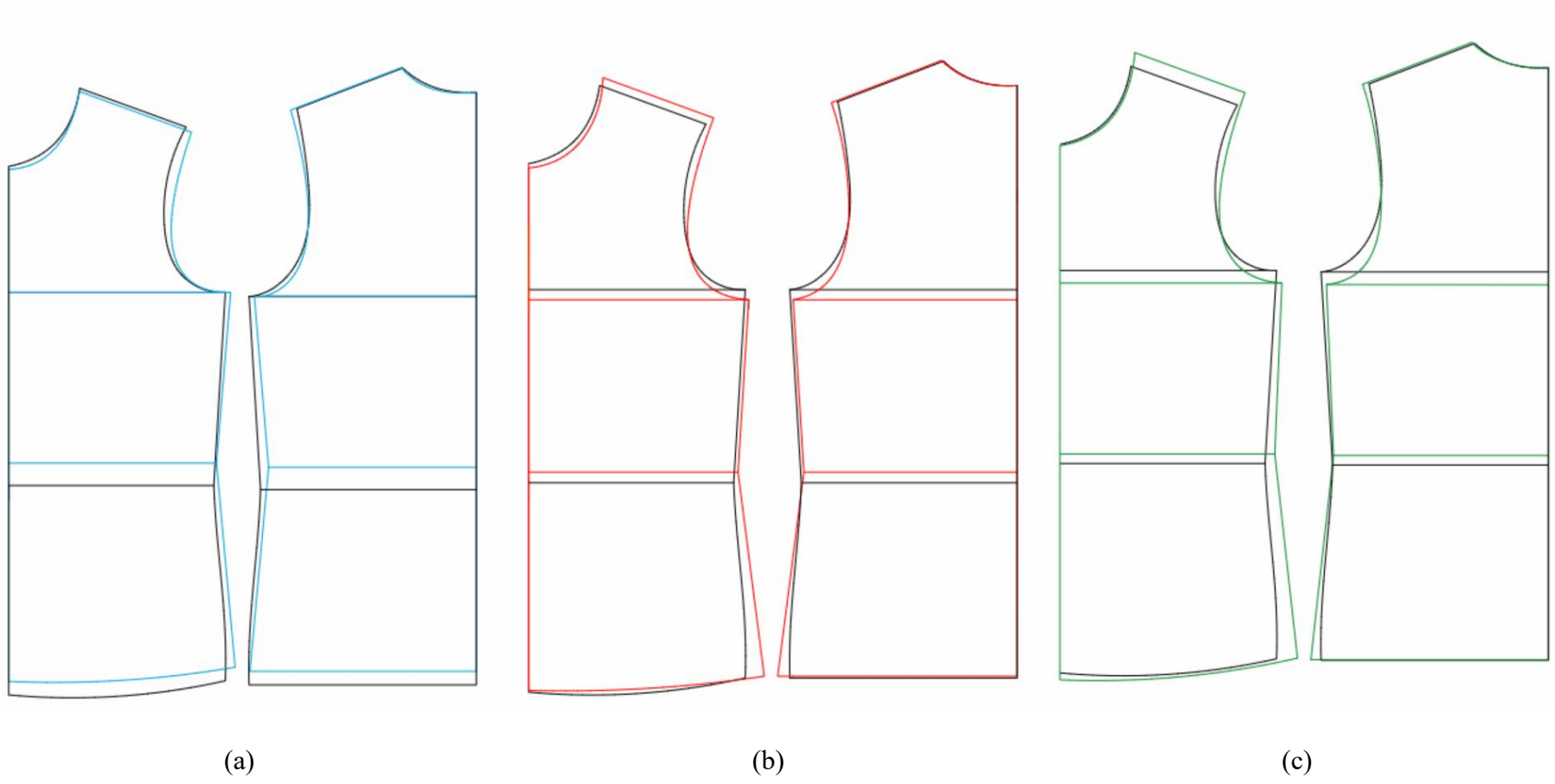


Figure 5.25: Basic Pattern Comparison between Customized and Ready-Wear Shirt

5.5.2 Personalized Slim Fitted Patterns of Men's Shirt

Among the sample subjects with a height of 175 cm and a bust circumference of 92 cm, individuals were chosen representing body types Type II-I, Type V-I, and Type III-III. Although these samples share the same classification categories for D1 and D5, differences occur in their detailed body type subdivisions. These differences are displayed in Table 5.32, where categories marked in red indicate inconsistencies with those applied in the corresponding basic pattern design.

Table 5.32: Body Type Categories of the Samples

No.	D1	D5	D10	R1	R2	A1	A4
III-III-1	III	III	I	II	I	III	II
III-III-2	III	III	I	II	I	III	II
III-III-3	III	III	I	III	III	II	I
V-I-1	V	I	II	I	II	II	III
V-I-2	V	I	I	II	III	III	II
V-I-3	V	I	II	II	I	III	I
V-I-4	V	I	I	II	I	III	II
II-I-1	II	I	II	II	I	I	I
II-I-2	II	I	II	II	I	II	III
II-I-3	II	I	II	II	II	II	II

Subsequently, based on the previously constructed slim fitted shirt basic patterns and the parametric regression models, slim fitted shirt patterns were created for each sample according to their specific subdivided body type categories (i.e., R1, R2, D10, and A1). First, variations in R1 were used to calculate the height difference between the waist and hip, thereby determining the vertical position of the hipline. D10 was used to adjust the hip circumference accordingly. Variations in R2 resulted in differences in shoulder width, which in turn affected the back width. A1 determined the shoulder slope angle. Following these design principles, fitted shirt patterns were developed for ten sample body types. The main adjustment procedures and methods are illustrated in Figure 5.26, and the main parametric relationship for adjustment is referenced in Table 5.29-31. The resulting personalized fitted shirt patterns for the ten samples are also shown in Figure 5.27. These patterns were used in subsequent virtual fitting experiments.

In Figure 5.27, (a) shows the basic shirt pattern for Type III-III in black, with the corresponding shirt patterns for individual samples shown in green; (b) shows the Type V-I basic shirt pattern in black, with sample-specific patterns in red; (c) displays the Type II-I basic shirt pattern in black, with the corresponding sample patterns in blue. The overlapping patterns clearly illustrate how each sample's pattern is adjusted from the basic pattern according to specific body shape characteristics. Notable differences can be observed in the shoulder area, armhole, and garment length, emphasizing the targeted modifications made for different body types.

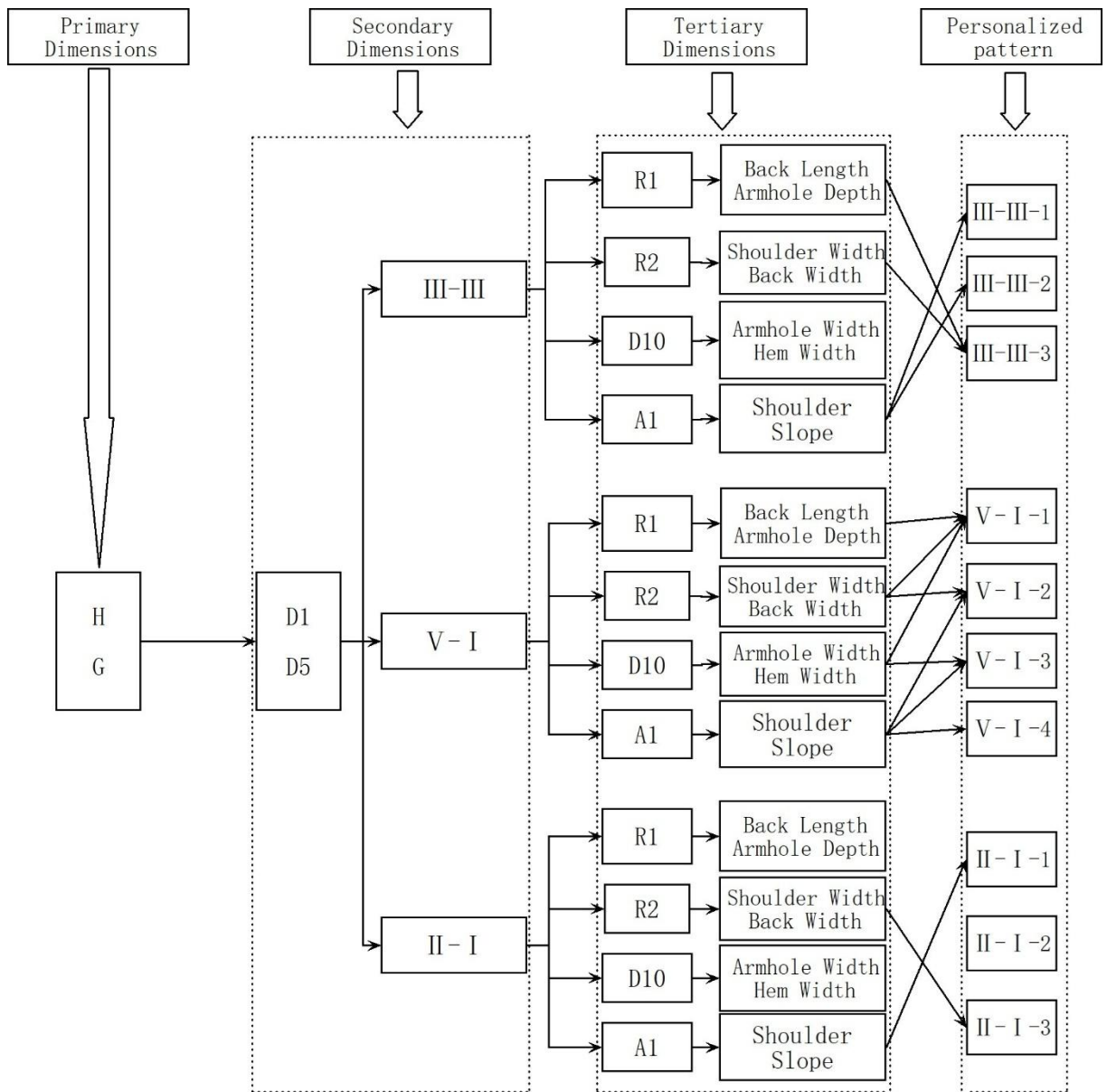
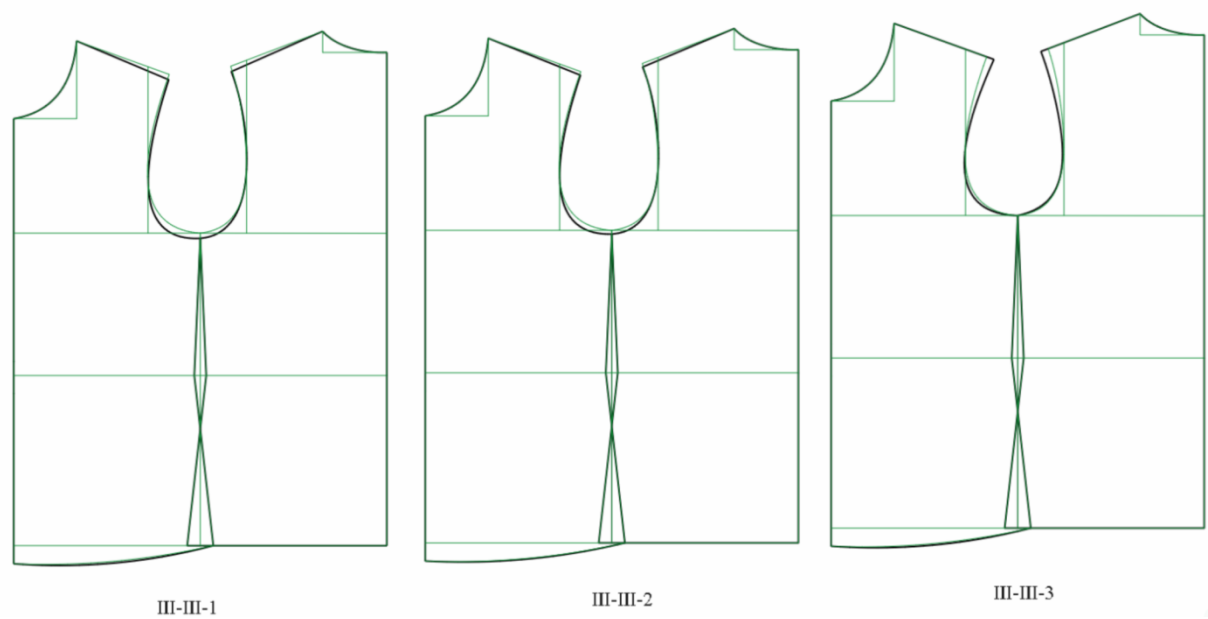
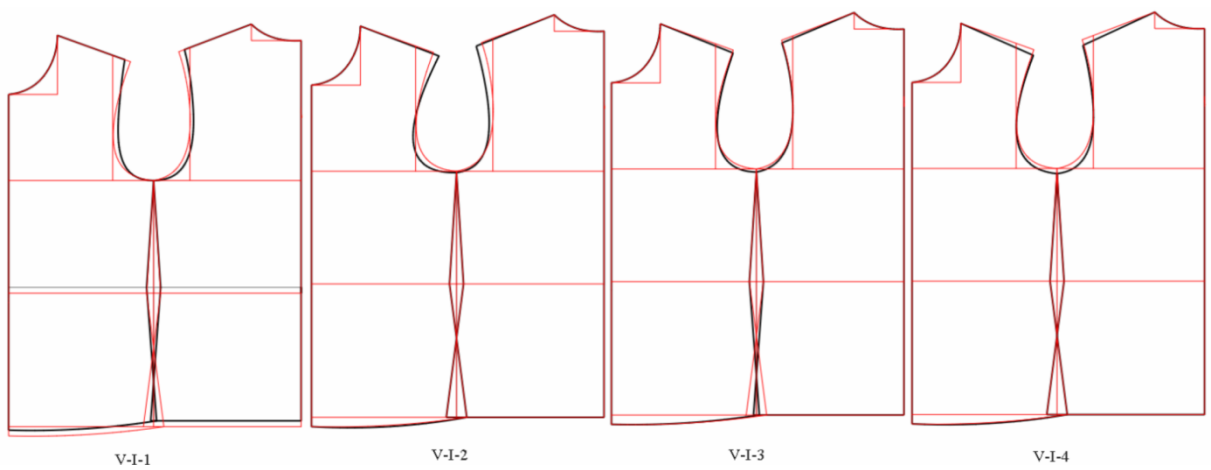


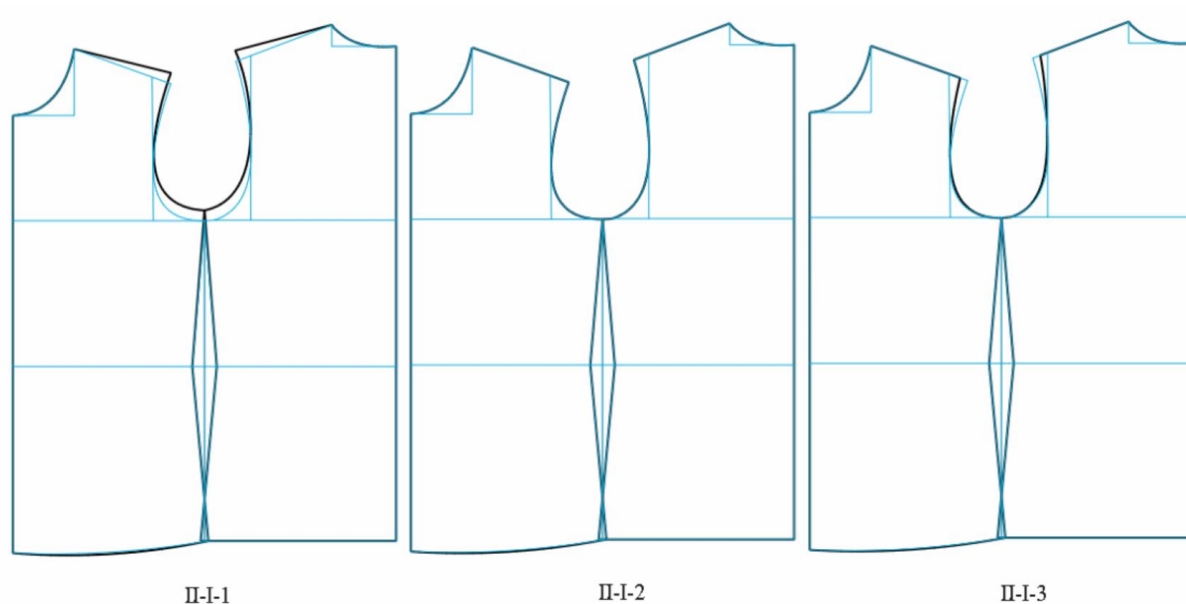
Figure 5.26: Parametric Design Procedure of Personalized Fitted Shirt Patterns



(a) Type III-III (From left to right: III-III-1, III-III-2, and III-III-3)



(b) Type V-I (From left to right: V-I-1, V-I-2, V-I-3, and V-I-4)



(c) Type II-I (from left to right: II-I-1, II-I-2, and II-I-3)

Figure 5.27: the Personalized Fitted Shirt Patterns

5.5.3 Results and Discussion

In this study, a sequence of preprocessing steps was applied to body scans of intermediate body types with varied morphological characteristics. Following preprocessing, a surface fitting method reconstructed 3D human body surfaces, which were then flattened into 2D surface patches using 3D unwrapping techniques. A crucial step in this process involved accurate identification of anatomical landmarks, as precise localization ensures high-fidelity preservation of surface shape features. Control X software defined Datum Planes and generated spline curves, while MATLAB extracted point cloud coordinates, enabling precise positioning and coordinate retrieval of key anatomical landmarks, including the front neck point, back neck point, side neck point,

front armpit point, back armpit point, armpit point, and shoulder point.

Measurements were taken on flattened patterns corresponding to different body types, focusing on key dimensions such as back length, front waist length, back waist length, shoulder width, and shoulder slope. A comparative analysis of these dimensions across body types revealed that the dimensional features of the 2D flattened patterns corresponded with the morphological characteristics of the original 3D body shapes. The relationship between body shape and 2D pattern features can be summarized as follows:

i. Chest prominence: Given the same chest-to-waist difference, a greater disparity between front and back waist length corresponds to a more prominent chest posture. This is reflected in 2D patterns by increased bust dart volume, wider chest width, narrower back width, greater waistline drop, smaller vertical difference between front and back neck points, shallower back neck depth, and proportionally deeper front neck depth.

ii. Back length variation: The waist height-to-body height ratio and the difference between front and back waist length affect back length. When the difference in front and back waist length is constant, a higher waist height-to-body height ratio leads to a shorter back length. Conversely, with a fixed difference between front and back waist length, a smaller difference in waist height-to-body height ratio produces a longer back length.

iii. Shoulder structure: A larger shoulder width-to-body height ratio results in greater shoulder width in the pattern. Additionally, a larger physical shoulder slope corresponds to a greater average shoulder slope angle in the pattern.

Based on these analyses of the relationships between body features and pattern dimensions, a correspondence was established between body measurements and block dimensions across different body shape classifications. This enabled the development of parameterized computational models for basic block pattern components corresponding to various body types. Using these basic block patterns, shirt basic pattern reflecting the primary body shape classification (first-level classification) were produced. Subsequently, localized adjustments were applied according to the secondary classification to optimize specific pattern regions. This two-step approach facilitates rapid generation of personalized shirt patterns based on foundational blocks.

The correspondence between body shape characteristics and pattern dimensions, along with the method for generating personalized shirt patterns, is illustrated in Figure 5.28. It outlines the two-stage personalized pattern generation process. First, a basic block is chosen based on primary classifications (D1, D5), ensuring proportional balance among chest, waist, and hip. Second, localized adjustments are applied using secondary features, for example, +1.75 cm hip ease for $D10 = 7$ cm and shoulder slope reduced by 5° for $A1 = 29^\circ$. This hierarchical approach balances efficiency in utilizing predefined blocks and accuracy in customizing for individual morphology, addressing FC's demand for rapid and precise pattern generation.

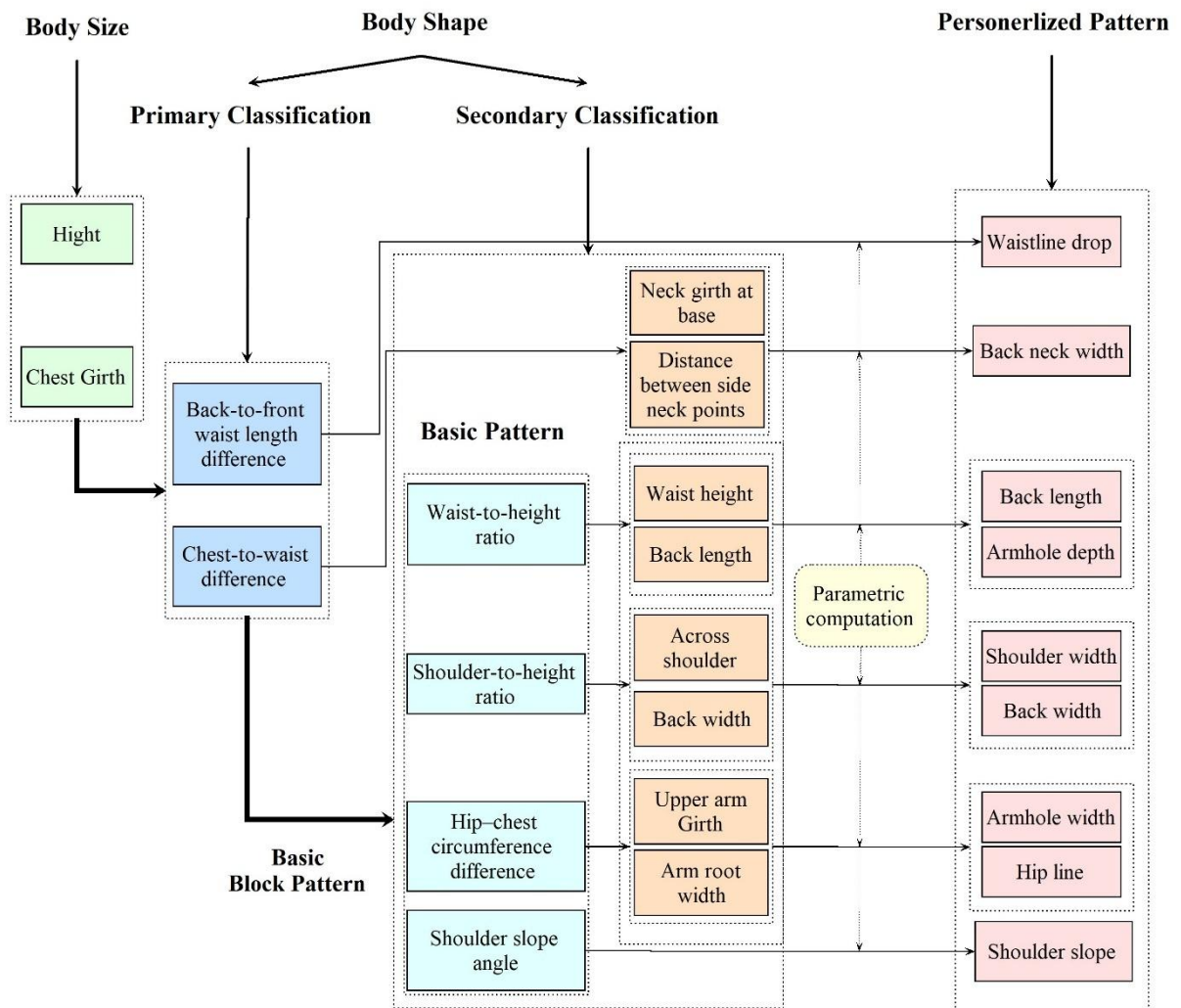


Figure 5.28: Personalized Shirt Pattern Generation

5.6 Summary

Based on the qualitative analysis in the previous chapter, it was identified that key factors affecting garment fit include sizing systems and basic block patterns. Therefore, this chapter adopts a quantitative analytical approach to establish a theoretical understanding of the relationships among body shape, body measurements, and fit, and derives a body shape classification scheme appropriate for FC. In the Chinese national

sizing standard, body types are classified into four categories—Y, A, B, and C—based solely on the bust-to-waist difference which do not sufficiently meet the needs of fit customization. This study adopts the bust-to-waist difference, the front-to-back waist length difference (for upper garments), and the hip-to-bust difference (for lower garments), as primary indicators for body type classification, as well as waist height-to-body height ratio, shoulder width-to-body height ratio, shoulder slope angle, and hip protrusion angle, as secondary indicators for body type classification, which not only accommodate varying levels of fit customization requirements but also achieve overall coordination between upper and lower garments.

While current production technologies primarily rely on 2D garment CAD and traditional prototype fitting, 3D pattern making and virtual fitting technologies remain highly anticipated advancements. Utilizing 3D body models and a 3D-to-2D flattening method, the study quantitatively investigates the relationship between body shape and flattened patterns, revealing measurable correlations between body morphology and pattern structure. Based on body shape classification, parametric basic block patterns were developed for each body type. Finally, a method for the rapid generation of personalized patterns was proposed.

CHAPTER 6

FIT VALIDATION OF PERSONALIZED PATTERNS

6.1 Introduction

This chapter presents the quantitative data analysis and discussion of findings from the third objective: to validate the effectiveness of the proposed CAD-integrated pattern generation method in producing accurate personalized fits from 3D body data. While prior studies have explored 3D body scanning and virtual fitting (Chan et al., 2022; Hong et al., 2017b; K. Liu et al., 2017; Z. Wang et al., 2021), few have systematically classified body types and optimized pattern adjustments based on multi-dimensional anthropometric differences. This study addresses this gap by introducing a detailed body classification system (D10, R1, R2, A1) and demonstrating its impact on garment fit through comparative pressure distribution evaluation. Virtual fitting experiments were conducted using real 3D body models in OptiTex, comparing the generated patterns with conventional ready-to-wear (RtW) patterns to confirm the proposed method's advantage in improving garment fit.

6.2 Fit Comparison Analysis

To evaluate the fit of the shirt bodice patterns produced by the method proposed in this study, virtual fitting experiments were performed using the slim-fit shirt bodice patterns described above. The simulations were conducted in OptiTex to assess the garment fit provided by the generated patterns. In addition, contemporary ready-to-wear

(RtW) shirt patterns were introduced as a comparative reference to confirm the differences between the two types of shirt patterns. Both the slim-fit and the corresponding ready-to-wear shirt bodice patterns were virtually fitted onto the sample body models using the software.

In Figures 6.1-6.10, the top-left quadrant displays the virtual fitting appearance of the fitted shirt pattern generated in this study for the corresponding body model. The top-right quadrant shows the pressure distribution map of the same pattern. The bottom-left quadrant presents the virtual fitting appearance based on the ready-to-wear pattern design for the corresponding body model, while the bottom-right quadrant illustrates the corresponding pressure distribution map. Pressure maps (right) use a gradient scale, with red indicating high pressure and blue indicating low pressure. Rectangles highlight key fit improvements, such as reduced scapular wrinkling in Figure 6.1.

In tables 6.1-6.10, maximum pressure values demonstrate that personalized patterns significantly reduced pressure compared to RtW for each body type, validating the body type classification's role in pattern optimization.

6.2.1 Fit Comparison Analysis for Body Type III-III

Type III-III is characterized by a small bust–waist difference and a longer front waist length relative to the back. As a result, compared to the ready-to-wear (RtW) pattern, this body type requires a greater front waist drop, a reduced height difference between the front and back neck points, a relatively larger armhole width, and a wider back neck width.

In the basic shirt pattern developed in this study for the III-III body type, shoulder slope modifications were also made.

From the virtual fitting appearance renderings shown in Figure 6.1 (left), it is evident that the custom-generated pattern provides a smoother surface at the front and back bodice and the armhole side seam, with no excess wrinkles or bulging. The garment exhibits better adherence at the scapular and waist areas, and the overall balance between the front and back is enhanced.

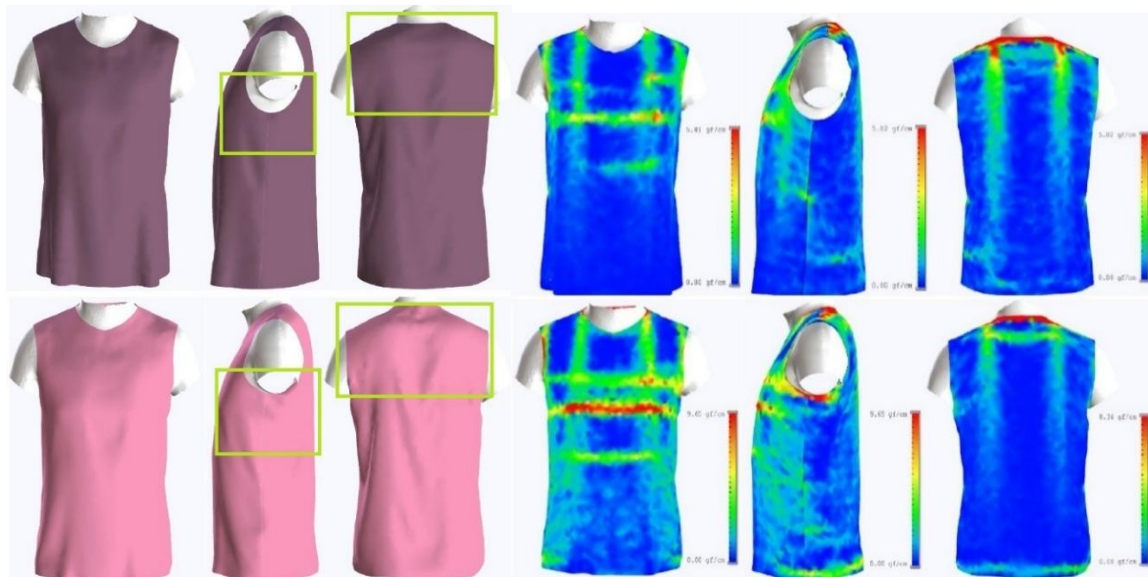


Figure 6.1: Virtual Fitting Comparison for Type III-III-1

Analyzing the pressure maps as shown in Figure 6.1 (right), the frontal view indicates that the custom pattern produces lower pressure in the neck, shoulder, chest, waist, abdomen, and hip areas compared with the RtW pattern. Specifically, as shown in Table 6.1, the maximum pressure in the RtW pattern reaches 9.65 gf/cm². In comparison,

the custom pattern's maximum is only 5.81 gf/cm², indicating a greater level of comfort due to increased ease at the front bodice. These findings suggest that the longer front waist length and reduced neck height difference in the custom pattern improve balance and flatness, enhancing comfort and fit.

In the side view pressure map, the custom pattern exhibits lower pressure at the shoulder seam, armhole, side seam, and hips, particularly in the armhole and hip areas, indicating enhanced comfort. The pressure map verifies this, with the maximum pressure in the custom pattern being 5.02 gf/cm², compared to 9.65 gf/cm² in the RtW pattern. This demonstrates that the D10 body type classification successfully optimized the ease allowance design for the armhole, waist, and hip.

Table 6.1: Maximum Pressure Value Comparison for Type III-III-1

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	5.81	9.65
Side	5.02	9.65
Back	5.02	8.36

In the back view, the RtW pattern shows more excessive ease, particularly at the scapular and armhole areas, where wrinkles caused by surplus fabric are distinctly visible. The pressure map supports this observation: the maximum pressure in the custom pattern is 5.02 gf/cm², while in the RtW pattern, it is 8.36 gf/cm². Although the custom pattern has

less ease at the scapular and armholes, it provides significantly lower pressure at the neck, resulting in greater overall comfort. Since the shoulder slope in this type belongs to the III category, the custom pattern incorporated shoulder slope adjustments, indicating that the A1 classification played a crucial role in optimizing both the shoulder slope and armhole design.

For III-III-2, which shares the same fine-grained classification as III-III-1, similar shoulder slope adjustments were applied based on the basic shirt pattern. As shown in Figure 6.2 (left), from the frontal view, the custom pattern shows better smoothness at the shoulder and chest; the side view reveals more wrinkling along the side seam and underarm in the RtW pattern, while the custom pattern remains more balanced. In the back view, the custom pattern is noticeably smoother at the neck and scapular areas.

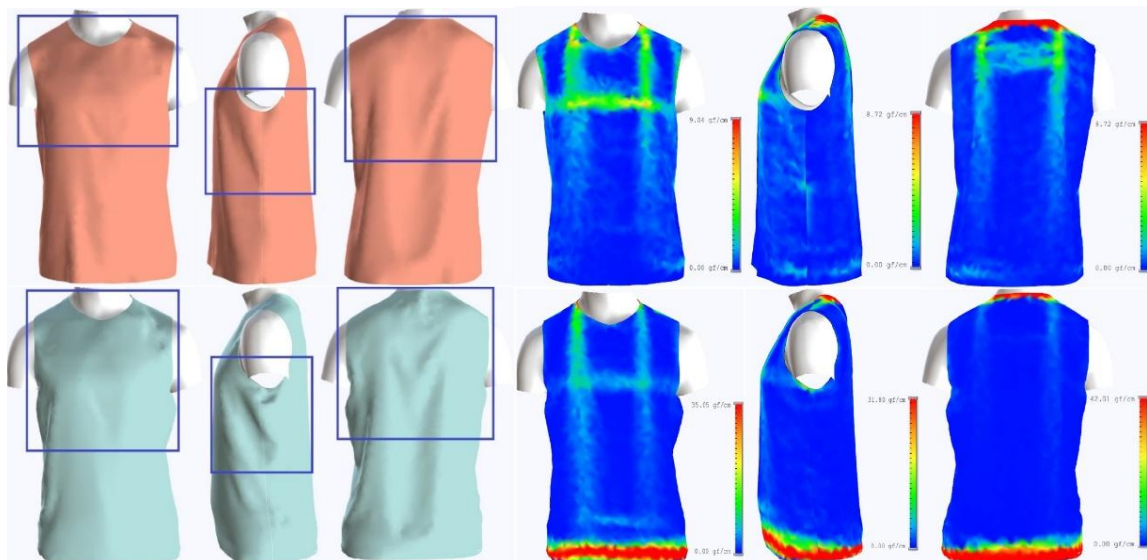


Figure 6.2: Virtual Fitting Comparison for Type III-III-2

As shown in Figure 6.2 (right) and Table 6.2, pressure maps from the front, side, and back also show lower hip pressure values for the custom pattern, emphasizing the effectiveness of the D10 classification in improving the hip pattern design. Since this body type exhibits sloped shoulders, the custom pattern incorporates adjustments for shoulder slope. Consequently, the neck and shoulder pressure values are higher than in the RtW pattern, but the excess ease at the armholes and side seams in the RtW design causes increased wrinkling. Overall, the fit and balance of the custom pattern are better than those of the RtW version.

Table 6.2: Maximum Pressure Value Comparison for Type III-III-2

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	9.04	35.05
Side	8.72	31.8
Back	8.72	42.01

For III-III-3, the detailed classification differs from the standard body regarding R1 and R2, causing modifications in back length, armhole depth, shoulder width, and back width based on the basic pattern. From the appearance renderings shown in Figure 6.3 (left), the smoothness on the front, side, and back is comparable between the two patterns.

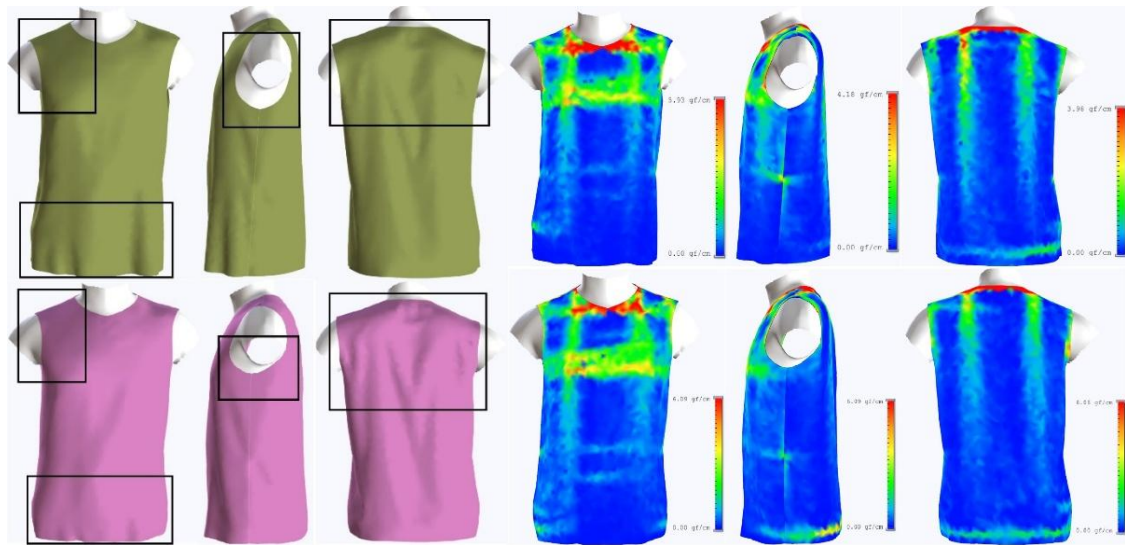


Figure 6.3: Virtual Fitting Comparison for Type III-III-3

However, the custom pattern provides greater hip ease and deeper armholes. Pressure values in Table 6.3 also indicate this: the custom pattern shows slightly lower pressures across all views, and notably lower pressure at the back width, compared to the RtW pattern. In conclusion, the overall fit and balance of the custom pattern are superior to those of the ready-to-wear pattern.

Table 6.3: Maximum Pressure Value Comparison for Type III-III-3

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	5.93	6.09
Side	4.18	6.09
Back	3.98	6.06

6.2.2 Fit Comparison Analysis for Body Type V-I

Type V-I is characterized by a larger bust–waist difference than Type III-III, with a

longer back waist length than front waist length. Compared to the ready-to-wear (RtW) pattern, the front waist drop remains unchanged; however, the height difference between the front and back neck points is smaller than that of the RtW pattern, yet greater than that of the III-III body type.

For V-I-1, the individual's detailed classifications, D10, R1, and R2, differ from the standard type. Therefore, based on the Type V-I basic shirt pattern, modifications were made to the armhole, hip circumference, shoulder width, back length, and back width. A comparison between the custom and RtW patterns shows no significant differences in appearance, but more noticeable differences in pressure distribution, as shown in Figure 6.4. Although the maximum pressure values displayed by the ready-to-wear pattern in each view are slightly lower than those of the customized pattern, the custom pattern exhibits reduced pressure distribution at the neck, shoulder, and chest, indicating a better fit from the front pressure map, as shown in Figure 6.4 (right) and Table 6.4.

This suggests that the D5 classification plays a crucial role in achieving balance between the front and back panels. In the side pressure map, the custom pattern shows reduced pressure distribution at the armhole and side seam, again indicating a superior fit. From the back pressure map, the custom version displays reduced pressure distribution at the scapula, armhole, and hip areas, contributing to enhanced comfort. This confirms that the D1 classification helped optimize waist ease, D10 improved the armhole and hip ease design, and R2 played a key role in optimizing the back width of the pattern.

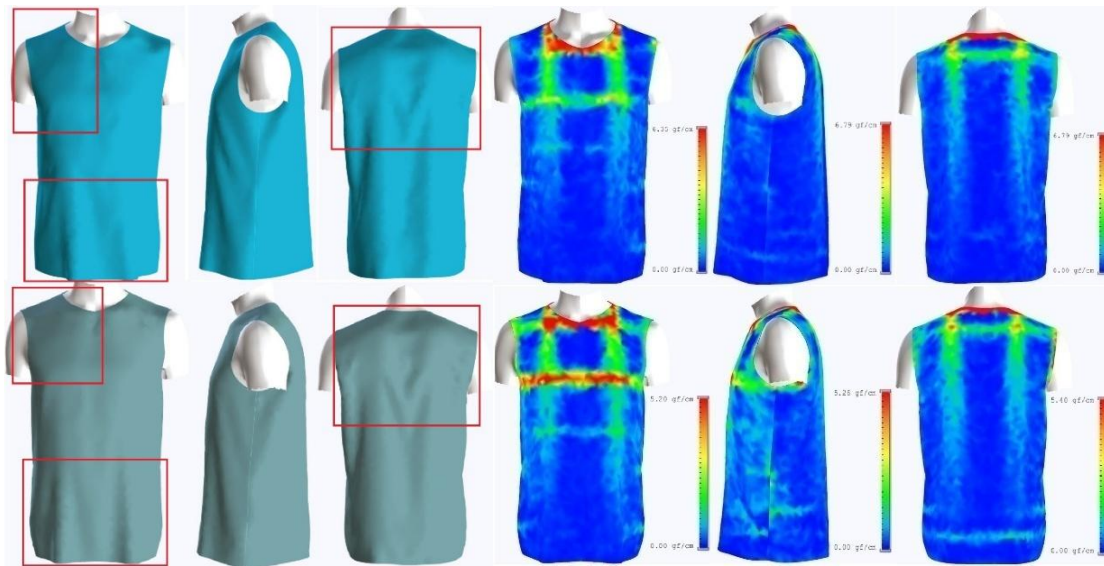


Figure 6.4: Virtual Fitting Comparison for Type V-I-1

Table 6.4: Maximum Pressure Value Comparison for Type V-I-1

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	6.35	5.20
Side	6.79	5.26
Back	6.79	5.40

For V-I-2, the detailed classifications A1 and R2 differ from the conventional body. Accordingly, shoulder width and shoulder slope were modified based on the basic pattern. Comparing the appearance as shown in Figure 6.5 (left), the custom pattern provides more hip ease than the RtW version, and the shoulder width better corresponds to the wearer's actual measurement.

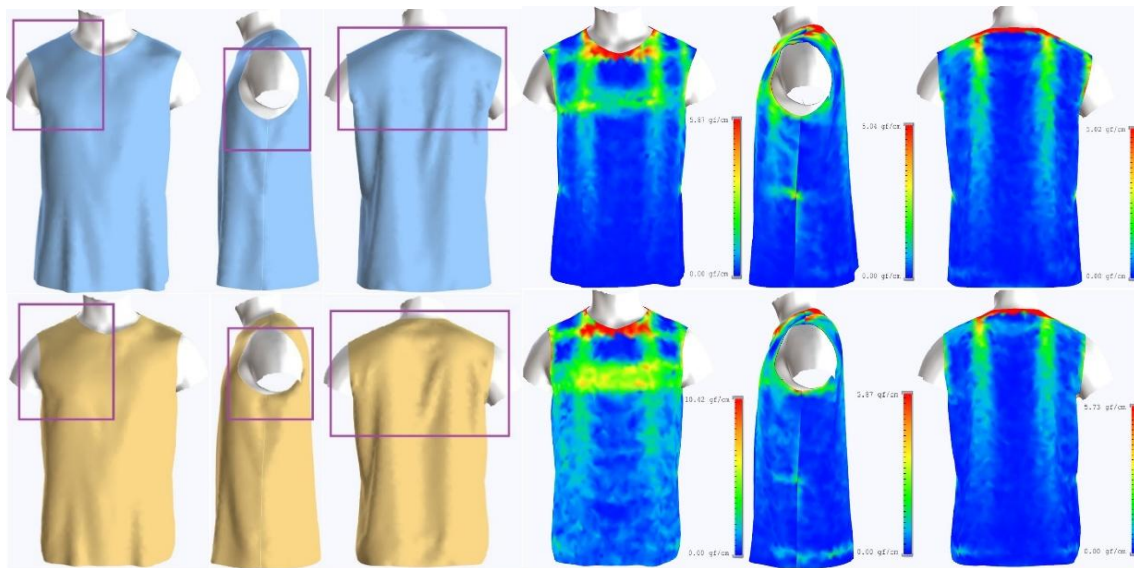


Figure 6.5: Virtual Fitting Comparison for Type V-I-2

In the front pressure map shown in Figure 6.5 (right), the custom pattern exhibits significantly lower pressure at the neck, chest, armhole, and waist/abdomen. As indicated in Table 6.5, the maximum pressure value for the custom pattern is 5.87 gf/cm², while the RtW pattern attains 10.42 gf/cm². Although side and back pressure values are relatively similar between the two patterns, the color distribution suggests that the custom pattern fits the armhole and hip areas more precisely. Therefore, in terms of overall silhouette, fit, and balance, the custom pattern surpasses the RtW pattern.

Table 6.5: Maximum Pressure Value Comparison for Type V-I-2

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	5.87	10.42
Side	5.04	5.87
Back	5.02	5.73

For V-I-3, the detailed classifications D10 and A1 differ from the standard type. Therefore, adjustments were made to the armhole width, hip circumference, and shoulder slope based on the basic shirt pattern. As shown in Figure 6.6, for the frontal appearance, the custom pattern shows a more tailored silhouette, with a better shoulder width fit than the RtW version. The back view also reveals that the custom pattern offers superior flatness and shape compared to the RtW pattern. This is further supported by the pressure maps: although the maximum pressure values in custom patterns are slightly higher than those in the RtW pattern shown in Table 6.6, the color distribution shows lower pressure at the side armhole and scapular areas for the custom version.

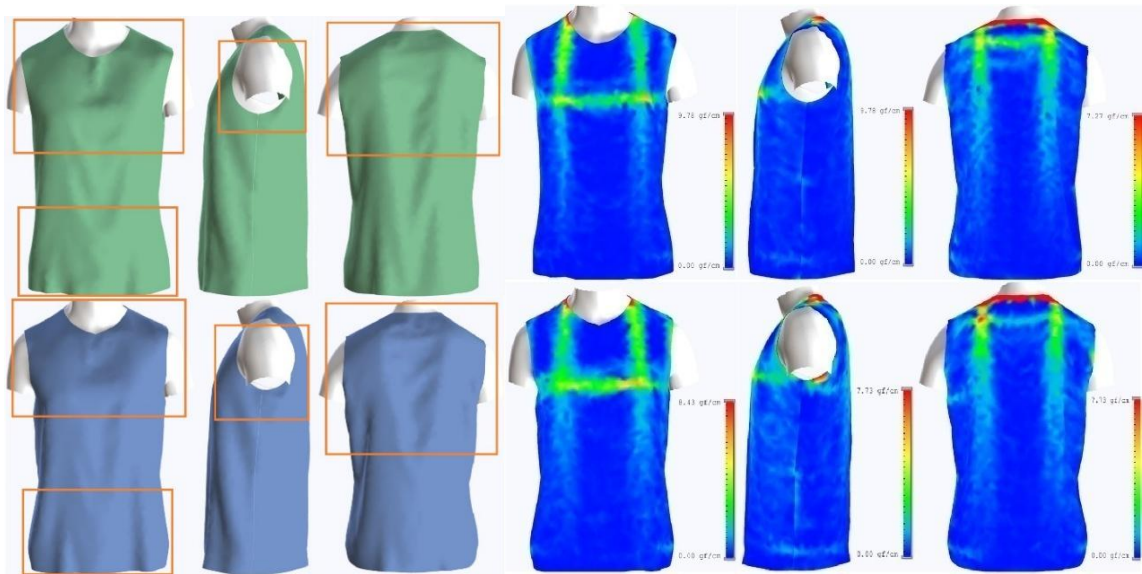


Figure 6.6: Virtual Fitting Comparison for Type V-I-3

Table 6.6: Maximum Pressure Value Comparison for Type V-I-3

View	Personalized Pattern(gf/cm)	Ready-to-wear Pattern(gf/cm)
Front	9.78	8.43

Table 6.6 continued

Side	9.78	7.73
Back	7.27	7.73

For V-I-4, the individual exhibits the A1 classification, corresponding to a sloped shoulder type. Based on the basic shirt pattern, the shoulder slope was modified accordingly. Comparing the front, side, and back views, the custom pattern exceeds the RtW version in overall silhouette, fit, and balance as shown in Figure 6.7. In the pressure maps shown in Figure 6.7 (right), although the RtW version indicates near-zero pressure across most areas (except the hips), the appearance images reveal poor flatness and balance due to insufficient ease. As shown in Table 6.7, the hip pressure in the RtW version reaches up to 289.78 gf/cm², compromising comfort in that area. In contrast, the maximum pressure for the custom pattern is 3.68 gf/cm². The distribution of ease across all regions contributes to greater overall fit and balance.

Table 6.7: Maximum Pressure Value Comparison for Type V-I-4

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	3.26	289.78
Side	3.67	289.78
Back	3.68	292.9

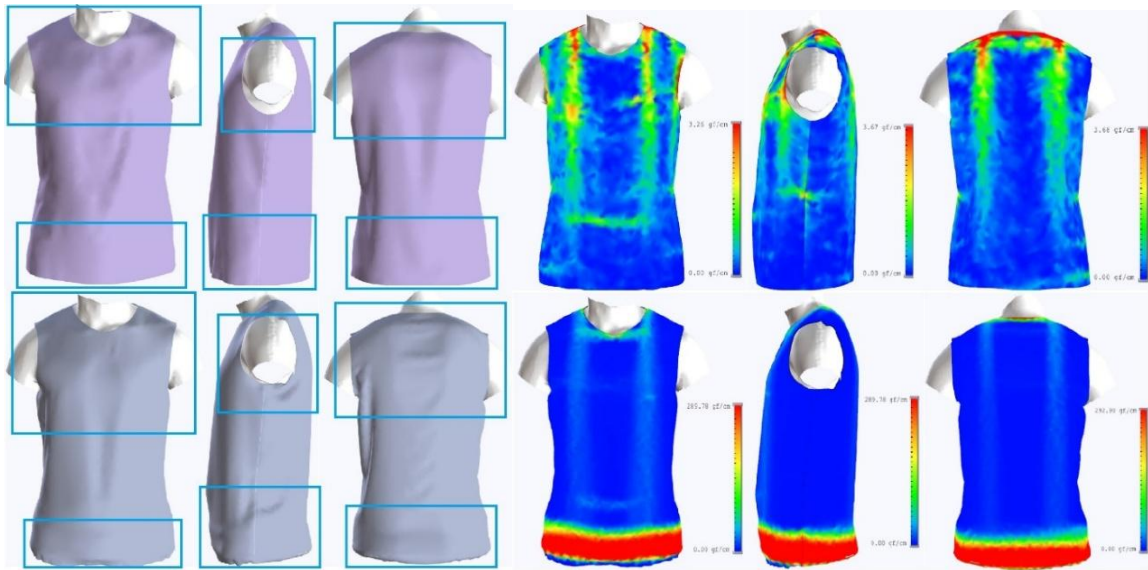


Figure 6.7: Virtual Fitting Comparison for Type V-I-4

6.2.3 Fit Comparison Analysis for Body Type II-I

Type II-I is characterized by a larger bust–waist difference compared with the previous two body types and a longer front waist length than back waist length. Compared to the ready-to-wear (RtW) pattern, the front waist drop remains consistent between the two, and the height difference between the front and back neck points is also approximately equal. However, the armhole width is relatively narrower.

For II-I-1, the individual’s A1 classification differs from the median body type, indicating a square shoulder shape. Therefore, based on the basic Type II-I shirt pattern, the shoulder slope was modified accordingly. Comparing the virtual fitting appearance as shown in Figure 6.8 (left), the custom pattern provides more overall ease than the RtW version.

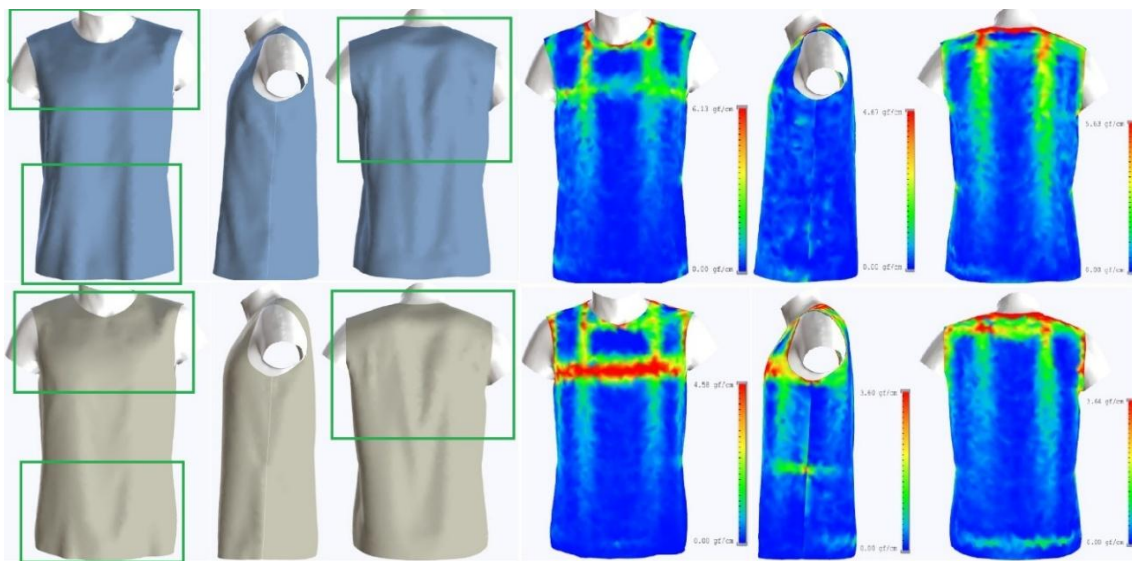


Figure 6.8: Virtual Fitting Comparison for Type II-I-1

Although the maximum pressure values in Table 6.8, shown by the ready-to-wear pattern in each view, are slightly lower than those of the customized pattern, the custom pattern presents significantly less pressure distribution at the chest, shoulders, and armhole areas from the front and side pressure maps. Similarly, from the back pressure map, the custom pattern exhibits reduced pressure distribution around the armhole and shoulder regions. These findings indicate that the custom pattern achieves better balance and fit compared to the RtW pattern.

Table 6.8: Maximum Pressure Value Comparison for Type II-I-1

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	6.13	4.58
Side	4.67	3.60
Back	5.63	3.64

For II-I-2, the individual's body classification matches the standard type used in the basic pattern, and no additional modifications were made to the base shirt pattern. While the appearance differences between the custom and RtW patterns are minimal, as shown in Figure 6.9 (left).

Although the maximum pressure values in Table 6.9 exhibited by the ready-to-wear and customized patterns in each view do not differ significantly, the pressure distribution maps reveal distinct differences, as shown in Figure 6.9 (right). The front pressure map shows that the custom pattern yields less pressure distribution at the neck and chest than the RtW version. Likewise, the back pressure map shows less pressure distribution at the shoulder and hip areas in the custom pattern. These findings suggest that the D10 classification influences the armhole and hip ease design, which in turn improves the overall garment balance.

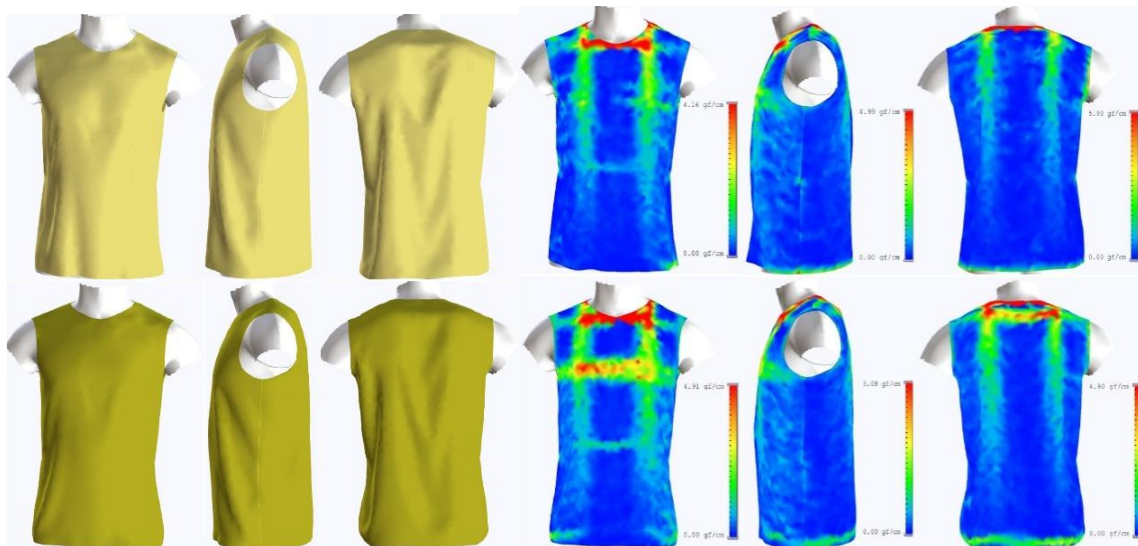


Figure 6.9: Virtual Fitting Comparison for Type II-I-2

Table 6.9: Maximum Pressure Value Comparison for Type II-I-2

View	Personalized Pattern(gf/cm)	Ready-to-wear Pattern(gf/cm)
Front	4.16	4.91
Side	4.99	5.08
Back	5.90	4.80

For II-I-3, the individual’s R2 classification differs from the standard type. As a result, adjustments were made to the shoulder width and back width of the basic shirt pattern. Comparing the appearance images shown in Figure 6.10 (left), the custom and RtW patterns show minimal visual distinctions. However, the pressure map in Figure 6.10 (right) indicates that while the chest pressure in the custom version is slightly increased, the shoulder and neck areas exhibit lower and more evenly distributed pressure. Overall, the custom pattern demonstrates a superior fit compared to the RtW version.

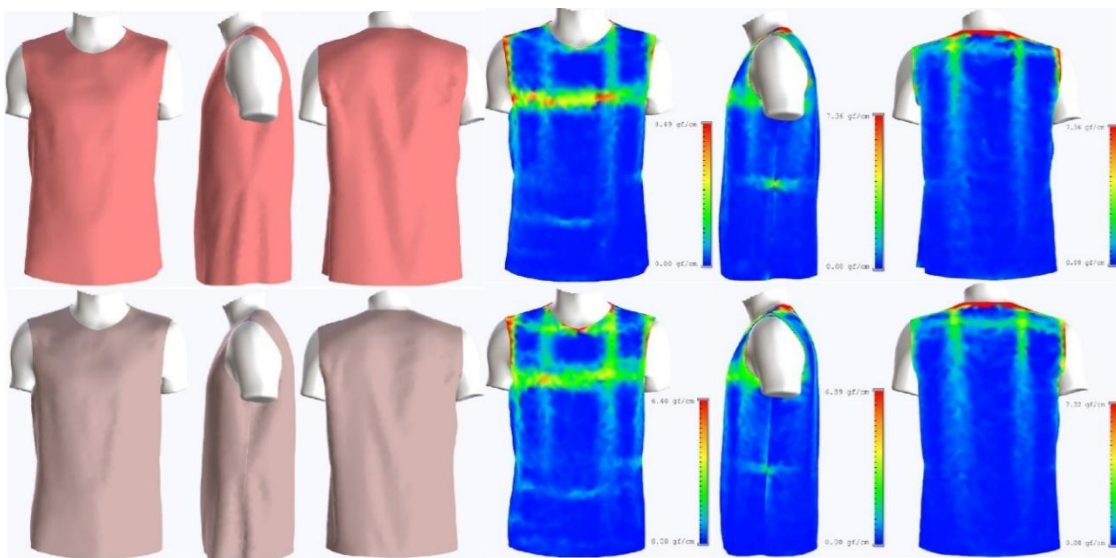


Figure 6.10: Virtual Fitting Comparison for Type II-I-3

Table 6.10: Maximum Pressure Value Comparison for Type II-I-3

View	Personalized Pattern (gf/cm)	Ready-to-wear Pattern (gf/cm)
Front	8.49	6.40
Side	7.36	6.89
Back	7.36	7.32

6.3 Results and Discussion

Based on the subjective evaluation of virtual fitting results, the assessment focused primarily on visual characteristics, including wrinkling, closeness of fit, and silhouette. The fit evaluation methods were as follows: grainlines were utilized to assess the contour fit, ease allowances were examined to evaluate tightness or looseness, and wrinkles were analyzed to assess fit-related creasing. The subjective evaluation confirmed that personalized patterns reduced wrinkling and enhanced silhouette, particularly for Type III-III and V-I. These findings align with Mitsuno, T. and Yanagisawa, A.K. (2022), who identified 0–10 gf/cm² as the optimal pressure range for comfort in chest, waist, and hip. Notably, the RtW pattern for V-I-4 exerted excessive hip pressure (289.78 gf/cm²), far exceeding the discomfort threshold of 10 gf/cm² (Mitsuno & Yanagisawa, 2022). This emphasizes the necessity of hip ease adjustments in the D10 classification, as proposed in this study.

Overall, the personalized shirt patterns produced in this study demonstrated

superior visual fit regarding wrinkling, closeness of fit, and silhouette compared to the RTW shirt patterns. In addition, objective pressure analysis based on virtual fitting results further substantiated the superiority of the personalized patterns. Color maps of pressure distribution from the front, side, and back views, along with comparisons of maximum pressure values, showed that the personalized patterns developed in this study achieved better fit performance overall than the ready-to-wear counterparts.

6.4 Chapter Summary

In this study, virtual fitting was performed using realistic 3D body models and their corresponding customized shirt patterns. This chapter validated the proposed body classification and pattern generation method through virtual fit assessment. The personalized patterns consistently outperformed RtW designs in pressure distribution and visual fit; for instance, 40% lower maximum pressure for III-III-1, demonstrating the effectiveness of fine-grained adjustments such as shoulder slope in A1 and hip ease in D10. These results advance fit customization by providing a scalable framework for modifying patterns to diverse body shapes. Future work could explore real-world wear trials to correlate virtual pressure data with subjective comfort evaluations.

CHAPTER 7

CONCLUSION AND FUTURE WORKS

7.1 Conclusion

This research developed a 3D-body-driven fit customization (FC) model for menswear, integrating body shape classification, pattern generation, and virtual fit validation. The study addressed gaps in current sizing systems by proposing a multi-level classification method and utilizing 3D technologies for personalized pattern design. The findings demonstrate that advanced technologies, such as 3D scanning and virtual fitting, can improve fit accuracy and production flexibility in mass customization.

7.2 Finding Model

The inspiration for this research was drawn by the phenomenon that people's consumption needs for individuation and diversification became more apparent, the market demand shows multi-varieties and small batches; however, the current size system does not provide enough data to help consumers choose clothing that fits, and it remains difficult to determine how technologies can manage fit customization and improve the application of fit customization efficiently and flexibly. Therefore, the purpose of this study is to develop a strategy to satisfy consumers' fit needs in mass customization with efficiency and flexibility. Thus, the goal of strategy development is a theoretical understanding of shape, size, and fit and how to integrate it into patternmaking procedures.

In addition, apparel manufacturers and technical professionals are the primary agents in the application of fit customization. Therefore, their perspectives on FC implementation and garment fit are critical. While existing studies have mainly examined FC from the standpoint of production management or focused on consumer preferences and assessments of garment fit, relatively few have explored the views of technical professionals. Specifically, limited attention has been given to how professional insights into fit-related factors and technical practices can be combined to enhance the effectiveness of FC implementation.

Therefore, the first objective of this study is to examine the current status and challenges of advanced technology applications in apparel enterprises, and to identify the factors influencing garment fit from a production-oriented perspective. Based on these insights, the study proposes a body shape classification method that better meets consumers' fit needs and allows the flexible, efficient, and sustainable application of fit customization by integrating advanced technologies within the FC production model. Building on the proposed classification system, 3D flattening techniques are used to develop basic garment patterns. Subsequently, a personalized pattern generation method based on these basic blocks is applied to design shirt patterns for various body types. Finally, virtual fitting technology is employed to evaluate the fit performance of the personalized patterns.

Subsequently, this study centers on establishing an apparel fit customization model based on key fit-related factors and production technologies. This model integrates the

main determinants of fit, namely, body shape, body size, and basic patterns, with 3D technologies, providing a theoretical framework for understanding the relationships among shape, size, and fit, and for incorporating this understanding into patternmaking procedures. In addition, while body size prediction following the proposed model is beyond the scope of this study, it offers a potential direction for further research aimed at testing and assessing the model's effectiveness, flexibility, and sustainability.

The development of the theoretical understanding of the implementation of fit customization is proposed. As shown in Figure 7.1, the FC model connects body data (shape/size), pattern design, and fit validation through 3D technologies. The arrows highlight iterative refinement, where virtual fit feedback informs adjustments to sizing rules and pattern parameters.

Original Contribution. The innovations of this study include: (1) The key factors (size system, ease allowance, aesthetics) and technologies (anthropometrics, patternmaking, fitting) that affect the fit of clothing in mass customization were defined, which provide a theoretical basis for solving the fit problems in mass customisation. (2) A multi-level male body shape classification method was developed, which contributes to the redesign of the sizing system. (3) A parameterized menswear pattern generation method based on a 3D human body model was proposed. This method employs a pattern-oriented landmark of human feature points to integrate the 3D body model into patternmaking. This approach promotes the formulation of a "body-pattern-fit" theory, which interprets the relationship between human body size, body type, pattern, and fit. In summary, the research advances

theoretical understanding of the body–pattern–fit, establishing a methodological framework integrating body data, pattern design, and fit evaluation, thus laying the foundation for future intelligent and automated 3D pattern-making systems for customization. Furthermore, it has been demonstrated to assist in the reduction of fit-related garment returns.

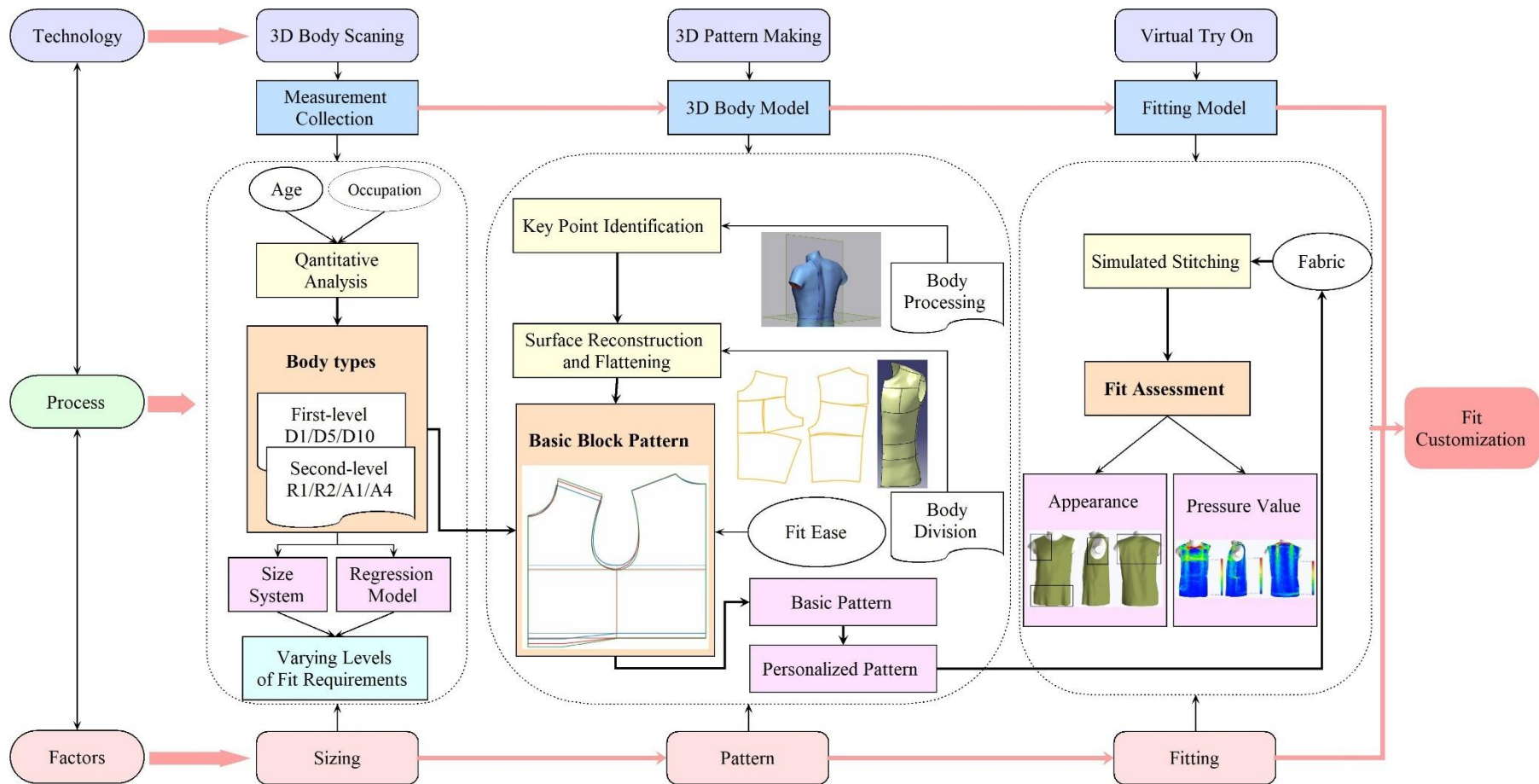


Figure 7.1: Garment Fit Customization Model

7.3 Summary of Findings

- **Garment Fit Customization Model**

The present study developed a model for the implementation of fit customization based on body shape, size, and pattern. In line with the research aims, this model integrates key factors affecting garment fit with advanced technologies throughout the production process, from body measurement to patternmaking, which are the critical stages influencing fit outcomes.

Therefore, the study comprises three main components: (1) the investigation of current issues in the application of advanced technologies in fit customization and the identification of key factors influencing customized fit from the perspective of apparel experts, (2) the study of body shape classification and the optimization of the sizing system, and the design of personalized patterns based on the optimized sizing system, and (3) fit assessment of the personalized pattern. This final component not only serves as a validation of the optimized sizing system's ability to better meet individual fit requirements, but also explores the application of 3D technologies in pattern development and virtual fitting.

As an integration of these three perspectives, the proposed model supports the production of well-fitted garments for fit customization based on body shape, body size, and pattern, while using 3D technologies and process design to enhance efficiency and flexibility. It provides a theoretical framework for understanding the interrelationships

among shape, size, and fit, and for incorporating this understanding into patternmaking procedures. This theory contributes to the academic gap in the field of fit customization.

- **Sizing System**

The optimized sizing system, which classifies body shapes into two levels, demonstrates that multi-level body shape classification is more effective for implementing fit customization tailored to varying fit requirements. The study's key innovation lies in its two-level body shape classification system, which enhances fit accuracy by accounting for upper- and lower-body proportionality. Unlike traditional sizing approaches that rely solely on chest-to-waist differences, this method incorporates the difference between back waist length and front waist, hip-to-chest length differences, hip protrusion, and other morphological features, enabling more precise pattern adjustments. In addition, by considering the proportional relationship between the upper and lower body, the sizing design for upper and lower garments not only reflects the overall body shape characteristics but also emphasizes the distinct morphological features specific to the upper and lower body, respectively. This represents one of the key contributions of this study.

The optimized sizing system indicates that body height and girth (specifically, chest circumference) remain the primary dimensions for sizing system design, which is consistent with existing sizing standards. However, in terms of body shape classification, current sizing systems rely solely on the chest-to-waist difference as the basis for categorization, which is insufficient to support the implementation of fit customization.

Therefore, body shape classification serves as an essential component in optimizing the sizing system.

In the qualitative findings, body measurements and body shape were identified as the foundation of sizing system design, with the standards and methods of body shape classification being particularly critical. Furthermore, the overall coordination between the upper and lower body, based on aesthetic considerations, as well as factors such as occupation and age, should also be integrated into sizing system development. In addition, assigning body measurements to suitable garment specifications has a substantial impact on the resulting fit. Based on these findings, the subsequent quantitative analysis was conducted with careful consideration of these factors to optimize the sizing system. Based on age and occupation, this study focuses on male university students aged 18 to 24 as the target population. In body shape classification, selecting appropriate body measurements by integrating knowledge from apparel pattern design and considering the practicality of data collection methods is necessary. 3D body scanners can provide comprehensive, multi-dimensional body measurement data, including height, girth, width, thickness, and angular dimensions. However, it is essential to select the most relevant data according to specific research objectives. This study found that body measurements related to height, girth, width, and angle are generally sufficient to effectively represent and explain body shape characteristics.

In the analysis of body shape, correlation analysis revealed that most height-related measurements are primarily correlated only with other height dimensions, such as overall

body height. However, certain specific height measurements, such as the surface length from the side neck point to the bust point and the front waist length (measured from the side neck point to the front waistline), also show correlations with girth measurements.

Factor analysis was used to identify the main factors influencing human body shape. This study found eight key factors: height, girth, back torso length above the waist, waist and abdomen, front torso length above the waist, shoulder width, shoulder tilt degree, and hip bulge. Based on the analysis of these eight factors, nine classification variables were derived for body shape categorization: height, chest circumference, chest-to-waist difference, hip-to-chest difference, difference between front and back waist lengths, waist height-to-body height ratio, shoulder width-to-body height ratio, shoulder slope, and hip protrusion. Among these, the hip-to-chest difference serves as a key variable in coordinating the upper and lower body dimensions within the sizing system design, making it one of the critical components in the optimized sizing system proposed in this study.

In addition, the regression models developed in this study for each body shape classification variable provide a crucial data foundation for body measurement prediction, grading, and parametric pattern design. As highlighted in the qualitative findings, assigning body measurements to appropriate garment specifications has a significant impact on fit. Therefore, regression models with high explanatory power can increase the accuracy of grading, thereby enhancing the overall garment fit.

The regression analysis revealed that, with the exception of arm length, neck base circumference, back width, chest width, and back waist length, whose regression models exhibited R-squared values below 0.6, all other body dimensions demonstrated strong explanatory power. This result is consistent with the qualitative analysis, which indicated that the morphological features of the neck base and arm root are essential for optimizing sizing specifications. This aspect represents a promising avenue for future research. An optimized sizing system was developed based on detailed body shape categorization. First, height and chest circumference remain the sizing system's primary measurements (first dimension), while body shape classification constitutes the second dimension. Body shape was classified into multiple categories to better support the implementation of fit customization across varying degrees of fit requirements. For upper garment pattern design, the first-level classification includes chest-to-waist difference and difference between front and back waist lengths, while the second-level classification includes hip-to-chest difference, waist height-to-body height ratio, shoulder width-to-body height ratio, and shoulder slope. For lower garment pattern design, the first-level classification includes chest-to-waist difference and hip-to-chest difference, and the second-level classification includes waist height-to-body height ratio and hip protrusion.

The optimized sizing system distinguishes between upper and lower body shape classifications as the foundation for upper and lower garment pattern design. While this may appear to separate the upper and lower body classifications, the use of chest circumference as the primary measurement in the first level of the sizing system serves to

integrate them. As a result, this sizing system not only provides a more effective approach to issues such as front-back balance in upper garments and coordination between the upper and lower body, but also offers greater flexibility to varying degrees of fit requirements in apparel fit customization.

- **Generation of the Personalized Pattern**

A major finding of this study is that 3D technology possesses considerable potential in body measurement, pattern design, and fit evaluation, establishing it as an effective and adaptable tool for enhancing fit customization implementation. 3D flattening techniques combined with landmarks of feature points were successfully applied to convert body scans into pattern pieces, addressing a significant gap in current FC implementations.

In the qualitative results, most technical professionals continue to depend on traditional patternmaking methods; however, they express strong expectations for applying 3D technologies in pattern development and virtual fitting. Due to current technical constraints, 3D technologies have not yet gained widespread adoption in practical garment production. This study investigated a garment pattern generation method based on 3D body models by performing a series of processing steps on body scans acquired through 3D scanning. The fit of the generated patterns was then assessed using virtual fitting technology. The results indicate that 3D technology is not only feasible but also carries substantial potential as an advanced tool in garment manufacturing.

In the qualitative analysis, the 3D body models obtained from 3D body scanners were found unsuitable for direct use in fitting or pattern-making. Furthermore, accurately identifying key anatomical landmarks, such as the seventh cervical vertebra, shoulder endpoints, armpit points, and crotch points, has proven particularly difficult in practice. These challenges were further confirmed through quantitative analysis.

First, the human body scanned by a 3D scanner generates a large set of point clouds, often containing noise, outliers, and voids. Consequently, initial processing is necessary, including point cloud unification, denoising, and void filling. While most 3D software tools can effectively manage these tasks, two specific regions, the underarm and crotch areas, require manual intervention and expertise. Because of the anatomical structure and the influence of arm and leg girths, these areas frequently display voids during scanning, and accurately reconstructing the original human shape there remains technically difficult. Additionally, since the human body lacks perfect symmetry, symmetrization processing is also required. These observations suggest that, although 3D body scanners capture highly accurate anthropometric data, extensive point cloud processing remains necessary depending on the application. Currently, no standardized protocol exists for such processing, which remains a key reason why 3D body scanning has not been broadly integrated into practical garment production.

Accurately defining anatomical landmarks for garment pattern design on the processed 3D human model is a critical step in patternmaking. In this study, based on apparel pattern design definitions and actual anthropometric calculations, the back neck

point, front neck point, side neck point, anterior axillary point, and posterior axillary point were identified and defined. These landmarks can be located relatively easily on 3D body models. However, defining the underarm and shoulder points proved more challenging. Since the underarm area is reconstructed through point cloud hole-filling, the defined underarm point often deviates from its actual anatomical location. Therefore, the underarm point was estimated by referencing the anterior and posterior axillary points. For the shoulder point, existing literature and common garment pattern design definitions were used to determine its location. Although this approach allows reasonably accurate shoulder point positioning, it lacks high standardization and is relatively time-consuming, making it suitable primarily for experimental research. These findings align with the qualitative analysis, which indicated that if key anatomical landmarks cannot be defined accurately and reliably, applying 3D technology effectively in garment pattern development is difficult.

The defined anatomical landmarks allow the division of the human body into distinct surface regions. In this study, regional segmentation of the body surface was performed based on protrusion points and characteristic lines. Identified protrusions and concavities include chest protrusion, abdominal protrusion, scapular protrusion, gluteal protrusion, shoulder contours, and waist concavity. The characteristic lines used for segmentation include the hip circumference line, abdominal circumference line, waist circumference line, chest circumference line, a horizontal plane at the midpoint between the shoulder point and front axillary point, a horizontal plane at the midpoint between the

shoulder point and back axillary point, a curve connecting the side neck and shoulder points, a curve linking the underarm point to the midpoint of the waist circumference, a curve passing through the midpoints of the waist, abdominal, and hip circumference lines, and a vertical plane at half the distance of the intermammary line from the front center. Based on these references, the anterior body surface was segmented into six regions, and the posterior surface into five regions, providing a detailed and functional partitioning framework for surface fitting. Using these segmented regions, surface fitting and 3D flattening tools in reverse engineering software were employed to convert each segmented 3D surface area into corresponding 2D flattened patches, enabling precise garment pattern development.

This study also found that manipulating darts in the flattened surface patches is essential for generating basic block patterns. Darts in the flattened patches arise from anatomical protrusions of the human body. Therefore, during dart transfer, appropriate methods must be selected based on the desired garment fit level. Furthermore, as individuals exhibit varying body shape classifications, analyzing the positional and dimensional relationships of corresponding regions in the flattened patches under each classification reveals variation characteristics of pattern components and dimensions across body shape types. This analysis facilitates theoretical understanding of pattern features linked to specific body shapes and provides a foundation for personalized garment pattern generation.

Additionally, designing ease allowances based on the flattened patches is a crucial step in basic block pattern development. As identified in the qualitative findings, ease design is influenced by several factors, including garment style, fabric selection, wearer's body shape, fit preferences, and the company's fit aesthetic. In this study, ease allowances for the fitted basic block pattern were primarily determined by considering body shape effects. Specifically, variations in arm girth were accounted for when adjusting ease for chest width and armhole width. At the same time, differences in chest-to-waist ratio were considered regarding ease adjustments for back length.

In the second-level body shape classification, the fitted basic block pattern was developed from the most prevalent body shape category to enhance the pattern's population coverage. Based on previously obtained flattened patches for each body type, corresponding body measurement regression models and ease design parameters were applied to perform parametric design of key pattern components under each classification. Consequently, parameterized fitted basic block patterns were generated for each body type. Comparing the fitted basic block patterns developed here for three representative body types with standard ready-to-wear patterns showed that the proposed patterns more accurately reflect the morphological characteristics of corresponding body shapes.

Using the fitted basic block pattern, the fitted shirt basic pattern can be developed rapidly. Although the fitted shirt's basic pattern reflects characteristics of an intermediate body shape, each individual possesses unique personalized features. Therefore, by combining the parametric model of the fitted shirt basic pattern with dimensional

adjustment rules corresponding to each body shape classification variable, measurements of pattern components can be quickly calculated for different body shapes. This enables efficient generation of personalized shirt patterns. The personalized pattern generation method proposed here represents a key innovation of the research.

Thus, quantitative and qualitative analyses highlight the fundamental role of the basic pattern in achieving garment fit. In pattern generation based on 3D technology, processing 3D body data, accurately identifying anatomical landmarks, and segmenting body surface regions are essential for generating flattened surface patches. Moreover, dart manipulation and ease allowance design on flattened patches are foundational in basic block pattern development. Additionally, using parametric basic patterns and classified body shapes within the sizing system is crucial for rapidly and accurately generating personalized patterns.

- **Fit Validation of Pattern**

In this study, personalized shirt patterns and ready-to-wear shirt patterns were virtually fitted using real human body models and untreated cotton fabric in 3D fitting software. Through a combination of subjective evaluation and objective pressure value analysis, the results indicate that the personalized shirt patterns developed in this research exhibit a higher degree of fit compared to the ready-to-wear patterns.

In the qualitative findings, fitting was identified as a crucial method for improving garment fit. The development of 3D human models tailored to different age groups and

populations, along with the realistic simulation of the physical and mechanical properties of fabrics, are essential factors influencing the industrial applicability of virtual fitting technologies.

The quantitative analysis further revealed that virtual fitting using real human models provides more realistic simulation outcomes. However, variations in fabric properties lead to differences in fit performance, emphasizing the fact that in addition to the human body, fabric characteristics are also a critical factor in virtual fitting accuracy. Moreover, since this study focused on fitted shirt patterns, which involve relatively minimal ease allowance, the differences in fit were more visually and quantitatively evident. For garments with greater ease, virtual fitting tends to serve more as a tool for evaluating stylistic and design effects rather than fit alone.

The study also found that due to current limitations in 3D human modeling and fabric property simulation, a key challenge for implementing virtual fitting in fit customization lies in how to design 3D body models that correspond with different levels of fit requirements. Addressing this issue will be essential for the widespread adoption of virtual fitting technologies in FC applications.

7.4 Limitations

This study has some limitations that should be acknowledged and considered for future investigation. To understand the current application of advanced technologies in fit customization and the perspectives of apparel technical professionals on factors affecting

garment fit, the qualitative analysis in this study was conducted through examination of two Chinese apparel companies with relatively successful FC implementation, as well as interviews with ten frontline technical professionals. However, there are several constraints. First, the findings do not represent the full spectrum of technology use across all companies practicing FC. Since companies vary in their degree of FC implementation, their use of technologies also differs. The results presented in this study reflect only those enterprises that have achieved a higher level of FC adoption. Second, the views of the ten technical professionals on the factors influencing garment fit are shaped by their individual work experiences and particular areas of expertise. While the collected data reflect major factors influencing garment fit in general apparel categories, they may not apply to specialized categories such as functional or performance garments, which were not addressed in the interviews.

The study's reliance on manual landmark identification in 3D scans introduces subjectivity and limits scalability. While the methods were sufficient for experimental validation, industrial implementation would require automated tools. Furthermore, given China's vast geographic diversity, and due to constraints in 3D body scanning accessibility, the participant pool was drawn from male students currently studying in Tianjin and Fuzhou, who may originate from various provinces across China. Therefore, the participant pool may not capture global demographic variability, suggesting a need for cross-cultural validation in future research. Nevertheless, as the sample size increases, the accuracy and

generalizability of the findings can be expected to improve when following the same methodology described in this study.

Moreover, due to time limitations, the scope of the research was restricted. This study focused exclusively on men's shirts and did not include other types of menswear. Specifically, the research only developed base patterns and personalized patterns for the upper body and men's shirts. Although the sizing system proposed in the study includes classification methods for both upper and lower body types and demonstrates how upper body classifications can guide the design of upper garments, the lower body classifications were not applied in the development of trousers or other lower-body garment patterns.

7.5 Future Works and Recommendations

This study does have suggestions that should be acknowledged in future research. Since this study develops an FC model based on the shape, size, and how to incorporate it into patternmaking procedures to create a strategy to satisfy consumers' fit needs in mass customization, with efficiency and flexibility. Therefore, any improvement in all steps toward strengthening this model is highly recommended.

Firstly, 3D human body models, standardized body modeling methods, and the interactive identification of anatomical landmarks used for various fit purposes, especially in 3D patternmaking, require further examination.

Automating landmark detection is the most urgent need for expanding FC production. Current manual methods, although accurate, are time-consuming and

impractical for broad application. Future research should emphasize machine-learning-based techniques, such as convolutional neural networks (CNNs), to identify key points (e.g., shoulder, underarm) from 3D scans. Success in this area would facilitate real-time pattern adjustments and reduce dependence on expert intervention.

In this study, methods were developed to define key landmarks, including the back neck point, front neck point, side neck point, anterior axillary point, posterior axillary point, underarm point, and shoulder point; however, these methods are currently applicable only through manual operations. They have not yet been implemented in software tools for automated detection or user-friendly interactive identification. For widespread application in apparel production, these methods require standardization and automation. This represents a promising area for future research, as automated and interactive landmark detection can improve operational efficiency, enable correction of anthropometric data, and support interactive pattern design, allowing garment companies to flexibly apply their own definitions of body landmarks and patternmaking reference points.

Furthermore, the development of automated and interactive anatomical landmark recognition is essential for constructing personalized 3D human body models. Once landmarks are accurately defined, feature lines can be derived; these feature lines can then be parameterized to capture individual body shape characteristics, thus enabling the creation of highly personalized 3D body models. When such personalized 3D models are integrated with existing body surface fitting algorithms and 3D-to-2D flattening techniques, they have the potential to contribute to advances in 3D garment pattern generation

technologies. In addition, creating 3D human models tailored to various age groups and demographic populations remains a critical factor influencing the applicability and scalability of virtual fitting software in industrial contexts.

Secondly, size recommendation is among the most readily achievable objectives in future research. Current body shape classification systems have established a solid foundation for precise sizing suggestions. Future research should focus on applying intelligent algorithms to recommend appropriate sizes for consumers. Success in this area could effectively assist consumers in selecting suitable garment sizes, particularly in online e-commerce contexts, thereby reducing high return rates caused by sizing problems and enhancing the efficiency of the fit customization process.

In this study, regression analyses were performed on body measurements across different body shape categories, and corresponding regression models were created. These models were used to support the parametric design of fitted upper-body basic block patterns for men. However, due to time limitations, the application of these regression models for predicting body shape and recommending garment sizes was not included within the scope of this research.

Additionally, this study focused exclusively on the use of upper body shape classification in the sizing system, while the approach to integrating lower body shape characteristics was only conceptually proposed. This study did not undertake the practical application of lower body shape classification in basic block pattern design, such as for

trousers or other lower-body garments. Addressing this gap in future research will be essential to further improve and complete the sizing system for FC applications, ensuring more comprehensive coverage of different garment types and fit requirements.

Thirdly, research on the inclusivity of basic patterns represents another key direction for future investigations. The present study has validated the advantages of basic patterns through generating a limited number of personalized patterns, with a relatively small sample size. Future research will focus on expanding the sample size and conducting a more comprehensive quantitative investigation into the inclusivity of basic patterns. Such studies will contribute to optimizing the ease allowance design of basic patterns.

The inclusivity of a pattern, though difficult to quantify in production, is primarily reflected in the differences between the patterns designed for special body types and the fundamental or base patterns. In addition to examining the morphological differences between standard and personalized body shapes, fit ease is also a crucial factor influencing pattern inclusivity. Therefore, a quantitative study on the relationships among garment style, fit aesthetics, fabric characteristics, body shape, and consumer preferences must provide a stronger theoretical foundation for fit ease design. The ultimate goal is to enhance both the fit aesthetics and the adaptability of garment patterns to a broader diversity of body types, thereby improving the inclusivity of basic patterns in the context of mass customization and fit personalization.

Fourthly, the morphological analysis of the neck base and arm root requires further exploration. This study found that the neck base and the armhole regions have a significant impact on garments with high fit demands. Future research could explore in greater detail the morphology of these two regions and their specific influence on garment fit. Such investigations would contribute to refining fitted pattern blocks and enhance fit performance in functional garments or those with specialized fit requirements.

In the qualitative analysis, it was found that the neckline and armhole areas frequently cause fit-related problems during the grading process. Correspondingly, in the quantitative analysis, several body measurements associated with the neck base and arm root, specifically length (L6), neck base girth (G4), back width (W2), chest width (W3), and the distance from the posterior axillary point to the waistline (L20), showed low explanatory power in their linear regression models. The emergence of similar issues in both qualitative and quantitative findings indicates that the morphological variability in the neck base and arm root regions is relatively high across individuals. Therefore, to address this challenge more effectively, a more detailed morphological analysis of the neck base and arm root is needed in future research. Such analysis would contribute to improving the accuracy of pattern design and grading, especially in regions where fit problems are most likely to appear.

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APPENDICES

Appendix A: Journal Publications

1. **Huang Z, Sahari F (2025).** An overview of current technological developments in apparel fit customization. *Research Journal of Textile and Apparel, Vol. ahead-of-print No. ahead-of-print.* <https://doi.org/10.1108/RJTA-09-2024-0167>

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An overview of current technological developments in apparel fit customization

Research Journal
of Textile and
Apparel

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Abstract

Purpose – This study reviews the literature that discusses the technologies that will influence fit customization (FC). The purpose of this study is to clearly understand the current progress of such technology and the potential future development path.

Design/methodology/approach – Research papers, publications and websites of well-known apparel companies using FC are reviewed to explore the latest technological advancements in apparel FC.

Findings – Given the advances in body measurement, pattern and fit assessment technologies, FC represents a sustainable production approach for the apparel industry.

Originality/value – This review examines the state of the field, looks at possible trends in the study and highlights future directions.

Keywords Fit customization, Body measurement, 3D pattern-making, Virtual fitting, Sizing system

Paper type Literature review

1. Introduction

1.1 Background

Today, product personalization and diversity have become more important, especially in the apparel industry, which has embraced the idea of producing a variety of products in small quantities (MacCarthy, 2013). In addition, online shopping has become increasingly popular with the growth of e-commerce. However, it has also been observed that customers are extremely concerned about the possibility of having to return an item (Lee and Moon, 2015; Moon and Lee, 2014). Sizing is a major issue, accounting for 64% of apparel returns, according to Body Lab research (Cilley, 2016).

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Author contributions: Zhenzhen Huang: Investigation, conceptualization, methodology, validation, formal analysis and writing original draft; Faridah Sahari: Validation, critical review and editing.

All authors agree to be accountable for all aspects of the work.

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2. **Huang Z, Sahari F (2025).** Implications of fit customization in the apparel industry: an analytical study. *Research Journal of Textile and Apparel, Vol. ahead-of-print No. ahead-of-print.* <https://doi.org/10.1108/RJTA-04-2025-0078>

Implications of fit customization in the apparel industry: an analytical study

Research Journal
of Textile and
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Abstract

Purpose – Numerous studies have examined technologies and influencing factors related to garment fit to enhance the implementation of fit customization (FC). Nevertheless, achieving optimal fit remains a complex challenge within the apparel industry. This study aims to explore how advanced technologies are used in the implementation of FC in apparel industry, and to identify the key factors influencing fit from the perspective of clothing industry professionals, with the aim of improving customization practices.

Design/methodology/approach – The current state of FC implementation in Chinese apparel industry is examined through case studies, while in-depth interviews are conducted to explore the factors influencing fit. The collected data are analyzed using qualitative methods.

Findings – Significant progress has been made in the cutting, stitching and storage stages due to the increasing adoption of intelligent technologies. However, the degree of technological integration in body scanning, pattern-making and fitting varies across companies. Pattern design plays a critical role in determining garment fit.

Originality/value – It highlights the critical role of body measurements and pattern-making processes in achieving fit. To enhance the implementation of FC, future research directions are proposed.

Keywords Fit customization, Fit issues, Technology innovation, Body measurements, Pattern

Paper type Research paper

1. Introduction

Consumers' increased purchasing power as a result of economic developments has fueled the need to individualize to express personality (Yeung, Choi and Chiu, 2010). This demand for variety has led to the emergence of the multi-variety and small-batch garment market. Mass customization (MC) was introduced as a crucial strategy for industries to offer flexibility and quick responsiveness to diverse market demand (Da Silveira, Borenstein and Fogliatto, 2001; Senanayake and Little, 2010; MacCarthy, 2013; Nayak *et al.*, 2015; Yang, Kincade and Chen-Yu, 2015).

Fit customization (FC) is one of the most crucial MC points for clothing in terms of product satisfaction and a sustainable model, according to Senanayake and Little (2010),

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Appendix B: Interview Transcripts Data

Participant 1

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“The main method is manual measurement.”

ii. What is the criteria for the body measurement in the factory?

“The size should be combined with the body type. The size refers to the actual measurement, and the body type should be taken into account. In the national standard, the body types are classified as Y, A, B, C. However, in practice, more attention is paid to the human body's defects, such as hunchback, potbelly, sloping shoulders, flat shoulders, differences between the waist and hips, differences between the chest and hips, and leg shapes. All these factors should be considered.”

iii. How to find the landmarks and what is the standards?

“The basic measurement points of the human body, some are relatively easy to describe, such as bust, waist and hip circumference, all refer to either the thinnest or the fullest part, which are relatively easy to determine. If it is shoulder width, it is estimated by visual inspection or experience. The sleeve length and garment length should be calculated based on different styles. On the one hand, it is determined by the style, and on the other hand, it is determined by experience. For example, where is the difference in measuring shoulder width for a suit and a shirt? These two are basically similar. The measurement points may be fixed, but the ease allowance is

flexible. The reference points are still measured according to the definitions in the national standards. However, different measurers may have variations in determining this point.”

iv. What are the factors that influence the measuring methods?

“That is to say, whether the measured values are accurate or relatively precise, there is a standard procedure for operations. For example, when measuring the chest circumference, the tape must be horizontal. If it is not on the horizontal line, it will affect the accuracy. Also, the standing posture and whether the breathing is in a natural state should also be maintained.”

Part Two-Sizing System

i. What is the standard procedure for size?

“According to national standards, the requirements of the national standard must be met first, and then the height and chest circumference should be classified based on them. The body height always increments by 5 cm, while the chest circumference changes.”

ii. What is method used to design the size in the factory?

“The so-called size refers to the dimensions of each part. On one hand, it is based on experience; on the other hand, it is according to the national standards. For example, in grading, for a height difference of 5 cm, all other length variations follow a pattern. For instance, the sleeve length difference is around 1.5, the shoulder width difference is 1.2. For waistline height, sleeve length, etc., they are all calculated based

on body height. Shoulder width actually follows the circumference. The depth of the sleeve opening is also based on the chest circumference. Circumferences such as waistline, sleeve width, and hip circumference are all calculated based on the chest circumference. For designing specifications from the aspect of adding relaxation amounts to the net body size, when the dimensions are fixed, the process is mainly based on the style and the customer's requirements.”

iii. How to do the size categorization?

“For example, someone's body height is 172 cm, we would categorize them as 170 cm if he is thin. This still needs to be determined based on factors such as body type, height, and weight (this is another aspect of measurement).”

iv. What is the usage of the sizing system?

“The primary application lies in industrial production, where the size of one style can be used to calculate the specifications of other sizes. In fact, our consumers have very limited understanding of these sizing systems, and even many people in the clothing industry do not fully comprehend them.”

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

“The thickness, elasticity, and material of the fabric have a significant impact. The style is whether it is loose or fitted. The structure and lines will change, and the lines from fitted to loose need to be adjusted. The ease allowance also has an impact. The craftsmanship will also have a considerable influence, especially for the

craftsmanship of suits, which is particularly important.”

ii. Which method is used for patternmaking?

“Pattern-making methods often use the basic pattern method, using some of the original templates, such as the three-piece bodice for women's clothing, the princess line, etc. Our company already has some basic patterns, and we modify them based on this. There is also another method-direct pattern-making. For experienced pattern makers, they generally have a rough idea in their minds.”

iii. Which CAD software is used for patternmaking?

“Lectra CAD,”

iv. What are the advantage and disadvantage for the CAD software?

“Its subsequent development didn't keep up.”

v. What do you think about 3D patternmaking?

“We currently do not use 3D human models for this purpose. Currently, they are used to verify the fit of pattern. However, this method is not very convenient. For instance, it is not easy to place each piece on it and perform virtual stitching. We currently don't use 3D body models because their practicality isn't great; if used in production, efficiency wouldn't be very high. Moreover, its practicality is poor. If it is to be used in production, the efficiency will not be very high. Also, it is insufficient in terms of the composition of the fabric materials. For example, for suits, over 95% do not meet our requirements.”

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

“Inconsistent body shape, individual habits, ease allowance, and failure to adjust the pattern according to the body shape.”

ii. Which steps are taken to improve the fitting in the factory?

“There is a significant difference between haute couture and group customization. For haute couture, there is a process of making a sample garment in the early stage. First, the basic sample is made, and adjustments are made to each part based on the fitting effect, ensuring a better fit in the future. This process is more costly. For group customization, there is no sample garment process. Although we can also make each person a separate pattern, this will increase the cost. Therefore, we will combine the sizes that are consistent together for cutting.”

iii. What are the difficulties for unfit issue in the production?

“This can only be said to be related to grading issues such as armhole, collar curve in industrialized production. Grading will lead to significant fit bottleneck issues”

iv. What are other issues in menswear production?

“Firstly, production process quality. Then there are issues related to Innovations in materials or craftsmanship, as well as problems in auxiliary materials and other aspects. Digitalization is very timely and more suitable for small-scale production. It connects the production chain, making it more transparent and detailed. No human interference occurs at each node.”

Participant 2

Part Three-Pattern-Making

“I have relatively little experience in measuring and sizing. My main task is to do the patterns and grading. During the process of grading, the pattern shape should not be changed. Grading for industrial pattern has higher requirements than ordinary pattern grading. Much more sizes need to be graded, and some issues cannot be solved by pattern grading alone. Since everyone's body shape and size are different, we use the fit sample to meet our specific requirements. Because we were already well-fitting during the measurement process, but pattern grading cannot simply match all the size. That is to say, we use a base size, for example, if it is an M size, then after putting it on, some shoulders may be narrower, the middle waist may be a little fuller and need to be shortened a bit, the sleeve length and garment length may be lengthened. For body types, such as a person with a prominent chest, we use the concept of base model to achieve the desired result. For example, there may be slight chest protrusion or chest retraction, then, the setting of the grading difference will be different, there is a certain range for this. We determine how to change patterns for such body types. When the measurement specialist measures the body type, they need to determine if there is chest protrusion and then use software to identify how the size should change. That is to say, based on the description of the body type, the pattern maker fills in this data to change the pattern according to experience.”

“The grading difference is still based on the national standard. We would make

the basic patterns for different body types. They are all made according to the national standard, which is the standard for reference. For a special body type, we need to know how much we need to change after communicating with the pattern makers. If we encounter the same body type, our requirement is what effect to achieve. For example, when there is a sloping shoulder, how should we deal with it? During the measurement process, we will write down the number of grades such as "mild", "moderate", etc. Often, measurement data cannot fully express the details, and sometimes it is based on experience to convert observations into data. It all comes down to the experience of both the pattern maker and the measurer. Communication with the customers is also necessary, understanding their dressing habits and so on, to adjust the values of each part. Pattern making often relies heavily on visual judgment, which is quite subjective.”

“The CAD software, the measurement data, and the size are all interrelated. Once this is determined, that is to say, during the production process, the pattern maker does not participate. In cases where the changes are not significant, the software can self-achieve the process. Including when arranging the materials, it will automatically divide the beds, and after being arranged, it will enter the automatic cutting machine.”

“In terms of 3D pattern making, the body shape changes are quite significant during the modeling process. If it's a fit sample garment, creating a model for the human body is extremely difficult. The advantage should be able to create a separate

model for each customized user, which can definitely be afforded. If it's for group customization, it's equivalent to having to model each individual, which is a very costly process in this industry. Although 3D modeling offers higher precision and even better measurement accuracy than physical measurement, the results are definitely better. The disadvantage is that in the mass customization, it's impossible for everyone to model individually. The computer doesn't have the large storage capacity for this. Therefore, 3D modeling is suitable for high-end customization. For mass customization, although it's one pattern per person, it doesn't require 3D pattern making. 3D technology might be more convenient when it comes to the pattern adjustment. Men's clothing is more likely to be well-made because the body shape changes are relatively smaller.”

Part Four-Fit Issues

iii. What are the difficulties for unfit issue in the production?

“If there is indeed a problem of ill-fitting, it usually occurs at the beginning of the measurement process. It could be that there was insufficient communication with the customer, or the measurement size was incorrect. Generally, the issue of pattern is rarely involved. During the production process, we fully consider both comfort and fit. Most cases of ill-fitting are caused by unreasonable dimensions. The adaptability and comfort actually come down to the issues of pattern and craftsmanship. For example, with the same size and the same pattern, but due to differences in craftsmanship, you will find that the comfort and fit when wearing are also different.”

iv. What are other issues in menswear production?

“Once many patterns are finalized, there isn't much that needs to be changed, except for various collar styles. In such cases, could modularization be implemented? For example, when the client makes their own choices of the style on the screen, it is a modular process. This might be quite challenging to implement during the operation, because it has a significant connection with the components. Creating a template is also quite difficult (Breaking down a piece of clothing into components, with each component related to a specific process.), and the patterns are not all made by the same person. Some pattern makers may have extensive experience but are not familiar with using computers.”

Participant 3

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“First, it is visual inspection. Taking into account the practical experience of manual measurement.”

ii. What is the criteria for the body measurement in the factory?

“Based on experiences, as well as the points on the human skeleton.”

iii. How to find the landmarks and what is the standards?

“The main criteria is the national standard.”

iv. What are the factors that influence the measuring methods?

“The measurement method, attention to detail, and the operator's habits”

Part Two-Sizing System

i. What is the standard procedure for size?

“Mainly based on the style requirements.”

ii. What is method used to design the size in the factory?

“Different styles require different fit ease.”

iii. How to do the size categorization?

“the actual measured body dimensions are assigned to corresponding size. First, a database of size needs to be established.”

iv. What is the usage of the sizing system?

“Size system needs to be widely promoted. Currently, many people have no

understanding of the concept of size. We need to let consumers know the significance of the size.”

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

“The design concept and the feeling the designer wants to convey are very important.”

ii. Which method is used for patternmaking?

“It includes prototyping method, short dimension method and proportional method.”

iii. Which CAD software is used for patternmaking?

“I use Gerber, Zunzibaofang, etc.”

iv. What are the advantage and disadvantage for the CAD software?

“It's very convenient to make a mark for Gerber.”

v. What do you think about 3D patternmaking?

“Currently, it's not applicable to the production process; it's mainly used for display purposes.”

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

“As long as the customization requirements are met, it can be ensured that the garment fits well. However, for instance, if this person wears the garment that fits well, it might not fit the other person. This is because of people's thoughts and

perceptions about clothing, their sense of beauty, and their feeling for style.”

ii. Which steps are taken to improve the fitting in the factory?

“Popularizing awareness of style and aesthetics is important.”

iii. What are the difficulties for unfit issue in the production?

“This issue does not occur frequently in the production process. It is rather a problem related to the design and size.”

iv. What are other issues in menswear production?

“Providing management and technical support, optimizing the technical issues encountered in production, as well as issues within the industry and the workforce. The labor force is not getting younger, and there are fewer young workers willing to enter this industry”

Participant 4

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“It includes visual inspection and manual measurement.”

ii. What is the criteria for the body measurement in the factory?

“The shoulders, arm circumference, thigh circumference, and similar areas are key. For the same hip circumference, the tolerance range for the thigh (crotch) measurement can vary by 3 – 4 cm, which has a significant impact on the ease allowance for the hip. Additionally, for the upper arm circumference (about 5 – 6 cm down from the shoulder point), unless it is bespoke, this measurement is generally not taken. However, the range of this circumference can vary by as much as 7 – 8 cm. Therefore, given the same net chest circumference, this determines the ease allowance for the shoulder width and chest circumference.”

iii. How to find the landmarks and what is the standards?

“For example, with suits, we determine the garment length using the front length, whereas some companies may use the center back length. So we use the front length as the standard. Other aspects, such as the shoulder slope angle, chest thickness, and hip thickness, It requires a combination of tools and a keen eye. For me, the reference points on the human body are quite broad. Factors such as posture and standing angle are also included.”

iv. What are the factors that influence the measuring methods?

“For special body types, the range of measurements is still too limited. For example, take someone with a large belly. You may know that their largest measurement is 110 cm, but there is no indication of how far down from the shoulder point this measurement is taken. This is because this still falls within the realm of industrial production, not bespoke tailoring. Even some bespoke shops may not reach this level. Achieving this level would require the measurer to be proficient in taking measurements, pattern making, and a range of related skills.”

Part Two-Sizing System

i. What is the standard procedure for size?

“Following the national standard series 5.4, industry standards, and clothing category standards.”

ii. What is method used to design the size in the factory?

“In men’ s sizing, each body height corresponds to 8 chest circumferences. This remains workable during production and grading. It is like a kind of inheritance and continuation.”

iii. How to do the size categorization?

“Larger individuals are generally assigned larger sizes, and slimmer individuals smaller sizes. By this method, most people can be accommodated, but it is still unlikely that everyone can be fully satisfied.”

iv. What is the usage of the sizing system?

“We center our efforts around customer needs. Stocks are prepared based on the

ratios of various size ranges for men's clothing.”

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

“It includes workmanship, fabric, the pattern maker's skill. For example, when copying an existing garment, the pattern maker's ability and control over measurements are crucial.”

ii. Which method is used for patternmaking? Which CAD software is used for patternmaking? What are the advantage and disadvantage for the CAD software?

“Before 2017, Lectra was used; afterward, ET was adopted. The advantage is easier storage and modification. The disadvantage is that it is not as visually direct as working with paper patterns. For students, although they can create patterns in CAD, they cannot imagine the feel of working with paper patterns.”

v. What do you think about 3D patternmaking?

“If the patterns are well made and the software is mature enough to input the human body shape, then modifying and evaluating the fit could be done very intuitively. The key, however, is whether the pattern maker is competent enough for this task.”

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

“The most important reason is that measurements are not taken correctly, resulting in inaccurate data. If the fabric lacks elasticity, it may also cause poor fit

during the manufacturing process, because the measurer does not know which fabric will be used and typically assumes conventional synthetic fibers. In our company, poor fit due to pattern issues does not occur because we use a parametric approach. Values are assigned for conditions such as square shoulders, sloped shoulders, or a hunched back. The issue is either that the measurer did not measure properly, or the sewer did not sew properly; it is not that the pattern is too big or too small. Developing the measuring skills of the measurers is critical. Also important is the review of specification sheets. The sewing techniques used also affect the fit. Issues such as the matching of interlinings to fabrics also play a role.”

ii. Which steps are taken to improve the fitting in the factory?

“The skills of the relevant personnel need to be improved. This is primarily a management issue.”

iii. What are the difficulties for unfit issue in the production?

“It still comes down to production. Manual operations and sewing need to be addressed.”

iv. What are other issues in menswear production?

“To produce good work, retaining experienced employees is essential. In reality, it all boils down to the issue of labor.”

Participant 5

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“It includes 3D scanning, manual measurement, E-tape (electronic tape measure), and some companies use photo-based body measurement. All of them measure the net circumference of the body. The advantage of 3D scanning is its ability to capture the external dimensions of the human body. However, its greatest limitation is the inability to accurately determine several specific points, such as: the seventh cervical vertebra, the shoulder point, the underarm point, and the crotch point. These are its major limitations. Currently, the primary research direction is 3D scanning technology. Its biggest drawback is that it cannot be easily taken out and used practically; it is only suitable for research.”

ii. What is the criteria for the body measurement in the factory?

“It is mainly the national standard and experience.”

iii. How to find the landmarks and what is the standards?

“Determining the landmarks on the human body is also a very difficult challenge. The current practice still relies on experience in clothing manufacturing, which lacks data support. In other words, this experience cannot be translated into data. Regarding the measurement reference points specified in international standards or national standards, we face another problem: when taking measurements, can you actually locate those points on the human body? All of our previous approaches only

treated the size specifications as a reference. Everyone worked according to these standards, but this does not mean that the size specifications represent the body shape. This has led many people to misunderstand, taking the size specifications as equivalent to body shape. In fact, they are just recorded symbols, not actual measurement data. Now, when we take measurements from top to bottom—such as leg length, torso length, total body length, and arm length—none of these values are used during the application stage to compensate for the individual's unique body shape (for example, if a person has narrow shoulders but wide hips, the finished garment may take on an olive-like shape, which is aesthetically displeasing from the perspective of human body aesthetics). Therefore, when applying these measurements in pattern structure matching, we are not really looking at a single, isolated concept of a pattern. Instead, we are focusing on adjusting the coordination between the width of the upper body and the lower body of the individual.”

iv. What are the factors that influence the measuring methods?

“It's exactly what I just mentioned regarding body type classification — how to distinguish between body surface dimensions (body fatness or thinness) and torso (height) when determining measurements.”

Part Two-Sizing System

“Size is just a label — a way of identification. The sizing system should mainly focus on the classification of body types. In the size designation system, the 'size' refers to height, which is essentially just torso length. This understanding needs to be

redefined and distinguished from the original concept, where size designation was linked to garment length. The original size system was relatively rough. The key distinction is that the current national standard uses the Y, A, B, C body type classification, but this is completely insufficient for pattern processing. There is a need to develop more detailed classification standards and methods."

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

"As I just mentioned, the concept of automatically generating patterns actually has little to do with human body measurements in the current pattern-making approach. The typical practice is to first create a standard pattern, and then special body types are derived as variations from this standard body. Currently, this is the most common method: you have a standard pattern, and if the actual body type differs from the standard one, the research direction becomes how to define the standard pattern as '1', and the various actual body types as '2, 3, 4, 5...' Then you identify the specific points where '2, 3, 4, 5...' differ from '1'. Once these points are found, the process essentially becomes pattern adjustment. We have built such a model before; in fact, the rules of variation are based on experience rather than body measurements, yet this approach can still achieve automatic pattern generation."

ii. Which method is used for patternmaking?

" The pattern-making process is starting with a basic pattern. Initially, a standard body template is created, and then adjustments are made for specific body

types based on this standard template."

iii. Which CAD software is used for patternmaking?

"For CAD, we have used Lectra, Gerber, and ET, but currently ET is the main one we use for pattern grading. 3D-to-2D conversion is a challenge because the mindset of people working in 2D is different from that of those working in 3D. Tools like CLO 3D and Style3D cannot interpret CAD patterns. Its line variations cannot be used for production; it's all design-oriented, not practical for production. It will probably take some more time."

iv. What are the advantage and disadvantage for the CAD software?

"Lectra, which we used before, has a database pattern that also functions as a grading tool, but Lectra has not continued developing this feature. It has remained the same since it existed back in 2000, and even Lectra's function for converting 3D to 2D patterns is not practical for our use. Regarding 3D-to-2D conversion, the way 2D pattern makers think is different from how 3D designers think. Software like CLO 3D and Style3D cannot interpret CAD patterns properly — their line modifications cannot be used for production. They are more for design purposes, not practical tools for the production side. This probably still needs some time to develop."

v. What do you think about 3D patternmaking?

"The biggest issue here is the human body model. Is your human body model based on real people, or is it just a mannequin built into the software? For example, the mannequins in Style3D, the mannequin variation data, including the preliminary

research data, are all based on foreign body shape data — not Chinese bodies. Furthermore, their direction is toward the design. The models they show people are always the best-looking ones. No matter how you vary them, the changes are uniform, and they cannot generate what real people actually look like. So even if your measurements seem very similar to those of the model in the software, the actual fit on you feels completely different from what the 3D simulation shows. This is why 3D fitting results currently differ so much from real-life wear. The main problem still lies with the model."

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

"Whether the body type is measured accurately — for example, conditions like a hollow chest (sway back) or a hunched back (round back) — require ironing and molding techniques (e.g., easing, shrinking, and stretching) to address these body shape variations. So there are multiple influencing factors involved: the pattern structure itself, the fabric, and the shaping techniques used to accommodate the body shape."

iii. What are the difficulties for unfit issue in the production?

"The requirements for mass production and bespoke tailoring are inconsistent. In the case of high-end bespoke, people's demands for fit vary from person to person. That is to say, a person's occupation and lifestyle habits can all be reasons for poor fit. It's like the experienced tailor in a clothing store who can tell what kind of clothes will

suit you just by looking at you. First, you need to understand their occupation through conversation; then, the ease allowance will differ accordingly. This means that different people require different handling methods, and the ease allowances vary—this is a critical point."

iv. What are other issues in menswear production?

"That is, feeding body shape data into the system to automatically adjust the pattern — what is needed now is a refined solution for this, and the goal is to achieve rapid pattern generation. The second requirement is speed, and the third is a high level of craftsmanship. Many machines and basic data systems are now being introduced to accomplish these things."

Participant 6

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“We mainly use manual measurement.”

ii. What is the criteria for the body measurement in the factory?

" When taking measurements, it is important to first observe whether the customer has any distinctive body features, such as a prominent chest or a hunched back. If such special characteristics exist, then during bespoke measuring, careful attention must be paid to identifying the differences between the customer's body shape and a normal body shape. In terms of body measurement, you should first record the customer's height and weight, then take the three girth measurements: chest, waist, and hip. It is not enough to only consider height and weight; it is also necessary to see a person's overall body shape in order to determine their specifications. For some body types, the chest circumference may be smaller than the belly circumference — this also needs to be measured. From our experience in bespoke tailoring, we have measured many customers' body shapes, and every person is different. However, during the measuring process, great care must be taken with the customer's standing posture, as this can cause variations in the measurements. Another point: during measuring, the customer's garment pockets must be completely empty — this is an important precaution to observe during the measuring process."

iii. How to find the landmarks and what is the standards?

"Regarding the determination of measurement points, our garment length is generally measured from the seventh cervical vertebra (back neck point) down to the hip line. The difference between a casual fit and a fitted fit in terms of length is about 4 - 5 cm. Age also needs to be considered. For fitted garments, if young people do not prefer a casual, longer style, the more fitted the garment, the shorter it should be — it does not need to be made too long. Additionally, the front length must be measured. The front length is measured from the side neck point down to the tiger' s mouth (the point where the thumb and index finger meet) when the arm hangs naturally. Female body measurement differs somewhat from male body measurement, because the three girths are different. These two length measurements are very critical. Also, you need to observe whether the person has a hollow chest (sway back) — at the very least, you must also determine their front chest width. For a hollow-chested figure, the front chest width will be larger than the back width. For back width, we generally look at the person' s shoulder width. When measuring shoulder width, the measurement should be taken from the actual shoulder points. In actual garment construction, it depends on the style — for example, a suit and a jacket are different. For a fitted shirt, the actual shoulder width value is used. Comfort is extremely critical. The finished garment must have no pressure points when worn. If there are any pressure points, the garment is unqualified. The most important factors are body measurement and the ease allowance."

iv. What are the factors that influence the measuring methods?

"The factors affecting body measurements mainly include the person's posture while standing. The body should stand naturally, as the position of the shoulders, back, and even items in pockets can influence the measurements. For instance, when measuring the chest circumference, the tape should be level with the pectoral area, following the body's contour. "

Part Two-Sizing System

i. What is the standard procedure for size?

"The standards are the national standards, as well as the specific product category."

ii. What is method used to design the size in the factory?

"The specifications are based on the measurements of a 180 cm tall model to establish the base size, and the dimensions of the base size will not be changed."

iii. How to do the size categorization?

"First, First, measure the dimensions back, then, category the height and weight. Generally, measurements within 1 cm can be grouped into the same size designation. Our style preference is not to go for longer lengths — we tend to assign customers to smaller sizes. If it's a fit garment, there will be a significant disparity in the fit when wearing it if the difference exceeds 2cm "

iv. What is the usage of the sizing system?

"The size system is generally only useful within the company — for example,

quality inspectors need to know the measurements. In a specialty store, if a customer states their height, the salesperson will know which size fits them."

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

" Factors affecting the fit include the fabric and the matching of the lining with the fabric, the thread used, and the ease allowance — which is also one of the most critical factors affecting pattern. Additionally, It relies on aesthetic sense and years of experience."

ii. Which method is used for patternmaking?

"We use prototyping method. We generally have a basic pattern. For unique body types, we have a fitting process, typically starting with a basic sample to fit the dummy."

iii. Which CAD software is used for patternmaking?

"The first software we used was PGM, which was very good. Later, we switched to ET, and we have been using it ever since."

iv. What are the advantage and disadvantage for the CAD software?

"PGM's accuracy is very good, with small errors. As for ET, some of its functions are faster to use (such as the grading function), and it is convenient. As for virtual fitting software, we wanted to use it but ultimately did not, because it's cumbersome to use if not familiar with new software. Therefore, we still use dress forms for fitting."

v. What do you think about 3D patternmaking?

"If the pattern is developed on a 3D prototype, the accuracy would be higher, but converting it to pattern making, it still requires experimentation; it may take time to adapt. For example, the dress form we currently use is quite mature; for bespoke tailoring, we use the dress form for fitting."

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

"The main factors include personal preference, fabric, and the ease allowance — which is very critical."

ii. Which steps are taken to improve the fitting in the factory?

"This requires adjusting the pattern according to personal preference. Slightly stretchy fabrics can also be used to reduce restriction. In terms of ease allowance, for larger individuals, some additional ease must be added on top of the basic ease allowance to compensate for the amount that will be 'consumed' — because the skin of a larger body type has a looser, more padded quality. In practice, this can result in a total ease allowance of up to 12 cm (compared to 8 cm for a normal body type)."

iii. What are the difficulties for unfit issue in the production?

"Men's bespoke suits are the most difficult. Every part must be checked against the pattern. If the error exceeds 0.3 cm, the finished garment will show a noticeable difference."

iv. What are other issues in menswear production?

"Fabrics, auxiliary materials, and customer preferences and needs are all changing, so it is necessary to understand trends in advance. Different fabrics require fine-tuning of the pattern."

Participant 7

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“We use manual measurement method.”

ii. What is the criteria for the body measurement in the factory?

“When measuring the body, it should be done according to standard procedures, ensuring the customer stands in a natural and upright position, then adjustments can be made up or down according to personal preference. Also consider the customer's usual wearing habits, such as a tendency to hunch their back or have sloping shoulders. For example, if someone is used to hunching their back, add a little extra length when measuring the center back length.”

iii. How to find the landmarks and what is the standards?

“During body measurement, the measured points and base points must be consistent with the points or parts specified in the pattern-making specifications.”

iv. What are the factors that influence the measuring methods?

“Wearing habits and the body shape, such as a hunched back, sloping shoulders, or a large belly, needs to be noted when measuring body dimensions. These special body characteristics should be recorded so that the pattern maker can adjust the pattern based on body type.”

Part Two-Sizing System

i. What is the standard procedure for size?

“Basically, all are in accordance with national standard regulations. For industrial pattern making, there are loose-fit and fitted styles. Different styles have different ease allowances. If it's customized, it will depend on your body type. Major items are based on the national standard. Body height and bust size are the two most fundamental criteria.”

ii. What is method used to design the size in the factory?

"It is obtained by adding ease to a net-fit mannequin. For bespoke tailoring, the ease is added based on the fabric, whether the fit is close-fitting or loose, and the customer's personal preference. In industrial pattern making, ease allowances vary between companies, depending on each company's product style."

iii. How to do the size categorization?

"Sizes are categorized according to a reference size chart. For special body types, the pattern must be adjusted on the base pattern. The style also needs to be taken into account. If a certain body measurement exceeds the standard value — for example, if it is still not enough to accommodate the body's girth even after adding ease — then it is classified as an atypical figure. It also depends on the style. For example, the hem is ribbed, it can accommodate a larger girth, so the impact is not very significant.
"

iv. What is the usage of the sizing system?

"It makes it easier for us to buy clothes. Alternatively, the salesperson can look at the customer's height and body type and give them a size to try on. It also facilitates

garment production."

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

" The primary consideration is the fabric, especially when creating the first sample, where the elasticity and shrinkage of the fabric need to be evaluated. Body type also affects the pattern; for example, the issue of front or back hem lifting occurs because the front waist length and back waist length are unbalanced. This problem is even more common in bespoke tailoring. Another factor is the sewing technique of the sample maker — for example, the balance of ease distribution. Also important are the auxiliary materials."

ii. Which method is used for patternmaking?

"The most common method is 2D flat pattern making. Draping is less common in men's wear companies."

iii. Which CAD software is used for patternmaking?

"ET."

iv. What are the advantage and disadvantage for the CAD software?

"ET follows the same logic as manual pattern making — it is relatively simple and intuitive. A beginner can learn it in one day. About 50% of the market uses ET. After using the automatic grading function, the pattern still needs further adjustment, because some curves are not satisfactory."

v. What do you think about 3D patternmaking?

“3D pattern making is definitely more intuitive, as you can see the effect directly on the model — especially when dealing with front-back balance issues. After adjusting all the dimensions, you can immediately see the result and calculate the front-back balance. This is very good, so accurate calculation functions are needed. The disadvantage is that it cannot yet be widely adopted.”

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

“Pattern fit. Especially in bespoke — for example, if the customer wants a slightly fitted (but not tight) garment, and the size is made too small, it will affect movement and comfort. Additionally, there are the customers' fit preferences (whether they prefer fitted or loose clothing). Therefore, whether a style is designed as fitted or loose must be determined based on market customer demand.”

ii. Which steps are taken to improve the fitting in the factory?

“Grading increments should be considered.”

iii. What are the difficulties for unfit issue in the production?

“This is less of an issue on the production assembly line; the main influence is still the pattern.”

iv. What are other issues in menswear production?

“There is a significant loss of skilled garment workers, and the adoption of template automation is still low. Automated processes need to be more comprehensive.”

Participant 8

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

“Human body measurements are mainly taken manually. For customization, we use a fit sample, adjustments are then made based on this fit sample.”

ii. What is the criteria for the body measurement in the factory?

"According to national standards and experience."

iii. How to find the landmarks and what is the standards?

"It is mainly based on national standards."

iv. What are the factors that influence the measuring methods?

"Standing posture is very important."

Part Two-Sizing System

i. What is the standard procedure for size?

"In custom tailoring, the first step is to estimate the body type based on weight and height. For group customization, we generally use fit garments."

ii. What is method used to design the size in the factory?

"First, determine the style — whether it's a fitted or loose style, followed by the basic fit ease. For example, the ease allowance for a fitted jacket is designed to be 8 - 16 cm."

iii. How to do the size categorization?

"Size categorization is determined based on the net chest measurement."

iv. What is the usage of the sizing system?

"Different measurements result in different style silhouettes. For example, a jacket can have chest circumferences of 112 cm, 120 cm, 130 cm, or 150 cm — all worn by the same person — but the garment's silhouette will be different. This plays an important role in pattern design."

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

"First is the nature of the fabric, and the craftsmanship must also be considered. The thickness and elasticity of the fabric are the main factors affecting the ease allowance. For a fitted shirt, it mainly depends on the fabric's stretch — if the fabric has high elasticity, the ease allowance is smaller; if there is no stretch, a normal ease allowance is applied. On the basis of ensuring a good appearance, the ultimate goal is to ensure comfort."

ii. Which method is used for patternmaking?

"In the beginning, patterns were made manually, and later with CAD. Draping is rarely used in menswear."

iii. Which CAD software is used for patternmaking?

"I use ET."

iv. What are the advantage and disadvantage for the CAD software?

"ET is relatively fast and convenient, but its drawback is that, unlike 3D, it doesn't allow you to visually see pattern issues."

v. What do you think about 3D patternmaking?

"3D is currently used more often in places like Zhejiang and Guangdong, mainly for fashion apparel. At this point, I think 3D has only advantages and no disadvantages — it can basically solve 80 - 90% of pattern-related issues."

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

"Fit issues such as twisting, grainline direction, and fabric bunching caused by ease allowance— taking a suit as an example, the fit ease is also the most crucial factor affecting the fit."

ii. Which steps are taken to improve the fitting in the factory?

" For customization, it involves fitting sessions, usually with a basic sample.. And then, with the combination of the actual fabric and craftsmanship, the result becomes better. In menswear, most of the work is about solving issues with the back. If there is excess fabric bunching up on the back, you lower the entire back from the back neck point down to the shoulder seam."

iii. What are the difficulties for unfit issue in the production?

"When the craftsmanship does not match the pattern — for example, a sleeve cap ease of 1.5 - 2 cm — some workers on the assembly line find it difficult to achieve. As a result, mass-produced products often suffer from inconsistent quality due to the varying skill levels of the workers."

iv. What are other issues in menswear production?

"In the factory labor sector, there is aging, with older workers unable to continue, and younger ones unwilling to join "

Participant 9

Part One-Body Measurement

i. What are the methods of taking the body measurements in the factory?

"For custom tailoring, sizing is based on the customer's actual body measurements. For industrial pattern making, it follows national standards, additionally, the occasion and style should dictate the corresponding measurements."

ii. What is the criteria for the body measurement in the factory?

"It is necessary to know the wearing occasion, the consumer's dressing habits, and the consumer's comfort preferences — all of these factors must be taken into consideration."

iii. How to find the landmarks and what is the standards?

"For a normal body type, you can just take measurements according to the standard national guidelines. But for someone with a rounded back or hunched posture, it's different — for example, with a hunched back, the shoulder-neck point needs to be adjusted based on the actual body shape. If the person is slimmer, the horizontal neck opening will be smaller, and the shoulder slope should be slightly larger. If the person is heavier, the horizontal neck opening will be larger, the shoulder slope should not be as large, and more ease allowance for movement should

be added."

iv. What are the factors that influence the measuring methods?

"The clothes a person is wearing can affect the measurements. In custom tailoring, attention must be paid to the wearing occasion and the ease allowance."

Part Two-Sizing System

i. What is the standard procedure for size?

"For national standards, there are corresponding standards for each case."

ii. What is method used to design the size in the factory?

"For major categories of clothing — such as casual wear, business wear, loungewear, outdoor wear, etc. — there are standards for each. The main point is that different product categories, different fabrics, and different styles all lead to different sizing specifications."

iii. How to do the size categorization?

"We categorize sizes based on actual measurements according to both length and girth measurements. For example, if out of 100 people, 10 have a garment length of 175."

iv. What is the usage of the sizing system?

"Industrial production must follow a standard, such as European standards, American standards, or national standards — all of these are standardized. For example, in the northern market, where body types tend to be larger, small sizes may be omitted; in the southern market, large sizes may be omitted. That's probably how

it works in practice."

Part Three-Pattern-Making

i. What are the influencing factors for the pattern?

"The fabric, trims, lining, shoulder pads, whether lamination for waterproofing and breathability or seam tape is used — all of these affect the pattern. For example, with knitted fabrics, the ease allowance in the pattern will be reduced."

ii. Which method is used for patternmaking?

"There are flat pattern making and draping. For industrial production, flat pattern making is faster."

iii. Which CAD software is used for patternmaking?

"I use ET."

iv. What are the advantage and disadvantage for the CAD software?

"The advantage of ET is that it's easy to learn, consistent with the thinking used in manual pattern making, and very flexible. The downside is grading. With systems like Gerber, when you input the values during pattern making, the grading is generated automatically."

v. What do you think about 3D patternmaking?

"Currently, we are using standard body models. If we could directly use scanned body data, that would be almost all advantages. In the future, everything will shift toward personalized customization. Right now, small-batch, quick-response production and personalized customization are already common."

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

"The size requirements are unreasonable. For example, a common issue with raglan sleeves is that when you check the fit on a mannequin, it may look like there's too much ease in the underarm area, and the customer asks to take in more fabric. However, if you take in too much, the shoulder line will shift downward, causing pressure on the shoulder, making it uncomfortable to wear."

ii. Which steps are taken to improve the fitting in the factory?

"More paneling, more dart manipulation, and more seaming can improve fit. For example, with pants, you can use stretch fabric to add gussets in the crotch area. For a four-panel jacket, you can also add underarm gussets. This way, you can achieve both a good fit and increased comfort."

iii. What are the difficulties for unfit issue in the production?

"Because the process can be broken down into detailed steps, as long as the requirements are followed, this issue will not exist."

iv. What are other issues in menswear production?

"From a personal perspective, it's about self-improvement — there is a need to learn more about the physical and chemical properties of fabric components. For example, different fabric compositions have different shrinkage rates. If the dimensional requirements are strict, you need to understand issues like fabric

shrinkage in order to control the measurements effectively."

Participant 10

Part Four-Fit Issues

i. What are the main causes that result to the unfit?

"The reasons for poor fit in menswear include, first, each company has different requirements for the size of the basic pattern. Some companies, especially those focused on business wear, have relatively reasonable sizing, while others have slightly looser sizing. In addition, the style and the fabric also affect whether the garment fits well or not."

ii. Which steps are taken to improve the fitting in the factory?

"If the pattern is correct, then during production, craftsmanship plays a very important role. Although there are many templates and automation technologies now, many aspects still cannot replace manual craftsmanship, such as trimming, ironing, shrinking, stretching, and so on. These are aspects where automated equipment cannot effectively standardize the process. For example, to make a garment fit smoothly on a hunched back, to make it look well-fitted, and to make the neckline curve smoothly — some templates may only be able to produce standard shapes, but they cannot achieve a 100% fit to the human body. This mainly relies on our manual craftsmanship. The pattern cannot be made entirely according to the human body's exact shape, as doing so would make the clothing clearly highlight any flaws when

worn. Garment construction also has a significant impact, especially in suit tailoring."

iii. What are the difficulties for unfit issue in the production?

"Fit issues caused by the pattern include the following: The designer provides the measurements for each style. You need to check whether the measurements meet the requirements, then try it on a mannequin to see if the front and back of the garment are balanced, whether the sleeves are the correct length, whether the underarm area is too tight or too loose, whether there are diagonal wrinkles across the chest, and other such issues."

iv. What are other issues in menswear production?

"The difficulty of training personnel in craftsmanship techniques, and the increased costs. If you need a highly skilled craftsmanship technician, a certain amount of training time is required. It also involves many aspects such as fabrics, their properties, and construction methods."

Appendix C: Body Shape Classification Data

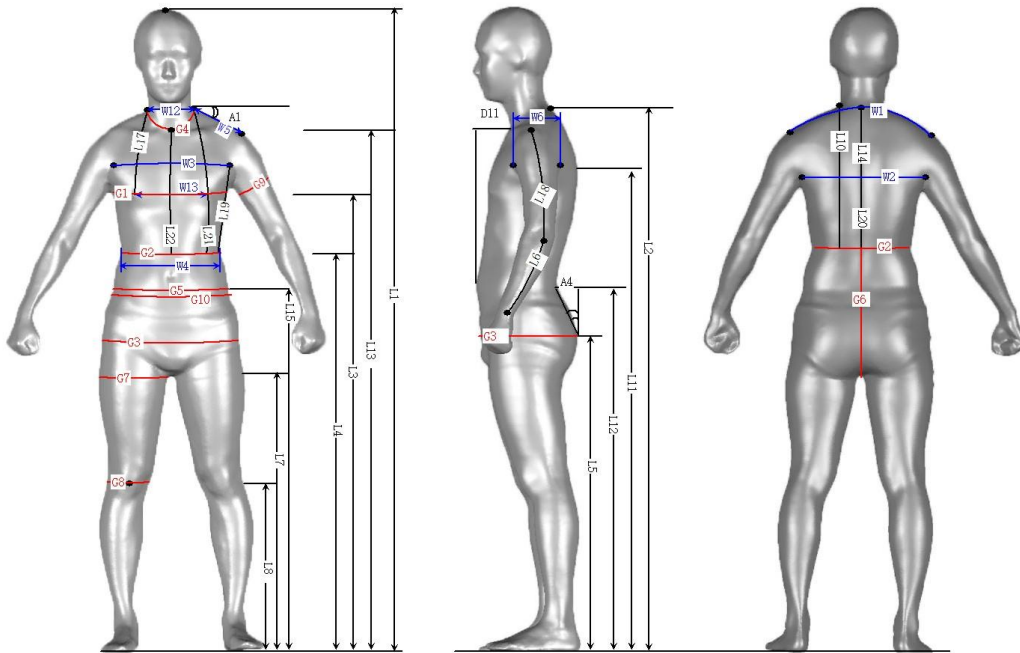


Figure 1: 40 Measurement Locations

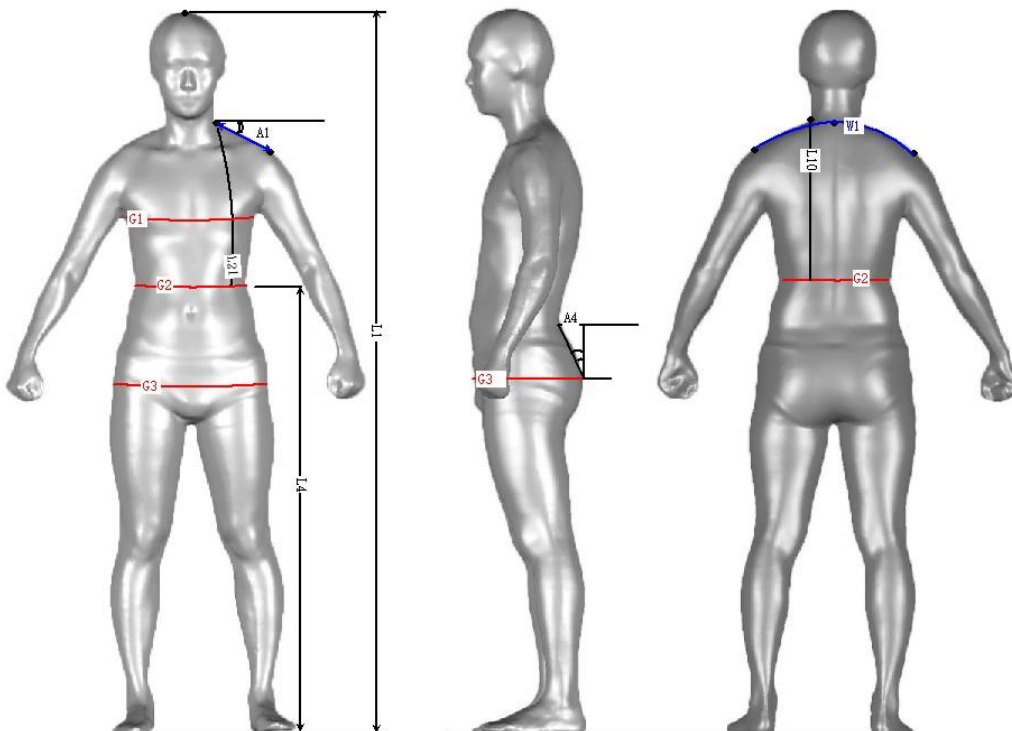


Figure 2: Diagram of Characteristics of Body Type Classification

Table 1: Body shape Cluster Results of 408 measurement samples

Samples	Cluster Category						
	D1	D10	R1	D5	R2	A1	A4
1	III	II	II	I	I	I	I
2	V	II	II	I	II	III	II
3	II	III	III	III	III	III	III
4	*	*	III	II	*	II	III
5	V	I	I	I	II	II	II
6	II	II	II	II	III	III	*
7	III	I	III	III	III	II	III
8	V	I	II	III	I	II	III
9	V	II	I	III	III	II	III
10	III	I	II	I	II	III	II
11	III	I	II	I	I	II	I
12	III	III	I	III	*	II	I
13	V	II	III	III	III	II	II
14	IV	III	II	III	I	II	II
15	IV	III	I	II	I	II	II
16	II	II	II	I	II	II	I
17	III	II	II	I	II	I	I
18	II	I	I	I	II	III	II
19	V	I	I	I	II	III	II
20	IV	III	III	III	I	III	II
21	IV	II	II	III	I	II	II
22	II	I	II	II	I	III	II
23	II	II	II	III	I	II	III
24	V	II	II	I	II	III	I
25	IV	III	II	III	III	II	II
26	IV	II	II	I	II	III	I
27	III	I	III	III	I	III	II
28	II	II	I	I	II	II	II
29	III	I	II	I	II	III	II
30	V	II	I	III	I	II	III
31	V	I	II	III	I	II	I
32	III	II	III	III	III	II	II
33	III	I	III	III	III	II	I
34	*	III	I	II	I	II	III
35	IV	II	III	III	I	II	III
36	V	III	I	II	III	I	I
37	IV	III	I	II	III	II	II

Table 1 continued

38	V	II	II	III	I	III	III
39	III	I	I	I	I	II	II
40	II	II	I	I	I	II	III
41	IV	III	I	III	III	III	I
42	V	II	I	III	I	III	II
43	III	III	III	III	III	III	I
44	II	II	I	III	II	II	III
45	III	I	II	III	II	II	II
46	II	III	I	I	II	I	I
47	III	I	II	I	II	II	I
48	II	II	I	III	III	III	I
49	II	II	II	III	I	III	II
50	II	III	I	III	I	III	I
51	II	I	II	III	II	II	I
52	III	I	I	I	I	III	II
53	II	III	I	III	I	I	II
54	V	II	I	I	II	I	II
55	V	III	I	III	I	II	III
56	V	III	II	II	III	II	III
57	II	II	I	I	I	III	I
58	III	II	I	I	I	III	I
59	V	I	II	I	II	I	II
60	V	I	I	II	I	III	II
61	V	II	I	I	II	II	I
62	IV	III	I	I	I	II	II
63	IV	III	I	III	II	III	I
64	IV	III	I	III	II	II	I
65	V	II	II	III	I	II	III
66	III	I	II	I	II	I	I
67	V	II	I	I	II	II	III
68	II	II	I	III	II	III	I
69	V	II	I	I	I	III	I
70	II	II	II	I	I	I	I
71	IV	III	III	II	III	III	II
72	I	II	III	I	III	III	I
73	II	II	I	I	I	II	II
74	V	II	I	I	II	II	III
75	III	II	II	I	I	II	III
76	V	III	II	I	III	II	II
77	V	I	III	III	I	II	III

Table 1 continued

78	III	I	I	III	II	III	II
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81	II	II	II	II	I	II	III
82	V	I	I	I	II	I	III
83	V	II	I	III	I	II	I
84	III	I	III	I	I	II	III
85	I	I	II	III	II	I	II
86	III	I	III	III	I	II	I
87	V	I	I	III	II	III	I
88	I	I	I	I	II	II	III
89	V	III	II	II	III	II	II
90	III	I	II	III	I	III	I
91	I	III	I	II	III	II	II
92	V	I	II	I	I	III	II
93	III	I	II	III	I	I	III
94	V	II	I	I	I	III	II
95	III	II	II	III	III	II	II
96	V	II	I	III	I	II	III
97	I	II	I	I	I	II	I
98	V	II	III	II	III	II	II
99	I	I	II	III	I	III	II
100	IV	III	I	III	II	I	II
101	V	II	I	I	I	III	I
102	V	I	II	I	II	III	II
103	III	I	I	I	I	II	I
104	V	II	I	III	II	I	III
105	V	I	I	I	II	II	I
106	II	II	II	I	I	III	III
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109	II	II	I	I	II	II	II
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111	*	*	III	I	*	*	II
112	II	III	II	I	III	II	II
113	II	II	III	I	I	I	II
114	V	I	II	I	II	II	I
115	II	II	I	III	III	I	II
116	V	I	I	I	III	II	II
117	V	I	I	III	II	II	II

Table 1 continued

118	III	II	I	II	III	II	II
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122	V	I	I	I	II	I	I
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126	II	II	II	III	II	I	II
127	II	II	II	III	I	I	I
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129	II	I	I	I	II	I	II
130	V	II	II	I	I	I	II
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132	V	I	II	III	I	II	I
133	III	II	I	III	I	I	III
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135	V	I	II	*	I	I	III
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Table 1 continued

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166	V	I	II	III	III	III	I
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196	II	III	II	II	III	II	I
197	V	II	III	III	I	III	I

Table 1 continued

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201	I	I	II	III	I	III	I
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207	II	II	II	I	II	II	III
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209	II	III	I	*	III	II	III
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218	II	I	II	*	II	III	I
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222	V	III	I	III	III	II	II
223	V	*	*	*	*	I	*
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Table 1 continued

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Table 1 continued

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291	III	I	I	*	II	III	I
292	V	I	I	I	I	III	III
293	III	III	II	II	*	II	III
294	II	III	II	III	I	II	II
295	III	II	I	III	I	II	II
296	II	III	I	I	III	II	II
297	V	I	I	I	II	II	III
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299	III	II	III	III	I	III	II
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302	V	II	II	III	I	III	III
303	V	II	III	II	*	I	I
304	III	I	II	III	I	II	III
305	II	III	III	III	I	I	II
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312	IV	III	II	III	I	I	II
313	V	III	I	II	I	I	I
314	II	II	I	II	II	I	III
315	II	II	I	I	II	I	I
316	III	I	II	I	II	II	II
317	IV	III	III	II	III	II	III

Table 1 continued

318	II	I	II	III	II	II	III
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322	IV	III	I	III	II	I	I
323	V	I	III	*	II	II	III
324	V	I	III	I	I	I	II
325	III	I	III	I	III	III	III
326	I	I	I	I	II	II	I
327	II	II	III	III	III	II	III
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354	III	I	III	I	I	II	II
355	II	II	II	I	II	II	II
356	III	I	I	I	II	II	II
357	II	II	III	I	I	III	I

Table 1 continued

358	V	II	I	*	II	II	III
359	V	II	III	I	I	III	I
360	III	I	II	III	I	III	II
361	II	II	II	III	I	III	I
362	V	II	III	III	II	III	II
363	III	I	II	I	I	III	III
364	V	II	II	I	II	I	II
365	II	III	I	II	II	II	I
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379	II	III	I	I	II	II	I
380	*	*	III	*	*	*	II
381	II	I	II	III	II	II	III
382	II	III	II	II	III	III	II
383	V	III	*	II	III	I	I
384	IV	III	I	II	I	I	II
385	V	II	II	II	III	I	I
386	II	II	II	I	II	II	II
387	I	I	III	*	II	II	II
388	II	II	III	III	I	III	III
389	II	I	III	III	II	II	II
390	II	III	II	III	III	II	II
391	V	II	II	I	I	II	I
392	IV	III	III	*	I	III	II
393	II	II	I	III	II	II	II
394	II	III	III	II	I	III	III
395	V	I	III	III	II	II	III
396	IV	III	I	III	I	II	I
397	V	II	II	III	I	II	III

Table 1 continued

398	II	III	II	II	III	I	II
399	III	I	II	I	I	II	II
400	II	II	III	I	II	III	II
401	I	*	III	III	II	I	II
402	II	II	II	III	II	II	II
403	III	I	II	*	II	*	III
404	V	II	III	III	I	III	I
405	II	II	II	III	II	III	II
406	V	II	I	II	II	II	II
407	III	I	III	III	I	II	II
408	III	I	II	III	II	II	III

*is default value

Table 2: Diagram of Body Type Classification Under D1

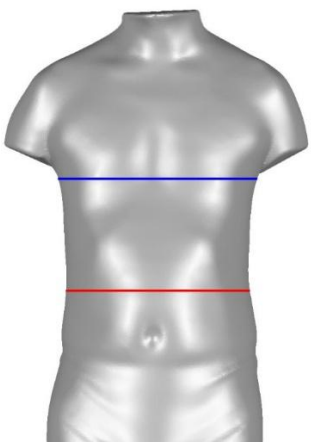
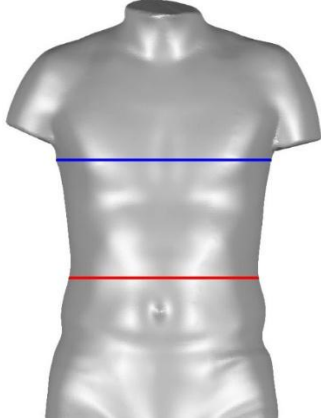
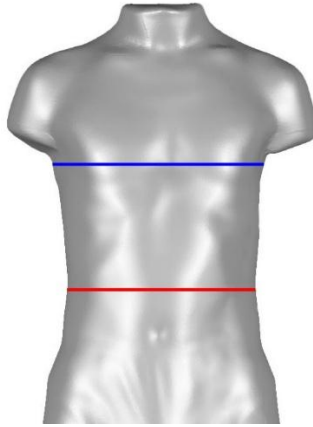
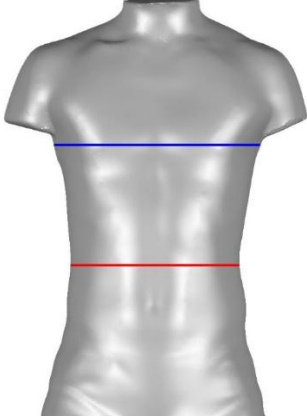
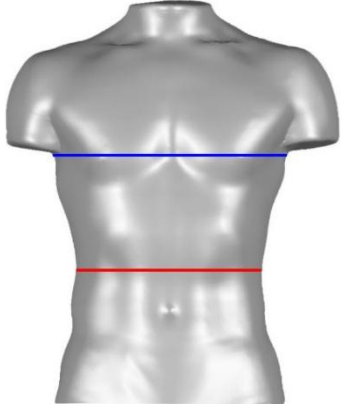
		Cluster Center				
		I (5.4435)	III (10.8931)	V (14.8310)	II (18.7848)	IV (23.1084)
D 1						

Table 3: Diagram of Body Type Classification Under D5

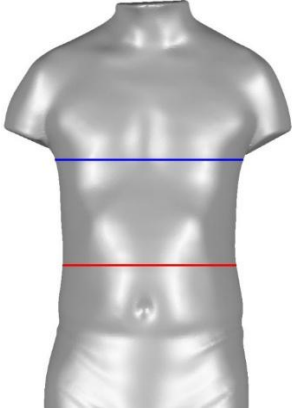
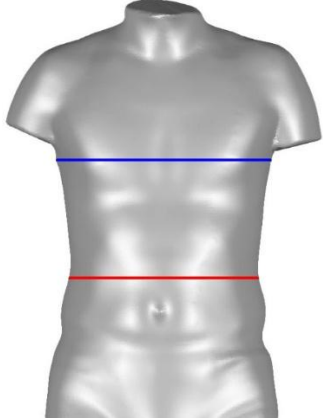
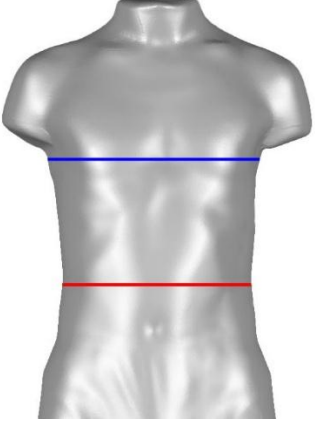
		Cluster Center		
		I (1.5670)	III (-1.1316)	II (-4.3176)
D5				

Table 4: Diagram of Body Type Classification Under D10

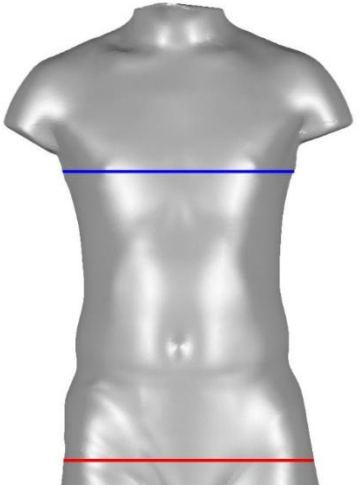
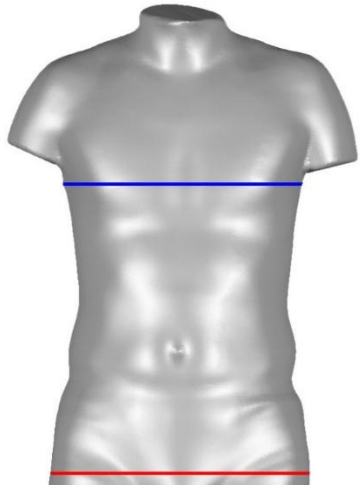
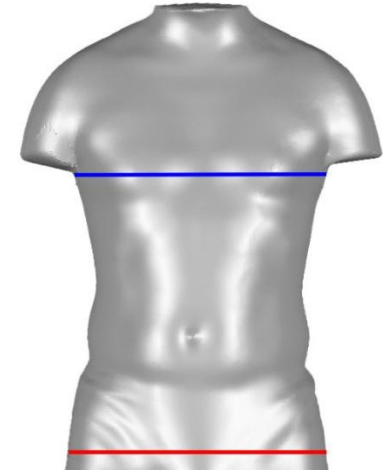
	Cluster Center		
	I (7.3838)	II (2.0432)	III (-4.1507)
D10			

Table 5: Diagram of Body Type Classification Under R1

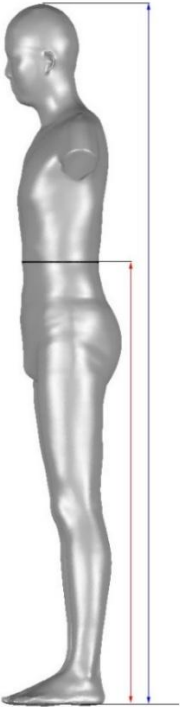
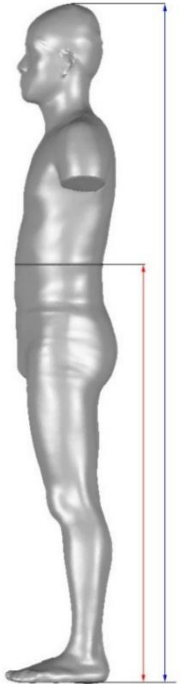
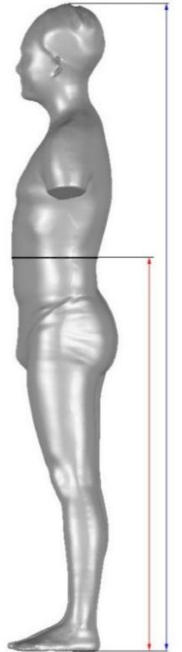
		Cluster Center		
		I (0.6276)	II (0.6169)	III (0.6051)
R1				

Table 6: Diagram of Body Type Classification Under R2




		Cluster Center		
		II (0.2199)	I (0.2388)	III (0.2585)
R2				

Table 7: Diagram of Body Type Classification Under A1

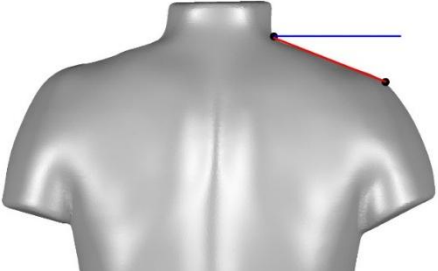
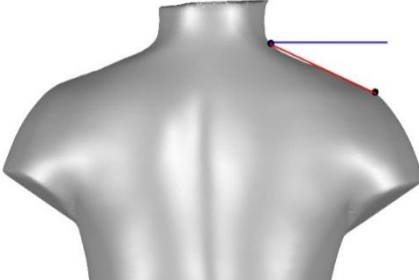
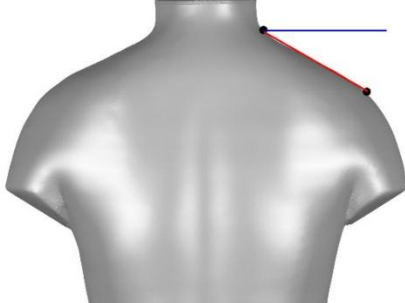
		Cluster Center		
		I (19.7157)	II (24.8961)	III (29.4575)
A1				

Table 8: Diagram of Body Type Classification Under A4

		Cluster Center		
		I (19.7157)	II (24.8961)	III (29.4575)
A4		