DEVELOPMENT OF AN INTELLIGENT PERSONALIZED PATTERNMAKING SYSTEM BASED ON D2C MODEL

ZHANG XIN

PhD

The Hong Kong Polytechnic University

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The Hong Kong Polytechnic University

School of Fashion and Textiles

Development of An Intelligent Personalized Patternmaking System Based on D2C Model

ZHANG Xin

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CERTIFICATE OF ORIGINALITY

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ZHANG Xin (Name of student)

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ABSTRACT

In today's fashion market, consumers, particularly the young generation, often prefer personalized products, whereas for manufacturers, producing products at lower costs and a faster speed are at the top of the agenda, contributing to the increase in competitiveness and hence the growth in profits. To meet the needs of both parties, mass customization appears to be a crucial strategy. Nevertheless, most clothing products that customers currently purchase are still ready-to-wear (RTW) produced by mass production model. RTW garments are typically produced based on garment size charts, which are derived from size tables of the brands, where each brand has its own target customer segment and thus its own size table, representing a certain body shape, named as '*average figure*' of the brand. In RTW production, grading is an inseparable part of producing multiple-sized garments, but the current grading methods show inevitable limitations. Specifically, the use of proportional grading in the mass production, in which uniform deviations are assumed in the grading process, failing to reflect the characteristics of different bodies and resulting in ill-fitting garments. Individuals, whose body shapes deviated from the average figure, are forced to choose which body area they want their clothing to fit.

To address these issues, an intelligent personalised patternmaking system is proposed

and developed in this study to create better fitted garments more easily and efficiently. In the proposed system, the auto-grading technique, as a crucial function, is designed to address the limitations of the traditional proportional grading method commonly utilized in the RTW production, aiming to provide customized clothing patterns for individuals with diverse body sizes and shapes. Meanwhile, a novel method for size recommendation is also developed to offer size suggestions for customers to cater to the environment of current RTW mass production.

This study involves a total of three developments, building upon a comprehensive review of related theories, practice and research. The first development in an integrated size table that covers very broad body size ranges as well as a large variety of body shapes, which can serve as a valuable size database to provide key sizes and range of measurements of individuals. In the second development, automatic size recommendation method first introduces a quantitative fit evaluation scheme, helping customers identify appropriate size of RTW clothing. This quantitative fit evaluation method also provides the theoretical rationale to formulate the grade distributions to be used in the auto-grading function of the third development of an automatic personalised pattern generation system. Both the automatic size recommendation method and automatic personalised pattern generation methods were validated by carefully

designed experiments.

This study explores the relationship between garment fit, clothing sizes, and apparel customization. Given the rapid expansion of international fashion e-commerce in recent years, the proposed intelligent personalised patternmaking system can be applied in direct-to-consumer (D2C) model to offers on one hand effective size recommendation for ready-to-wear products based on standard size charts; and on the other hand, not only provides optimal fit for customers of different body shapes but also gives manufacturers an easy way to customize clothing patterns for individual customers.

Keywords: Mass Customization; Sizing System; Sizing Standards; Body Shape Variation; Integrated Size Table; Size Recommendation; Garment Ease; Auto-grading; Pattern Alteration

PUBLICATIONS

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CHAPTER 1. INTRODUCTION

1.1 Research Background

1.1.1 Clothing Fit Issues with Online Shopping

With the development of internet technology, e-commerce has gained prominence worldwide (Hu et al., 2020; Kim & Kim, 2004). Fashion, specifically apparel, is one of the fastest growing categories in online shopping (Abdulla & Borar, 2017). Some e-shopping platforms, such as ASOS, Zalora, Taobao, and JD.com, provide customers with a simple and effective shopping model. Nevertheless, high return rates of between 30% and 50%, primarily due to inappropriate sizes, remain a major concern for customers and retailers alike (Ashdown & Loker, 2010; Baytar et al., 2020; Foysal et al., 2021; Hammond & Kohler, 2002; Peng & Al-Sayegh, 2014a; Yueqi, 2010). When shopping online, customers are not able to physically try on and assess the fit and appearance of the garment on their bodies (Zhao et al., 2021). Consequently, customers can only rely on clothing images and size charts to choose appropriate sizes by themselves, which frequently leads to poor fit and associated dissatisfaction (Almousa, 2020; Ancutiene et al., 2014; Ding & Xu, 2008; Kim & LaBat, 2013; Kim & Damhorst, 2010; Mao et al., 2018; Pierola et al., 2016; Zhang et al., 2019). Many online platforms and companies have implemented size recommendation function that provides customers with size guidance in order to try to address the issue of customers' inaccurate size selection and garment dissatisfaction (Baier, 2019; Hajjar et al., 2021; Januszkiewicz et al., 2017). However, an inherent limitation of current online size recommendations is the inability to accurately assess garment sizes that fit customer's body. Additionally, customers can only obtain a basic size suggestion without further information on how the recommended garment fits to their individual physique. For instance, when a customer makes an online clothing purchase, these platforms only provide a size suggestion, e.g. size S. The online size recommendation fails to give any evaluation of the specific proportions and fit of clothing in relation to individual body measurements. Such information can only be obtained until the customer physically receives a clothing and tries it on. Consequently, the size recommendation has not effectively served as a reliable shopping aid, leaving the existing problem insufficiently addressed.

In the apparel industry, garment misfits are also associated with the current sizing system. The existing size charts fail to accurately capture body measurements and the changes in body shapes, and also unable to cater to the increasingly personalized requirements of customers for clothing products. With mass-produced garments, the use of unreliable size charts can result in ill-fitting garments due to grading errors, ultimately impacting customer satisfaction.

Improving the clothing fit has attracted significant attention from companies and researchers alike. In order to cater to diverse body sizes and shapes and provide a personalized fit, this study initially focuses on the development of online size recommendation techniques, which can serve as a mean of improving the accuracy of size selection and ensuring a better fit for online shoppers.

1.1.2 Relationship of Sizing System and Grading

In today's apparel market, most clothes that customers currently purchase are still ready-to-wear (RTW) produced by mass production model (Loker, 2007; Mpampa et al., 2010; Zhang et al., 2011). Grading is a crucial aspect of RTW production to create multiple-sized patterns (M. Islam et al., 2020). It balances the relationship between various sizes, typically taking the middle size as the benchmark (base pattern) and calculating the distribution of the increase (or decrease) amounts at specific points to produce new patterns (Bye & DeLong, 1994; Nancy A Schofield, 2007; Workman, 1991; Xiu et al., 2009). Traditional grading techniques produce patterns that change proportionally in circumference and length (Cooklin, 1991). In the mass production of RTW, manufacturers develop a limited range of sizes through grading techniques to cater to a larger population, which contributes to minimizing production costs and improving manufacturing efficiency. The industry grading practice, however, frequently falls short of achieving a good fit performance. Bye et al. (2008a) evaluated traditional industry grading techniques and identified deficiencies in pattern grading. A good fit for one person cannot represent a good fit for a population of people due to the diversity of body shapes. Therefore, the most typical issue in traditional industry grading practice is that the uniform deviation does not accurately reflect the characteristics of different body shapes, while garments produced would only fit those bodies similar to the base model. Individuals, whose body shape deviates from the average proportions, are forced to choose which body area they want their clothing to fit (Bye et al., 2008a; Petrova & Ashdown, 2008; Taylor & Shoben, 1990). There are a number of customers who are not satisfied with RTW clothing, which was corroborated in the previous studies (Ashdown & Loker, 2010; DesMarteau, 2000; LaBat & DeLong, 1990; Peng & Al-Sayegh, 2014b).

In general, grading rules are developed from sizing specifications, sizing specifications are compiled from anthropometric surveys (Moore et al., 2001; Vong, 2011). To create garments in different sizes, the increments used to create each new pattern must be based on the body measurements associated with that size and organized in a sizing chart (Nancy A Schofield, 2007). Most of the previous studies relating to grading concerned suggesting a new size system to improve the accuracy and fit of sizes in garment production (Jeon, 2004; Jo & Choi, 2002; Jung, 2009; Schofield & LaBat, 2005b). However, the sizes in the sizing system only represent the ideal body types of the target population, and the grading rules generated from the updated sizing system still fail to accurately describe various body types. The sizes and shapes of the human body are the foundation for garment grading. In this study, body sizes and shapes are studied to provide an optimized grading method to address the prevalent issue of customers being unable to purchase personalized clothing that fit them perfectly.

1.1.3 Ready-to-wear to Customization in Apparel Industry

In recent years, customers' requirements for garment fit are increasing (Han *et al*., 2014). The evolution of customer preferences has shifted from RTW size to customized fit, where they seek to fulfil not only functional aspects of garments but also diverse and personalized needs. Consequently, apparel companies are in urgent need of a cost-effective, high-quality, personalized, and efficient mode of customized garment production. Currently, two directions of garment production have emerged: the first direction involves the implementation of a one-piece flow production mode through the use of made-to-measure (MTM) systems; the second direction is the participatory garment customization mode, which is facilitated by online platforms (Wan *et al*., 2021; Yuan & Huh, 2018).

The MTM system is an efficient and cost-effective production method for customized clothing, utilizing digital and information technology. The process involves several steps. Firstly, the customer's measurements are obtained through a 3D body scanner. Secondly, the customer selects the desired garment style from a database of available styles for customization. Subsequently, basing on the customer's body measurements, the body shape is analyzed, and the appropriate size is determined. Lastly, the basic pattern is modified accordingly, and an electronic order is generated and transmitted to the factory for garment manufacturing. However, despite the advantages of the MTM system, there are still limitations in achieving full personalization and efficient mass production during the customization process.

The participatory customization platform empowers customers to actively engage in the personalized purchase of their clothing, allowing them to express their individuality and enhancing their shopping experience (Hahm, 2017; Sanders & Simons, 2009; Wan *et al*., 2021). For instance, Itailor specializes in the customization of men's suits and shirts, utilizing static 3D models to showcase the garment's appearance for each style. Customers can visually evaluate the 3D effect of their customized garments[1]. Similarly, UNIQLQ-UTme service in Japan offers customers the opportunity to design their own

[1] https://www.itailor.com/

T-shirt patterns, going beyond the limitations of pre-designed options provided by designers[2]. This platform emphasizes personalized customization, providing customers with more prominent customization features. However, these customization platforms have often focused on expanding the range of clothing styles, while neglecting the crucial aspect of garment fit. Although customers participate in the customization process, the purchased products still fall under the category of ready-to-wear garments, resulting in noticeable fit issues.

Garment customization is an extensively researched topic and a necessary strategy for apparel enterprises to foster innovation in the clothing industry. Despite the emergence of numerous custom platforms by garment companies, there remain several challenges that need to be addressed. These challenges are not solely limited to the realm of mass production for customization but also encompass crucial aspects such as garment fit and meeting personalized needs.

1.2 Research Problem and Scope of Study

Based on the above discussion, research work on intelligent personalized customization has some known limitations.

[2] https://www.uniqlo.com/jp/ja/

Understanding the body sizes and shapes of customers across countries is an important aspect of garment customization and production in today's globalized e-fashion world. Body size and shape information can be directly inferred from sizing systems, which often differ across countries. Many apparel brands overlook customer targeting and rely on a generic commercial size chart to produce garments for international customers. However, these size charts, based on country-specific mass production, do not adequately align with international customers' body measurements. As a result, ill-fitting garments and size discrepancies have led to an increasing rate of returns (Ashdown & Loker, 2010; Foysal et al., 2021; Hammond & Kohler, 2002; Peng & Al-Sayegh, 2014b; Pisut & Connell, 2007). Based on the aforementioned limitations, this study provides a comprehensive analysis of all body sizes and shapes of various countries, aiming to develop an integrated size table and offer a practical solution for the growing global demand for personalized fashion items and address the inconvenience caused by inconsistent sizing practices. Chapter 3 of this study presents the whole process for achieving such an integrated size table.

At the same time, customers usually lack the eye on correct fit for different clothing items and are unable to assess how the various garment sizes fit their body as there are no try-on options for online apparel purchases, which usually leads to high return rates as well. To solve this problem, an automatic size recommendation model was developed basing on an analysis of the fit between the garment size and the human body to help customers identify the body fitting size from vague and uncertain size information. A comprehensive analysis will be illustrated in Chapter 4.

Pattern grading is a crucial step in apparel manufacturing for mass production, which is widely utilized in the fashion industry to produce garments of different sizes for customers. In the mass production of RTW, the industry grading practice fails to provide a good fit due to the proportional changes in limited sizes that do not accommodate variations in body size and shape. (Bye et al., 2008a). Therefore, this study aims to develop an optimized grading method specifically tailored for diverse body sizes and shapes. The ultimate goal is to achieve an auto-grading technique to generate the personalized garment pattern for individuals. To accomplish this, a thorough analysis of the construction of the optimized grading method is presented in Chapter 5.

To summarize, the existing work for understanding personalized customization and garment production has the following known limitations:

- The study of size charts is still an ongoing research topic, but the current size tables studied are not suitable for globalized clothing production in today's world.

- The garment fit cannot be quantified, and the existing size charts in shopping platforms cannot meet customers with diverse body shapes.
- The garments purchased by customers are still mass-produced ready-to-wear garments, which may cause ill-fitting issues.
- Current size recommendation techniques are still unreliable and fail to adequately cover a significant fraction of customers due to the above limitations.
- Traditional grading cannot be adequate in accommodating the diverse range of body sizes and shape variations among individuals.

1.3 Research Aim and Objectives

This study proposes and develops an intelligent personalized patternmaking (IPP) system, aiming to provide individual fit and personalized customization. The proposed IPP, based on a direct-to-consumer (D2C) model, would greatly improve the problems of inappropriate sizes and hence customer satisfaction. The ultimate goal of IPP system is to develop an intelligent customization technology for customers and manufactures to easily and efficiently create their preferred and fit fashion garment. To narrow the gap between customers and manufactures, the proposed system provides an effective grading method facilitating the garment process. To realize the intelligent auto grading, a novel method for size recommendation is developed to improve the accuracy of the garment size chart and mass production. More specifically, this study focuses on the following research objectives:

i. To establish a systematic understanding of body types and shapes, anthropometry surveys and sizing systems, size recommendations, grading techniques, virtual fitting, and apparel customization.
ii. To develop an IPP system to provide personalized clothing patterns with optimized fit for individual customers.
iii. To provide a reliable and comprehensive analysis of body sizes and shapes in various countries, using consistent criteria based on the most recent national sizing standards.
iv. To establish a comprehensive and highly compatible size table that encompasses a wide range of body sizes and accommodates diverse body shapes effectively.
v. To construct the size recommendation model that can assist customers in identifying appropriate sizes based on vague and uncertain size information.
vi. To offer customers the fit evaluation bases as to how each body dimension is accommodated within each recommended size.
vii. To develop the optimized grading method on various garments and diverse body

shapes to improve individual fit.

viii. To build intelligent auto-grading techniques for automatic garment pattern generation.

ix. To validate the reliability of personalized customization by virtual try-ons and actual wearing trials.

1.4 Overview of Research Method

Based on the defined research objectives, the IPP system consists of three developments: An Integrated Size Table Accommodating the Diversity of Body Shapes and Sizes, A Novel Size Recommendation Model, and Automatic Custom Pattern Generation Method, which contributes to the construction of the overall research framework, as outlined in Figure 1-1.

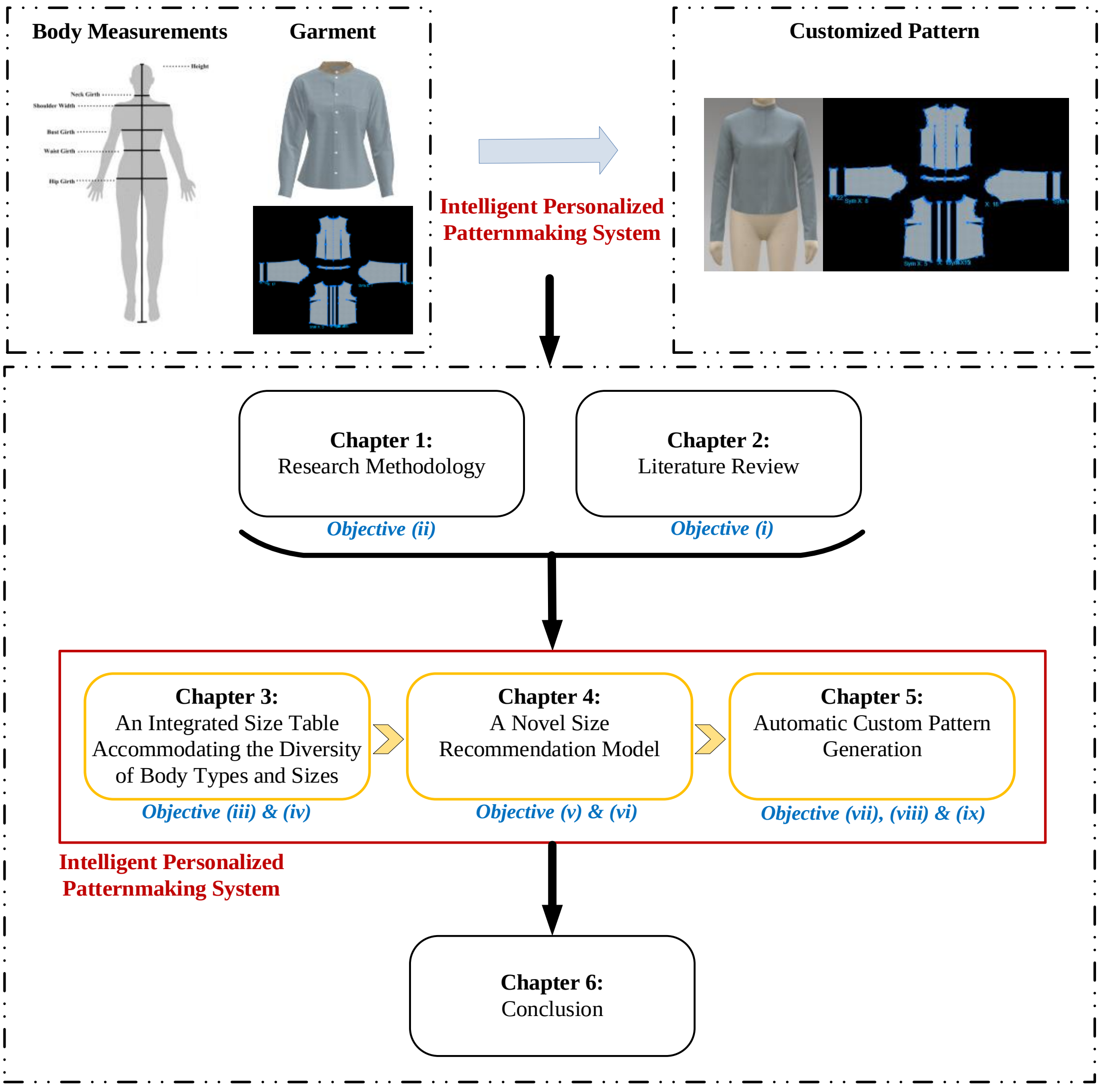


Figure 1-1 Research Methodology

In the proposed IPP system, each garment style is given with its corresponding clothing patterns for a base size. The IPP system is capable of recommending the best fit size and utilizing intelligent auto-grading algorithms to alter the clothing patterns from the base size to customized patterns. Within the IPP system, three modules are collaboratively work together to generate the customized clothing patterns. Here introduces the method rationale and the interconnections between the constituted modules, highlighting the problems solved and contributions made.

The three developments correspond to three modules of the IPP system (Figure 1-2), all aimed at addressing the challenges of achieving ideal fit between the garment and the wearer. The development of the integrated size table provides an exhaustive and reliable analysis of all body types in various countries based on defined consistent criteria using the most recent national sizing standards. The derived size tables can serve as a valuable size database for specifying key sizes and measurements tailored to individual customers, and this also assists manufacturers in defining the range of their target customers. Size is recommended by comparing customer key measurements against the size chart of a particular garment style with a set of size options. The second development is a novel size recommendation method that takes into account the multiple key measurements commonly used in size tables to recommend appropriate sizes for customers. This recommendation model offers a systematic method to evaluate garment fit based on the relationship between body measurements and garment sizes. By quantifying the fit errors and comparing them to the ideal ease, the model enables the evaluation of how well a garment conforms to an individual's body shape. The size recommendation model has introduced a quantitative fit evaluation scheme that can serve as the foundation for the development of automatic grading algorithm. Based on this fit evaluation framework, the third development focuses on developing automatic grading algorithms that generate customized patterns for diverse body shapes. With IPP, customers can receive customized patterns of their selected style, which are tailored to fit their body shapes and sizes, maximising clothing fit and customer satisfaction on personalised products.

The IPP system is developed to address previously unsolvable fitting problems, not only leading to an enhanced overall fit of the garment but also an increased customer confidence and loyalty towards the brand or product. Moreover, for manufacturers, it serves as an intelligent pattern generation system that optimizes three crucial aspects of apparel production, thereby improving production quality and efficiency. The IPP system can be applied in any fashion business offering direct-to-consumer (D2C) model. The three developments for IPP will be further explained in detail by separate chapters.

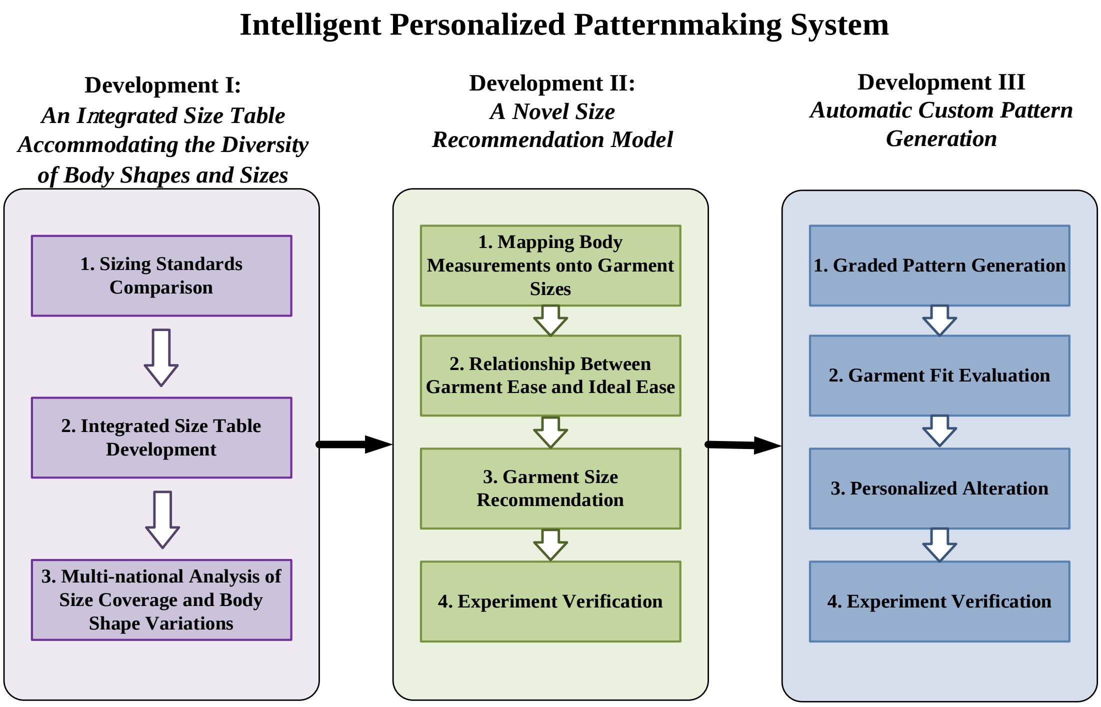


Figure 1-2 Methodology Outline for the Intelligent Personalized Patternmaking System

The remainder of this thesis is organized as follows: Chapter 2 reviews the work on body types and shapes, anthropometry surveys and sizing systems, size recommendation, grading techniques, virtual fitting, and apparel customization in detail, realizing the Objective (i). This section of Chapter 1 delineates the research methodology of this study, with a brief discussion of its significance (Objective (ii)).

In Chapter 3**,** an integrated size table accommodating the diversity of body types and sizes is introduced, giving the overview of the proposed method addressing to defined research Objectives (iii) and (iv). In this chapter, a comprehensive analysis of the body shapes in various countries using the most recent national sizing standards is given. A set of integrated and internationally compatible size tables are then derived, which provide a valuable reference for the analysis of body size and shape variation. This study covers both female and male sizing standards in the US, Europe, China, Japan, and some other countries.

In Chapter 4, a novel size recommendation model is developed, aligned with research Objectives (v) and (vi)). This chapter proposed an automatic size recommendation model that is based on the fit analysis between the garment size and the human body to help customers identify optimal sizes from vague and uncertain size information and provide the fit information of each body dimension. The proposed method prioritizes key body measurements based on their importance in affecting the overall fit of a garment. It also sets an ideal fit for each measurement, deriving an overall fit score for each size and ranking them accordingly to identify optimal size. The method was tested on two sets of databases comparing different styles of female shirts and then results are compared to those derived from traditional techniques.

In Chapter 5, automatic custom pattern generation is discussed (Objectives (vii), (viii), and (ix)). In this chapter, an optimized grading method is proposed to cater to diverse body shapes and achieve individual garment fit. Then, the intelligent grading technique based on the proposed optimized grading method is developed for automatic garment pattern generation. The garment virtual try-on and wearing trial experiments compared traditional grading techniques with the proposed method, verifying its effectiveness across various styles of female and male garments.

The last chapter, Chapter 6, would summarize the whole study, highlighting the contributions and key findings. Recommendations would be given for future work.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

The research background and objectives have been described in Chapter 1,an overall review of the substantial literature is presented in this chapter. It contains a review of the literature in six aspects: Understanding Human Body Types and Shapes, Anthropometry Surveys and Sizing Systems Construction, Size Recommendation, Grading Techniques, Virtual Simulation and Fitting, and Apparel Customization, which served as the theoretical framework for this study. The purpose of this review is to provide an in-depth analysis of previous research and thereby identify research gaps.

2.2 Understanding Human Body Types and Shapes

2.2.1 History of Body Shape and Somatotypes

Human body shape is a well-studied topic of continuous research throughout the ages. Characterizing and understanding human body shape variation is traditionally the subject of anthropometry (Ben Azouz *et al*., 2006). As early as 400 BC, the founder of modern medicine, Hippocrates, had presented the correlation between different body shapes and their susceptibility to various diseases (Well, 1983). Around the seventeenth century, anthropometry started to be used in combination with morphology. The 20th century witnessed significant advancement in the classification and recognition of body shapes. In the early 1920s, Ernst Kretschmer (1926) categorised the human body-build into four groups: pyknic (characterized by excessive instinctive development and extra fat), asthenic (thin, narrow, and light skeletal construction), athletic, and dysplastic (a combination of types). Additionally, Sheldon *et al*. (1940) introduced the concept of somatotype and developed a system to measure and numerically express the components, namely endomorphy, mesomorphy, and ectomorphy. Meanwhile Influenced by Sheldon, Douty (1968) recorded the information on body sizes and contour by using a light source, a translucent grid screen, and a camera, and further studied the human body shapes and developed body structure and posture, 5-point scales. In the 1960s, Carter continued the refinement of Sheldon's somatotype methodology (Heal, 1963). However, Carter *et al*. (1990) denied the point of Sheldon and maintained that the procedure of somatotype was laborious.

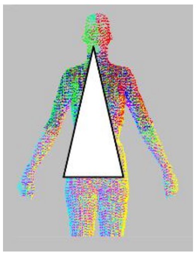
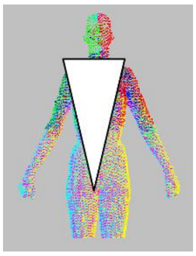
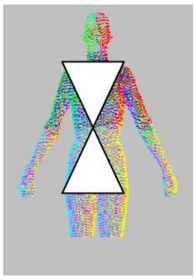
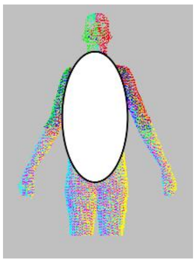
The study of human body shape classification has significantly advanced due to the rapid development of 3D body scanning technologies and measurement technology (J. Wang et al., 2021). Moreover, 3D body scanning has made a significant contribution in the domains of the apparel industry due to its practical applications. Vuruskan and Bulgun (2011) proposed to construct human contours from 3D scan data for the numerical classification of body shapes. Yu and Kim (2020) divided the upper body of young males into three parts and proposed a human body classification method that combines 3D scanning, manual measurements, human skeletal features, and statistical analysis. In the early 1980s, countries worldwide adopted the technology for use in large-scale population studies to summarize various body shapes.

2.2.2 Body Shape Classification

Body shape is one of the most important characteristics that describe the human body. Research on investigating and identifying the body shape of the human body has long been a focus of attention.

Reviewing the previous work on body shape, body types are classified by shape, letter/number, and the name of the fruit/vegetable (Istook, 2004). Table 2-1 characterizes these figure types.

Table 2-1 Classification and Nomenclature of Body Types (Istook, 2004)

Figure Type	Traits	Illustration
Triangle[c.h.i.j.n.o] "A" Frame[i.m] Pear[a.b.d.e] Spoon[g.k] Christmas Tree[f]	Shoulders narrower than hip. Bottom heavy with weight mainly in buttocks, low hips and thighs. Bust is small to medium. Upper body smaller than lower body.	
Inverted Triangle[c.h.i.j.o.n] Cone[g.k] "V" Frame[d.m]	The heaviest part of the body is on top. Shoulders are wider than hips. Weigh gain in upper body and stomach. Usually large chest. Very narrow hips.	
Rectangle[c.h.i.j.o.n] Ruler[g.k] "H" Frame[m.i]	No definition at the waistline. Shoulders and hip about the same width. Equal body proportions.	
Hourglass[c.g.h.i.j.k.n.o.] Figure 8[m] "X" Frame[i]	Equally broad on top and hips. Thin at the waist, usually 10 or more inches smaller than chest and hips.	
Oval[c.h.i.j] Circle/Rounded[o] Apple[a.e] Diamond[.o] "O" Frame[i]	The top and bottom are narrow. Chest and belly are where weight is found. Skinny legs.	

Note: (a)Self (2000) (b) IVillage.com (2001)(c) La.essortment.com (2001)(d) com (2001)(e) Fitness. (1999)(f) Rita (1996)(g) Jackowski (1995)(h)Fashions. (2001) (i) Mathis (2001)(j) Is. (2001)(k) Exude (2001)(l) Surville *et al*. (2010)(m) Image. (2001)(n) Palmer *et al*. (1998)(o) Liechty *et al*. (2010)

A large number of approaches to estimate the type of body shapes. However, not all bodies can be precisely categorized into a single figure type. Simmons (2002) developed a new shape identification software called FFIT ((Female Figure Identification Technique) for Apparel. Nine shape categories were identified: “hourglass”, “oval”, “triangle”, “inverted triangle”, “rectangle”, “spoon”, “diamond”, “bottom hourglass”, and “top hourglass” (Figure 2-1). Later, the Female Figure Identification Technique emerged as the leading body shape classification system, providing a comprehsive desicription of the 3D profile found within different populations (Parker *et al*., 2021).

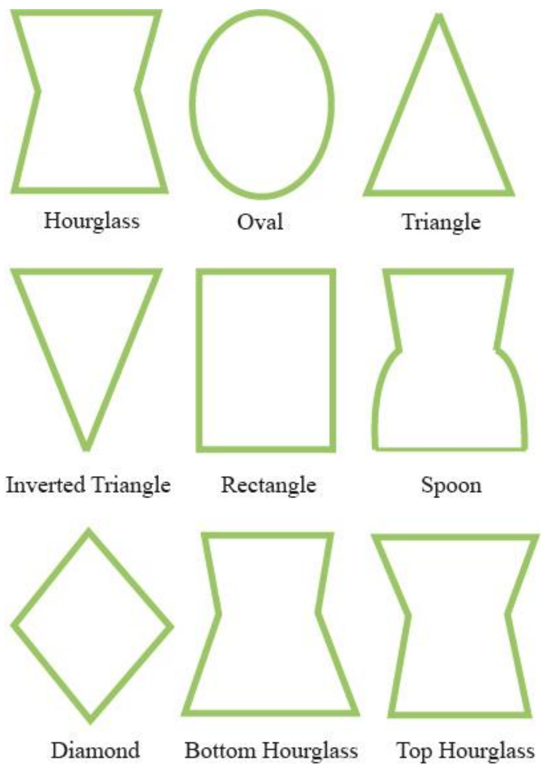


Figure 2-1 Body Shape Defined by FFIT (Simmons, 2002)

Connell *et al*. (2006) developed the Body Shape Assessment Scale (BSAS), which included the overall body shape of females from the front and side. From the front, the entire pectoral muscle of the female is divided into five shapes based on the shoulder (shoulder tail), waist and the widest point between the waist and the crotch, they are round, pear and shape, rectangle, inverted triangle and hourglass. Song and Ashdown (2011) proposed a novel method than others to classify body shapes. By utilizing body measurements obtained through 3D body scanning technology, researchers categorized the lower body shapes of females aged 18 to 35, with a BMI of 34.1 or less. Park and Park (2013) conducted the 3D body scan of 1,327 females in South Korea and obtained four body shapes through factor analysis and cluster analysis : (1) Large torso and below-average shoulder width, (2) wide shoulder and below-average lower body, (3) small torso and large lower body and (4) small figure. Song *et al*. (2022) classified four upper body shapes in 423 women (aged 40-69 years old) in the United States and found 8 factors that affected upper body shape in older women: acromial inclination, upper body slope, neck inclination, waist depth, shoulder angle, overall body length, upper back curvature and back protrusion height.

In the apparel industry, one of the main factors affecting the fit and satisfaction of clothing is body shape, so many apparel researchers have been attempting to observe and divide the body shapes. Chun (2012) examined the fit-related challenges associated with the existing sizing system for jeans in the apparel industry, aiming to address the fit issues experienced by diverse consumers and identify the variations in body shape among different ethnic groups. Liu *et al*. (2016) stated that height, waist circumference, and hip-to-waist difference are the key dimensions of lower body shape and proposed a fuzzy classification method of lower body shape based on triangular fuzzy numbers to further develop bottoms. Many studies have been conducted to create garment patterns based on body shape classification, resulting in more comfortable and well-fitting clothes (Chen, 2007; Kato, 1994; Okabe, 1995). However, the fit problems encountered in the apparel industry are often attributed to sizing systems that fail to account for the wide range of diverse body shapes. Moreover, the diversity of human body shapes observed across various ethnic groups and countries highlights the existence of distinct fit issues within the current sizing system. The field needs further research to explore and analyse the differences of body shape worldwide.

2.2.3 Acquisition of Human Body Shapes

There are two approaches to obtain human body shapes: (1) dynamical techniques (Bogo et al., 2015; Collet et al., 2015; Corazza et al., 2006; De Aguiar et al., 2008; De Aguiar et al., 2007; Gall et al., 2009; Leroy et al., 2017; Pons-Moll et al., 2015; Vlasic et al., 2008), the information can be used to research the natural motion of the human body, e.g., motion capture and surface deformation, and (2) statical techniques (Beeler et al., 2010; Capers et al., 2016; Do et al., 2012; Gonzalez-Sosa et al., 2017; Gupta et al., 2017; Park et al., 2021; Ran et al., 2020), which mainly focus on human modelling to investigate body shape and body measurements. Although such methods offer various possibilities for obtaining body shape information, the generated verbose data cannot be used directly for body shape analysis without systematic classification.

In addition, two metrics, body mass index (BMI) and body volume index (BVI), are commonly used to estimate the human body shape. BMI, also known as Quetelet’s Index, is calculated from an individual's mass (weight) and square of height, and is used to provide a measure of an individual’s fatness (BMI, 1998). Nuttall (2015) mentioned that BMI is a rather poor indicator of body fat percentage. Moreover, BMI also does not capture information about fat adipose tissue over the body and various body parts. Another body metric, namely, BVI, is a novel concept derived from comparative demographics that measure body mass index (BMI), waist circumference, waist-to-hip ratio, total body fat, adipose tissue, and body volume statistics by using 3D scanning technology, which can be used to calculate the location of adipose tissue (Stefan, 2005). BVI distinguishes individuals who have the same BMI but have a different body shape and weight distribution (Barnes, 2014). These metrics aim to track adiposity and estimate health risks, providing overall nutritional status and detailed health data in relevant healthcare, rather than comprehensive body shape analysis in practical application.

Body shape information can also be directly inferred from sizing systems. A sizing system is a table of numbers, derived from a large anthropometric survey, which summarizes the value of each body dimension used to classify the body dimensions encountered in the population for each size group in the system (Petrova, 2007). The sizing system composes four key components: 1) The control dimensions, also called the key dimensions, indicate the dimensions used to classify the population. For instance, bust and waist dimensions are control dimensions in the top size chart. Bust is the primary dimension and waist is the secondary dimension; 2) The size ranges, refers to ranges occurring in the population for each body dimension (Petrova, 2007); 3) The size interval, which refers to the number of groups into which the range of values for each dimension is divided; 4) The drop value. Within the same size group, the drop value is the difference between the primary and secondary dimensions, representing different body types. Through a series of data collection and induction efforts, involving these four key components, the body type characteristics of target populations can be analysed. In general, body type differs from body shape, body type refers to the overall build and skeletal structure, which is generally determined by the height and drop values (Yu, 2004b). In the case of linear body measures, body shape is generally obtained by calculating differences in height and girth, which describe the silhouette and contour of the body (Bougourd, 2007). Understanding both body type and body shape is important in determining proper clothing sizes and achieving overall health and fitness goals. In the sizing systems, body shape information can be concluded from the body sizes associated with the control dimensions that represent different body types.

A sizing system was derived based on the anthropometric data from the population that represents the target market (Ashdown & Loker, 2010). To benefit both the industry and their target population, various countries have conducted large-scale anthropometric surveys to collect demographic information such as gender, age, ethnicity, geographic location, habits, income level, for describing the population diversity and body type variation (King, 2014). For example, large-scale anthropometric surveys, such as CEASAR 1998, Size UK, 2001, Size USA 2005, Chinese size survey and Japanese size survey, are conducted to collect body data and also classify body types. These large anthropometric surveys are based on rigorous procedures and well-established processes, and anthropometric results are presented in the form of the national sizing standards to provide sizing guidance for the target population. The national sizing standards are created and adjusted by trial and error, which reflect the sufficiently comprehensive body size ranges and body type information of the specific country. Most countries reregulated and revised their sizing standards within a certain period to represent the current body structures of the population. Even though the morphological features of one geographical area have changed with life habits and immigration, the national sizing standards still serve as the indispensable industrial specifications to guide the industries of human-cantered and body shape-related in defining their target populations. Consequently, different national sizing standards are not aligned, resulting in differences in the body type classification of different countries.

2.3 Anthropometry Surveys and Sizing System Construction

2.3.1 Anthropometry Surveys

This section provides a short global survey of anthropological measurement and development of garment sizing systems.

1884: The initial efforts to standardize garment sizes involved collecting female body measurements from high schools. The measurements were first taken at Vassar College in New York in 1884, followed by Stanford University in California in 1890, and Schmith College in Massachusetts in 1903 (Ashdown, 1998).

1901: To establish standards for measurements in science and industry, the U.S. federal government established the National Bureau of Standards (NBS) (CS 215-58, 1958).

1921: The first report of anthropological measurements in the US was derived from the measurement of around 100,000 men during the World War I demobilization period (Fan *et al*., 2004).

1937-1938: Anthropometric measurements were organized in different climatic regions of Texas and 13 other U.S. states. These studies involved 3000 boys and 3535 girls between the ages of 7 and 14 years. They established standards for size and clothing construction (Whitacre and Grimes, 1959). Thirty-six measurements were taken on each subject. The study was conducted in 1941 and provided basic data on the physical development of children.

1937–1939: A comprehensive anthropological survey of 147,088 children between the ages of 4 and 17 was conducted to predict clothing sizes as well as the size of desks and other school furniture (O'Brien, 1939, 1941). The results were published in USDA Miscellaneous Publication No. 366, titled Physical Measurements of Clothing and Pattern Construction for Boys and Girls in the US (CS151 50, 1945).

1939-1940: The first comprehensive scientific survey organized by the USDA National

Office of Internal Economics involved approximately 150,000 American women. The results were published in 1941 in USDA Miscellaneous Publication No. 454, entitled Female Measurements of Clothing and Pattern Construction (NIST, 2011a, 2011b).

1957: A clothing sizing system was developed in the U.K. The JointClothing committee organized anthropometric measurements of 4,349 women between the ages of 18 and 70. Based on the analysis of data from these measurements, the association developed a sizing system for women's clothing and garment construction. There are three types based on height (short, medium, and tall) and three types based on fullness (slim, normal, and full) (Chun and Jasper, 1993).

1957-1958: The Hohenstein Institute (Germany) investigated body measurements based on representative figures of women and girls (Schierbaum, 1993).

1958: The American NBS published the commercial standard CS 215-58 *Body Measurements of Women's Pattern and Garment Sizes* (CS 215-58, 1958), to determine women's garment sizes based on anthropometric measurements. The data were obtained from 1939-40 years anthropometric survey (NIST, 2011a).

1960-1961: The German Research Institute carried out anthropometric survey of the female population for the German clothing industry with the aim of producing clothing suitable for the general population (Schierbaum, 1993).

1963: At the request of German professional associations, the Hohenstein Institute published size chart of clothing for women's and girls' outwear. The size charts were based on anthropometric data from 1957 and 1958 and from 1960 to 1961 (Schierbaum, 1982, 1993).

1965-1966: Anthropometric measurements were conducted on 7283 French men between the ages of 22 and 64 years (Fan *et al*., 2004).

1966: The Bekleidungstechnisches Institut Mönchengladbach (Germany) published size charts for men's and boys' outwear based on more than 80,000 measurements for approximately 10,000 people (Schierbaum, 1982). These size charts include 88 commercial sizes, 60 for men, 7 for boys and 21 for teenagers. Due to the growing importance of the European market, these tables include European sizes.

1966–1967: The Japanese standard JIS offered a review of garment sizes based on the measurements of approximately 35 000 people.

1969: Supplementary anthropometric measurements were carried out in France on 8037 women between the ages of 18 and 65 years and approximately 14000 boys and girls between the ages of 4 and 21 years (Fan *et al*., 2004).

1970: The NBS published a modernized commercial standard CS 215-58, beginning in 1968, in a new version as a voluntary product standard PS 42 70 for commercial purposes (PS 42-70, 1970; NIST, 2011c).

1970: Measurements of the female population were again organized in Germany, as filed reports showed that the garment size charts for women and girls' outwear were outdated because body measurements and proportions had changed over time. This survey measured the 10,000 women and girls and was presented in a table of women's and girls' outwear constructions (Anon., 1970).

1972: In November 1972, a body measurement chart for women's and girls' outwear was compiled for the second time in Germany (Schierbaum, 1982)

1974: The English standard was published for women’s outerwear garment sizes, under the designation BS 3666 (BS 3666, 1974; Boughey,1978).

1974: China began preparations for issuing garment-sizing standards, known as GB 1335–81. The standard was implemented in 1981 (Fan *et al*., 2004).

1975: The International Organization for Standardization (ISO) has developed a new sizing system that includes defining symbols for key dimensions and body types, that is, symbols to indicate the relevant body shapes.

1977: The British standard BS 5511 (BS 5511, 1977) was issued for garment sizes, which included definitions and measurement procedures.

1977-1982: The ISO Technical Committee (ISO/TC) has published a series of garment sizing standards: ISO 3635, 1981, ISO 3636, ISO 3637, 1977 1977, ISO 3638, ISO 4415, 1977 1981, ISO 4416, 1981, ISO 4417, ISO 4418, 1977 1978, ISO 5971, 1981, ISO 7070, 1982. 1977 1978, ISO 5971, 1981, ISO 7070, 1982.

1978-1981: A comprehensive survey was conducted in Japan involving approximately 50,000 people, including men and women of all ages (Fan, 2004)

1981–1982: Germany again organized anthropometric measurements of the female population, including some 10 000 women and girls.

1982: The British Standardization Office issued a series of garment sizing standards, that is, BS3666 (BS3666, 1982) for women's garment, BS3728 (BS3728, 1982) for children's garment, and BS6185 (bs6185, 1982) for men's garment.

1983: Japan issued a standard sizing system for women's garments JIS L4005.

1983: The German Association for Women's Outerwear (DOB) developed a sizing system, adapted to ISO standards.

1986-1988： China's current garment sizing standard was established on the basis of 15,605 body samples (5,500 men, 5,500 women and 4,605 children) measured in 11 provinces and cities between 1986 and 1988, after measuring the body measurements of nearly 400,000 people in 21 provinces and cities.

1988: In order to define size standards for military uniforms and equipment, the US issued an anthropometric study of military personnel called ANSUR. This survey included 1774 men and 2208 women (Ashdown, 1998).

1989: The European Association of Clothing Industry (AEIH) prepared a series of men's and women's body measurements, based on three size types and six other body measurements.

1989: ISO/TC 133 publishes the standard ISO 8559 on garment construction, anthropometry and body measurements for Standardization (ISO 8559, 1989).

1990: Members of the Technical Committee of the European Association of Clothing Industry (AEIH) developed a set of tables of garment measurements.

1991: The ISO/TC 133 Technical Committee of the International Organization has published Technical Information ISO/TR 10652 (ISO/TR 10652, 1991), entitled "Standard Garment Sizing Systems".

1992–1994: Japan was probably the first country to use 3D body scanners to organize comprehensive anthropometric measurements. The survey involved about 34 000 people (around 19 000 males and 15 000 females) aged between 7 and 90 years. The study found that the average height of the Japanese is 10 cm taller than it was 100 years earlier (NIBHT, 1997).

1994: The American Society for Testing and Materials (ASTM) published the latest standard D5585 94, which is based on new anthropometric methods, previous experience and a survey of the US market (Ashdown, 1998).

1994: The German Association for Women's Outerwear (DOB) developed a new size chart for women's outerwear which contained 24 body measurements.

1995: Anthropometric surveys of more than 6,000 women aged 55 years and older were conducted in the US, and a new standard D5585 95 was designed for this age group (ASTM D5585–95, 1995; Goldsberry, 1996a, 1996b).

1998: CAESAR (Civilian American and European Surface Anthropometric Resource) surveyed people from all walks of life aged 18-65 years for weight, ethnic heritage, gender, geography, and socioeconomic status, obtaining over 10,000 anthropometric records in South America, the Netherlands, and Italy. This study used a 3D body scanner and recorded three postures for each person, one standing position, and two sitting positions (Robinette *et al*, 1999; Ashdown *et al*., 2002,2007).

1999-2004: The first comprehensive anthropometric measurements (SizeUK) were conducted in the UK, in 8 different areas of the country, involving 5000 male and 5000 female subjects (bougoud and Treleaven, 2002).

2001–2004: The European Committee for Standardization (CEN) published the European standard size marking for clothing, EN 13402 (ENCS, 2006). The first part of the standard, named EN 13402 1 (EN 13402 1, 2001), deals with terms, definitions and measurement procedures. The second part of the standard, entitled EN 13402 2 (EN 13402 2, 2002), deals with primary and secondary dimensions. The third part of the standard, EN 13402 3 (EN 13402 3, 2004), describes measurements and the timing of measurement intervals. The fourth part, EN 13402 4 (prEN 13402 4, 2005), which deals with coding systems and is still under preparation.

2002-2003: The United States used methods and procedures similar to those used for the British SizeUK. The Anthropometric survey was taken on 10,800 people in 13 different locations (Anon., 2010a).

2006: The French Textiles and Clothing Institute conducted anthropometric measurements on 1562 people (men, women and children), aged from 5 to 70 years (Anon., 2012b).

2007-2009: The Hohenstein Institute Bönnigheim, together with Human Solutions, started a representative anthropometric project (called SizeGERMANY). The measurement phase ended on 31 Oct 2008 and included 13,362 men, women and children, aged 6 to 87 years.

2.3.2 Mapping Relationships between Anthropometric Data and Sizing Systems

Anthropometric data are gathered through anthropometric surveys, which serve as the basis for classifying and categorizing the diversity of body types within target populations (Zakaria, 2014; Zakaria & Ruznan, 2020). Based on the previous review, anthropometry surveys may vary across different countries and regions. The surveys are then established within the consensus principles of a governing standards organization and published as an industry sizing standard (LaBat, 2007). Sizing standards are tailored sizing systems developed for specific local target populations, aiming to classify body types and provide consistent size labelling for their customers within regional markets. Sizing standards are employed across a variety of industries that deal with the human body, with a particularly significant application in the apparel sector.

In apparel manufacturing, sizing systems list key body measurements that are used to classify the various body types that occur in the target population (Ashdown, 2014; Pei et al., 2017a). Through rigorous statistical analysis, sizing systems are constructed to contain four key elements: control dimension, size range, size interval, and drop value. The control dimension indicates which body sizes are used to classify the population. The selection of control dimensions within the sizing system are crucial for garment fit and styles (Petrova, 2007). For instance, bust girth, waist girth, hip girth and height are all control dimensions for European female sizing systems. For European male sizing systems, chest girth, waist girth, height and inside length are used to determine the different styles of garments (BS EN 13402-3, 2013). Size range within a sizing system records the ranges of key body dimensions appears in the target population. In a specific sizing system, the size range of each control dimension covers from minimum to maximum values to accommodate customers with diverse body sizes. Different control dimensions with diverse size ranges are divided into proportionally different size groups to cater to target populations. The differences between size groups are defined as size interval, which can be either a fixed or variable value (Petrova, 2007). Within the same size group, the drop value represented the calculated difference between different control dimensions. Body types are classified based on drop values, typically based on bust – hip drop values (O'brien, 1941). Sizing standards in mainstream countries typically classify body types according to distinct control dimensions, which will be illustrated in more detail in Chapter 3.

Apparel manufacturers compile the sizing system into size table formats tailored to their specific target customers. Size charts incorporate extra ease allowances based on size tables to accommodate body movements and design requirements, which are then applied in garment production. Size tables record average body measurements as the simplification from large population, indicating proportionally grow or shrink into larger or smaller sizes (Knight, 2012; WHITE, 2011). Meanwhile, garment manufacturers produce RTW garments in different sizes based on size charts by proportional grading techniques. When customers purchase RTW garments, they will compare their body measurements against the size ranges provided in the size charts. If their body measurements fall within one of the specified ranges, the customer will select the corresponding size. However, as not all customers have body measurements that align perfectly with the average sizes captured in the size tables, which leads to fitting issues with RTW garments. Therefore, reliable garment size charts and size tables, as well as sizing systems, are crucial for ensuring accurate apparel production and achieving optimal garment fit.

2.3.3 Sizing Systems Research and Its Limitations

Mass produced ready-to-wear relies much on a solid and reliable sizing system to ensure a good fit at a low cost and fast speed (Loker, 2007). The earliest sizing systems were created based on the tailor's own experience (Aldrich, 2000). The demand for military uniforms brought about by warfare in the 19th and 20th centuries accelerated the production of RTW garments, making the proportional scaling method inaccurate for the market (Aldrich, 2007). In the second half of the 20th century, statistical methods were used to measure body size to develop suitable size charts (Aldrich, 2007).

To achieve a more accurate and effective sizing system, some sophisticated statistical methods, linear regression, principal component analysis, factor analysis, and cluster analysis, were also used today to develop sizing systems for different target groups (Esfandarani & Shahrabi, 2012; Gupta & Gangadhar, 2004; Hamad et al., 2017; Hsu, 2009; Liu et al., 2016; Pei et al., 2017b; Salusso-Deonier et al., 1985; Zheng et al., 2007). But among them, linear regression analysis is a statistical modelling technique used to examine the statistical relationship between a dependent variable and one or more independent variables. Zheng *et al*. (2007) highlighted a drawback of the linear regression method, which is its limitation in incorporating only one or two primary measured dependent variables. As a result, the outcomes may not sufficiently capture the complexity of body dimensions. In addition, instead of using statistical methods to develop a sizing system, many researchers have added individual customer information to adjust the sizing system (Daanen & Byvoet, 2011; Mpampa *et al*., 2010).

However, researchers have only focused on developing more accurate sizing systems, less attention has been paid to the problem of inconsistent sizing across countries. Chun-Yoon and Jasper (1993) reviewed sizing standards in the United States, United Kingdom, Germany, Hungary, ISO, and Japan. Subsequently, Chun (2012) explored the methods used to define body type in the U.S. standard apparel sizing system and compared it to the UK, Germany, Japan, and Korea. The results of the study showed that most systems classify body types in terms of index values. In 2014, Chun updated to compare the sizing standards of the United States, United Kingdom, Europe, Japan, Korea and China (Chun, 2014).

Despite comprehensive analysis, these studies do not suggest a solution to the problem of inconsistent sizing standards across countries. The inconsistency of sizing standards among countries may cause problems for customers choosing their right sizes from fashion brands of different countries. For instance, two parallel international sports brands (with similar price ranges, garment types and target markets) Nike and Reebok, Table 2-2 shows the commercial size chart of regular fit female T-shirts. Customers may not know how to choose sizes among fashion brands from different countries as different brands may have differences even for the same size. The female T-shirt of S size in Reebok is not equal to S size in Nike, which can lead to confusion among consumers as they choose inconsistent sizes from different brands.

However, due to the inconsistency of sizes between different brands, international consumers cannot quickly identify unfamiliar size information in actual purchasing scenarios. This issue may become more compelling, especially in the context of the growing tendency of internationalization in the fashion industry through E-commerce. In a word, globally growing fashion business may not be able to satisfy consumers' fit needs if their sizing systems were developed from the anthropometry survey of only one country or area (Schofield & LaBat, 2005b). Therefore, instead of focusing on the development of a more accurate sizing system, this study addresses the problem of inconsistent sizing and establish a combined sizing system that satisfies the needs for fit for international consumers.

Table 2-2 Commercial Size Chart for Two International Sports Brands

Commercial Size Chart (Nike)			
Size	Bust(cm)	Waist(cm)	Hip(cm)
XS	76-83	60-67	84-91
S	83-90	67-74	91-98
M	90-97	74-81	98-105
L	97-104	81-88	105-112
XL	104-114	88-98	112-120
XXL	114-124	98-108	120-128
Commercial Size Chart for Reebok women's T-shirt			
Size	Bust(cm)	Shoulder(cm)	Length(cm)
S	46	40	62
M	50	42	68
L	52	43	71
XL	59	47	74

2.4 Size Recommendation

In recent years, there are growing developments, techniques and approaches related to size and fit recommendation, which can be classified as data-driven methods, mechanical modeling and simulation technologies, as well as visual recognition approaches.

Most of the research works and approaches are based on data-driven size recommendation, which utilizes data collection, such as user's body measurements, personal information, etc., to recommend the optimal size for customers, so as to improve the success of, and satisfaction with, online shopping and reduce the number of returns and exchanges due to inappropriate sizes. Statistical methods, using body size measurements, are commonly used to recommend the appropriate product sizes for customers. Kolose et al. (2021a) classified the anthropometric data of 1003 participants into different groups by using PCA, two-step method and K-means clustering, demonstrating that the divided clusters could be used to recommend sizes as appropriate. Subsequently, decision trees were used to analyze anthropometry variables to predict and assign uniform sizes for military personnel (Kolose et al., 2021b). Lu and Stauffer (2013) clustered users, who had purchased the same product, on the bases of height, weight and purchase history, and made size recommendations based on feedback from other users in the same cluster. Furthermore, Fu et al. (2022) proposed an improved clothing size recommendation approach based on the subdivision of female body types, PCA being used to extract five characteristic indices from anthropometric data to more accurately describe female body types.

Contrast to the above, other recommendation methods focus on gathering the personal data of each customer, such as body measurements, purchase records, personal preferences, etc., and construct a matching model recommended, wherein the size demonstrating the highest similarity to the customer's personal profile is deemed the most suitable for a selected product. Lane and Stewart (2002) and Onyshkevych et al. (2003) both introduced an automatic sizing recommendation method which involved converting the customer's body measurements, personal preferences and objective criteria into a size measurement. Januszkiewicz et al. (2017) analyzed the recommendation methods of nine leading virtual fit platforms. These platforms asked customers to input three attributes of their clothing preferences, namely past purchased history, fit feedback and preferred styles. Baier (2019) examined the extraction of product fit feedback from customers, using natural language processing techniques, and which could offer an in-depth insight into how a product’s fit is perceived by the person. Zhang et al. (2020) proposed a knowledge-based clothing recommendation system which formalized new consumer profiles (body data, style keywords, and visual images) and new product information (garment fitting and details) to generate the desired product information such as style and size for specific consumers.

In recent years, 3D virtual techniques, such as CLO 3D, VStitcher, and 3D Runway

Creator, have been developed for the apparel industry, providing more opportunities to better evaluate virtual garments (Z. Wang et al., 2021). Based on these mechanical modeling and simulation technologies, the apparel industry has been able to simulate real clothing designs and create realistic 3D virtual clothing products (Hong et al., 2018; Hong et al., 2017). By simulating the static and dynamic draping and fitting effects on specific 3D digital mannequins using selected fabric properties, it can provide consumers with the ability to visually evaluate virtual garments through web-based platforms, as well as allows them to better predict the garment fit and sizes (Liu, Zeng, Bruniaux, et al., 2018; Tao et al., 2018; Z. Wang et al., 2021). In addition, visual analysis by experts performs based on photos or videos is commonly used methods for predicting garments sizes (Lu et al., 2014; Tao & Bruniaux, 2013; Thomassey & Bruniaux, 2013). However, there are still notable challenges in terms of the reliability and accuracy of size predictions.

Providing accurate product size recommendations and fit predictions is crucial for enhancing the customer's shopping experience and reducing high return rates, which are major pain points for the apparel industry (Misra et al., 2018). In this study, we propose a novel size recommendation model based on data-driven method, utilizing multiple key body measurements and compared them against garment sizes to recommend appropriate sizes, which will elaborated in Chapter 4.

2.5 Grading Technology

2.5.1 Evolution of Grading

Pattern grading is part of the industrial patternmaking. In clothing production enterprise, the benchmark for a particular size pattern is used to establish a balance between different specifications or variations in body shape, which involves employing scientific calculations and a rational distribution of sizes, allowing for the creation of various specifications or patterns using a series of pattern shapes. In order to reduce the error caused by the shrinkage process, usually take the middle number of the size as the base pattern. Pattern grading not only improves the efficiency of garment industrial patternmaking, but also ensures the uniformity of industrial pattern series. It is considered to be one of the most critical technologies in apparel industry patternmaking.

Mullet et al. (2009) explained that a grading system is established using size specifications obtained from anthropometric measurements. When creating garments for each size, the increment value used to generate new patterns should be determined according to the body size corresponding to that specific size (Ashdown, 2007). The historical context of grading would establish that grading practices predate the widespread use of women's clothing size charts.

The women's clothing grading system was first developed between 1820 and 1840 as a proportional tailoring system (Kidwell, 1979). These pattern-drafting systems were used to locate and mark crucial points on a garment pattern, as well as designed to accommodate multiple sizes and were conveniently printed on a single sheet of paper (Ashdown, 2007). In fact, these systems do not include a size chart. A size chart comprises coded body measurements corresponding to each size within a range. However, when the pattern lines are drawn on a proportional tailoring system to create each pattern, the resulting pattern set bears resemblances to a modern set of patterns called a nested grade in several ways (Figure 2-2).

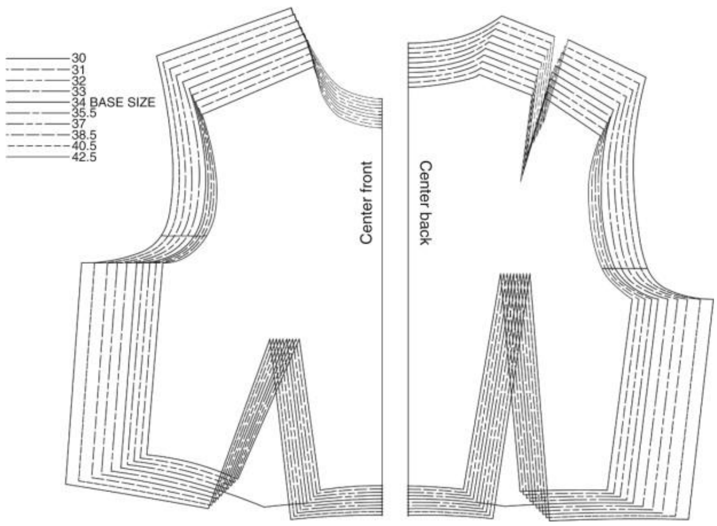


Figure 2-2 An Example of a Traditional Nested Grade: the TRAD Set of Patterns Based on Traditional Grading (from (Schofield & LaBat, 2005a) Reprinted by Permission of the International Textile and Apparel Association, Inc.)

Beginning in the 1880s, individuals could order custom garment through the mail. The patterns of garment were sized from one measurement and adjusted to the individual (Schofield & LaBat, 2005b). The first fitted ready-to-wear garments for women were produced in the late 19th century. According to Cooklin (1991), it was noted that the pattern grading system for these garments relied on the erroneous assumption of a fixed proportional relationship between girth and length, resulting in garments that fit only a limited number of women. It was not until the late 1940s that a more rational grading system was developed.

Early sources of grading information predate the publication of the first American anthropometric study in 1941 and the publication of size standards based on these data in 1958. There is no indication that the early sources of grading information (Auditore, 1947, Kirschner, 1951, Gebbia, 1955) were based on their grading exercises on size charts derived from anthropometric data (Nancy A Schofield, 2007).

2.5.2 Grading Method Development

The oldest sizing standard for women's garment was developed from the 1940 USDA (US. Department of Agriculture) survey, published in 1958 (O'brien, 1941). A few years later the specifications were revised and published as PS 42-70 Voluntary Product

Standard in 1971. The 1971 revision of PS42-70 female pattern was a more comprehensive size standard combining the standards of the 1940 survey with the addition of body types a few years later (Mullet et al., 2009). Nevertheless, PS42-70 was later replaced by ASTM D5585-95 due to the existence of vanity sizing in ready-to-wear production. For instance, the dimension for a size 12 in PS42-70 may be approximately the same as a size 6, 8, or 10 in current ready-to-wear. In the ASTM standard updated in 2006, the data of adult women were investigated and analysed, and the body characteristics were studied. Added up to 10 sizes on the basis of PS41-70 system. ASTM also publishes the body data standard and the grading system for Women 55 and older (Mullet et al., 2009).

The grading system is developed from sizing specification. In general, grading system divided into two ways: size range from 1-inch to 1 1/2-inch grade and from 1 1/2-inch to 2-inch grade. This numeric classification (1-inch, 1 1/2-inch and 2-inch) indicates the dimensional change from one size to adjacent size. It is very important to understand that the total grade is distributed throughout the pattern. Distribute these changes in size to all parts of the pattern, not only in the side seams, but also to follow a certain grade distribution to other parts. (Figure 2-3).

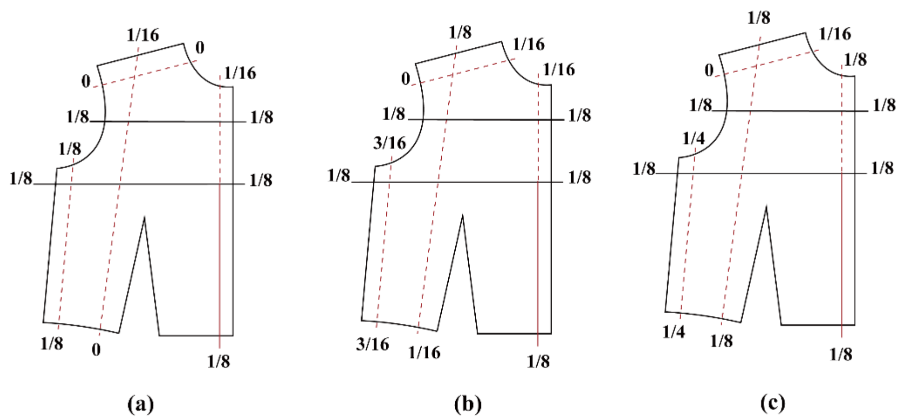


Figure 2-3 Grade Distribution for Total Circumference Grades((a) 1-inch Grade; (b)1 ½-inch Grade; (c) 2-inch Grade) (Mullet *et al.*, 2009)

Some researchers developed three grading system. Figure 2-4 presents a comparison between the Mullet et al. (2009) 's grading system, and system used by Handford (2003) and Price et al. (1996). Three types of grading systems are widely used and have become an indispensable part of pattern grading and garment production.

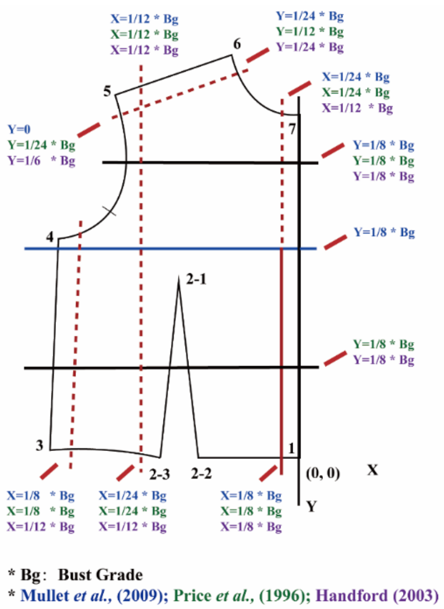


Figure 2-4 Comparison of Different Grading Systems((Mullet et al. (2009), Price et al. (1996) and (Handford, 2003))

2.5.3 Grading and Fitting Issues

Research on the inadequacies of the current sizing system and the development of alternative sizing system is ongoing. One issue that has not been addressed is the process, known as grading, by which clothing manufactures create pattern in a range of sizes.

Grade rules, increments between garment measurements, should be directly related to increments between body measurements for different sizes. There are some papers about the process or the methods used in grading. Price et al. (1996) mentioned that the grading just moves mechanically up and down in proportion, but the human body does not grow in standard proportion. On the basis of this research, Schofield (2000) used data from ANSUR women in 1988 to perform a regression analysis of 10 assumptions about grading based on the bodice fit and to compare them with traditional grading. Finally, the grade method of clothing size has little relationship with size measurement. The grading is based on the premise that garment sizes do not change increments or scale as the body size increases, in which case all garments within the size range must remain constant. For example, from chest to waist, chest level and shoulder seam angle (Figure 2-5).

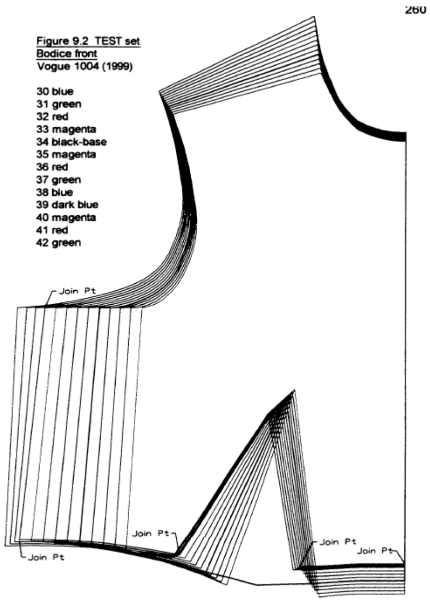


Figure 2-5 TEST set Bodice Front (Schofield, 2000)

In order to determine the best grading method, the traditional grading method and the suitable shape grading method were tested and compared in human body. Due to the disproportionate growth of the body, Bye et al. (2008a) used quantitative and qualitative analyses to highlight the role of body shape changes in individuals with the same chest, waist, hip, and height in the comparison between the two model groups. Participants were scanned while wearing the dresses, capturing a permanent record of the dress on their bodies (Figure 2-6). The results show that the grading practice should include measurement and shape change.

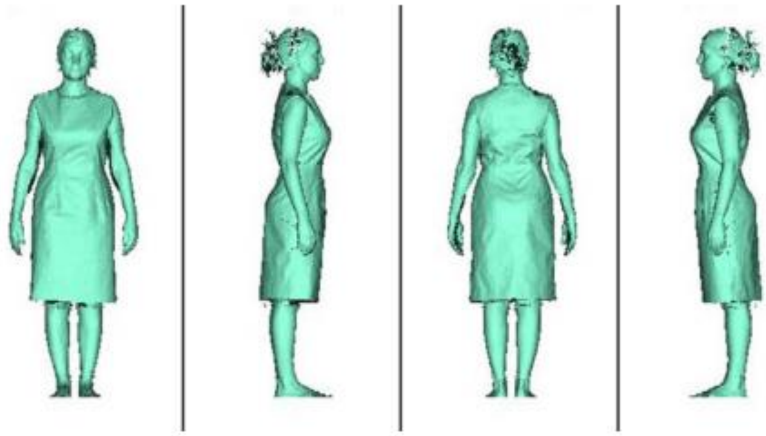
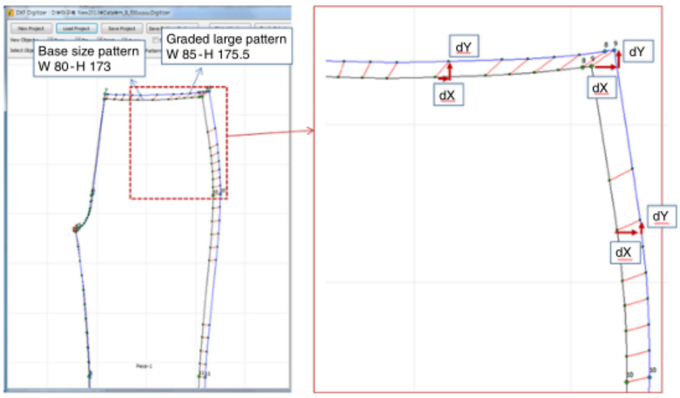


Figure 2-6 Four View Pose of the 3D Scan *(Bye et al., 2008a)*

Sayem *et al*. (2014) introduced the development of a new resizing design platform for virtual fitting using reverse engineering (RE) and 3D modelling techniques; pattern flattening and automatic grading of men's upper garments. Han et al. (2015a) has developed a width-height independent grading method is used to read half a custom automatic patternmaking system. (Figure 2-7).



Notes: dY is vertical difference; dX is horizontal difference

Figure 2-7 User Interface of Automatic Grading Value Extraction Software (Han et al., 2015a)

At present, with the mass production of apparel sizing, advanced computer-aided technology is being used to widely. Reviewing on previous studies, some researchers paid attention to garment CAD system to optimize grading techniques. Geng Huilai (2012) used garment CAD software to draw basic tops patterns and trousers patterns, numbered the key parts of the pattern and recorded the name table, entered the grading rules and sizes. The changed renderings are generated and then evaluated. Dongliang (2012) obtained distance sizes and girth sizes of the human body from the 3D human body model represented by the triangular grid. The 2D pattern was placed at a suitable position around the 3D model, and the human body was divided into six regions based on feature lines. Recorded the area where the control point of the pattern boundary falls and calculated the size ratio. Set the grading size of the 3D human body model and calculated the difference on patterns.

The pattern dividing is the most popular method in the garment industry, which is used for the mass production of different sizes. However, the defective dividing will affect the back-end operation of the machine production and affect the production cost and production efficiency. M. Islam et al. (2020) analyzed the traditional grading system and found out the factors that caused the pattern grading deficiency. Comparison was made by collecting three different measurement data and combining them into a complete specification (Figure 2-8). Draw all patterns and grade them according to different parameters. Subsequently, the pattern of the grading is measured and analyzed, and finally some suggestions are put forward. The aim is to achieve more precise grading, to make clothes fit better, and also to reduce the time required for factory sample approval.

Throughout the inception of apparel manufacturing, numerous methods have emerged to achieve accurate pattern grading. Nevertheless, it is important to note that most grading systems have own shortcomings. Thus, the manufactured garments will not reflect the consumer's body shape and garment needs. This study addresses this issue by developing an optimized auto-grading method to provide individual garment fit.

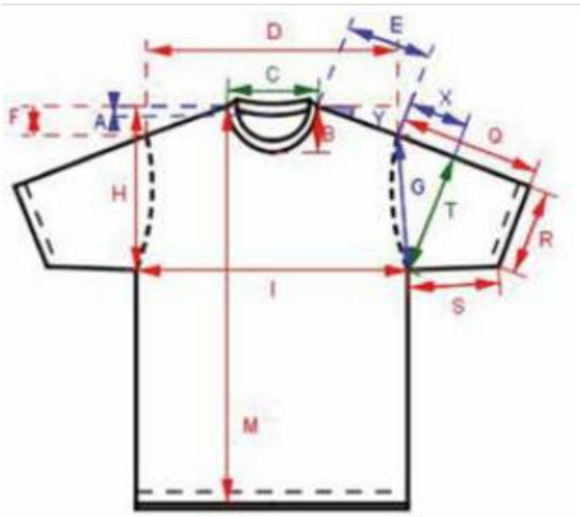


Figure 2-8 Combination of All Measurements Point of T-shirt (M. Islam et al., 2020)

2.6 Virtual Simulation and Fitting

2.6.1 Virtual Technique

Research on virtual garments started to gain traction in the 1980s, primarily driven by the film industry's growing fascination with 3D computer-generated images (Power *et al*., 2011). Since then, various systems for 3D visual garment simulation have been developed form different perspectives with diverse objectives (Lapkovska & Dabolina, 2018). The term 'garment simulation' refers to the realistic, three-dimensional, real-time simulation and visualization of individual customers and garments (Divivier *et al*.,2004). In the field of computer graphics, the first application of mechanical garment simulation appeared in 1987 with the work of (Terzopoulos & Fleischer, 1988; Terzopoulos *et al*., 1987) in the form of a simulation system that relies on the Lagrangian equations of motion and elastic surface energy. However, the first real application of simulating clothing started in 1990, considering many other techniques complementing clothing simulation (Choi & Ko, 2005; Lafleur *et al*., 1991), such as body modelling and animation, collision detection and response (Yang Y, 1993).

Instead of modelling and rendering the geometric and mechanical behaviour of garments over time and their interaction with human models, the textile technology community is concerned with the accuracy of these models in characterizing the physical properties of garments for application in product development. A virtual validation of the research topic is presented in Chapter 5.

2.6.2 Garment Modelling

Three-dimensional (3D) modelling of clothing holds a significant importance for the garment industry, as the reduction of production costs is a motivation for the research in this area (Chiricota, 2003).

Conventionally, garment development begins with a 2D sketch and the selection of material samples, which are interpreted into a 2D pattern by a pattern cutter. Each sample is then carefully cut out of the chosen fabric to make a sample or prototype garment. This often turns out to be a lengthy process as the samples undergo multiple fittings to ensure a satisfactory fitting before the garment is mass produced (Power, 2013). Using 3D garment simulation as part of the design development process will greatly reduce the time spent in the sampling phase, as the final product can be viewed, evaluated, modified and recreated without any actual tailoring.

Starting with the idea of mass customization, e-commerce, and the need for digital innovation in the apparel industry, 3D garment simulation offers opportunities for the apparel industry. Retail stores have the option to incorporate a 3D body scanner that is connected to 3D virtual garment simulation software, which contains a variety of styles and fabrics. Consumers can actively participate in the design process by choosing from a library of styles, materials, and colours. Once the customer is content with the simulated garment, these specifications are transmitted to a local manufacturing company, facilitating the creation of a custom-made product.

Virtual prototyping is a technology in the apparel development process that involves computer-aided design for apparel development and apparel virtual prototyping technology. When the accuracy of the virtual prototype design is reached, the garment that fits the mannequin can reflect and combine the characteristics of garment style, garment pattern design, virtual mannequin and textile mechanical properties.

2.7 Apparel Customization

In the field of clothing customization, garment can be delivered to customers quickly, and whether the version is in line with the customer's body shape is of vital importance. Customized products in the apparel industry mainly deal with the issues of fit (Hu *et al*., 2009; Mpampa *et al*., 2010; Tao *et al*., 2018; Teichmann *et al*., 2016) and design (Teichmann *et al*., 2016). Pursuing a satisfactory fit is a critical concern that garners significant attention in mass customization (Hu *et al*., 2009; Mpampa *et al*., 2010), since it is a fundamental need of customers.

With the continuous innovation of software system technology, the development of garment automation system can meet the needs of the garment industry and provide it with an efficient way of information. Some researchers developed the system on the basis of three-dimensional technology, aiming at accurate user data information, making the operation more humanized. Li *et al*. (2013) created a novel 3D garment customization approach based on a feature curve-net. The method supports both the 3D garment resizing and 3D garment editing (Figure 2-9).

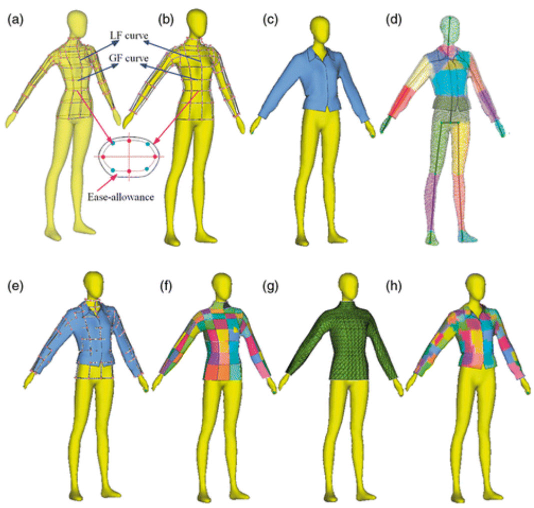


Figure 2-9 Feature Curve-net (Li *et al*., 2013)

Gupta and Eremenko (2014) pointed out that the system received the customer's order and performed a 3D scan of the customer. The size algorithm was extracted from the size parameters of the model, and the selected digital pattern was parameterized and scaled to the customer's body shape. Wang (2015) provided a shirt pattern intelligent generation device, which received human body measurement data through a third-party program, calculated the generation information of each part of the shirt in the system and automatically drew the pattern, and then generated the pattern in DWG/DXF format. Tianyu Xia (2017) designed a functional system for measuring pattern, which could identify the size of each part, showed the measurement method of each part and the actual position on the pattern, and identified the position of the cloth line. Xu *et al*. (2020) introduced a garment production planning system with a focus on mass customization. By using mathematical optimization methods, the system can generate an optimized size chart and cutting order plan, aiming to maximize efficiency in the production process. Wan *et al*. (2021) presented to combine the apparel customization system with participatory customization services to enhance the personalization of customized products by transforming the sales platform connected to the MTM system into a customer participation platform.

2.8 Chapter Summary

In this chapter, the relevant theories, industry practice and research work on the classification of body shapes, anthropometry surveys, sizing systems, size recommendations, grading techniques, virtual fitting, and apparel customization have been reviewed. Some research gaps are concluded as follows:

i. Current studies do not provide an exhaustive multi-country comparison of body types and shapes. The differences in body types and shapes across various countries have yet been analysed and compared comprehensively.

ii. In light of the problems found in the previous research, inconsistent body types and shapes between various sizing standards may cause problems for customer in choosing ergonomic products from fashion brands of different countries.

iii. Existing studies on size recommendation methods overlook the fact that customers do not typically stick to a single garment size for all styles or across different brands within the same company. Instead, they frequently switch between two or three sizes when making garment selections.

iv. Customers cannot evaluate the overall fit compatibility of the garment and body, which leaves most customers clueless about the recommended size.

v. A recognized limitation of current grading method is its inability to meet the needs of those with non-average body shapes, resulting in an ill-fitting garment and decreased satisfaction.

CHAPTER 3. AN INTEGRATED SIZE TABLE ACCOMMODATING THE DIVERSITY OF BODY TYPES AND SIZES

3.1 Introduction

As discussed in Chapters 1 and 2, size tables are developed in sizing surveys, which organize body measurements for different size groups. Typically, size tables include a range of body measurements such as chest/bust, waist, neck, height, and hip. Differences in measurements such as the chest/bust-waist difference and waist-hip difference often reflect variations in body shapes/types. These variations have been carefully and extensively documented in sizing standards that have been developed and utilized in different countries. By conducting a comparative analysis of body types/shapes and size ranges outlined in these national sizing standards, it is possible to create an integrated size table that encompasses a wide range of body shapes. The integrated size tables can serve as a valuable size database, offering crucial size identification and customer segmentation information for both customers and manufacturers. Customers can use the size chart as a reference to identify their sizes, while manufacturers can utilize it to produce garments that cater to the diverse body proportions of their target market.

The research framework for the development of the integrated size table is illustrated in Figure 3-1. Firstly, the sizing standards of the different countries are compared in terms of size definitions to identify the differences. Moreover, at this stage, it is focused on analysing the design of body type, as well as sizing strategies, notably size range, drop value and key dimensions, in the major sizing standards, since these are generally the fundamental reasons for the differences in the national sizing standards. Then, size ranges and drop values in various sizing standards are sorted and integrated into a size table with five sub-charts. In stage 3, the integrated size tables are analysed in terms of size distribution, size differences and body shape variations, and the characteristics of all body types of various countries.

Based on the above process, this chapter consolidates data from various national sizing standards for different body types as a means of creating an integrated size table for a wide range of body types, shapes, and sizes, which ensures customers with different body types can find appropriate sizes. Furthermore, the integrated size table plays a crucial role in establishing consistency across different sizing standards, thereby facilitating easier size conversions and reducing customer confusion in international markets. For manufacturers, the developed size table simplifies the design and production process and provides a comprehensive overview of body types and size ranges, which not only improves the accuracy of garment sizing but also allows manufacturers to optimize inventory management and customize products to better cater to the needs of their target markets.

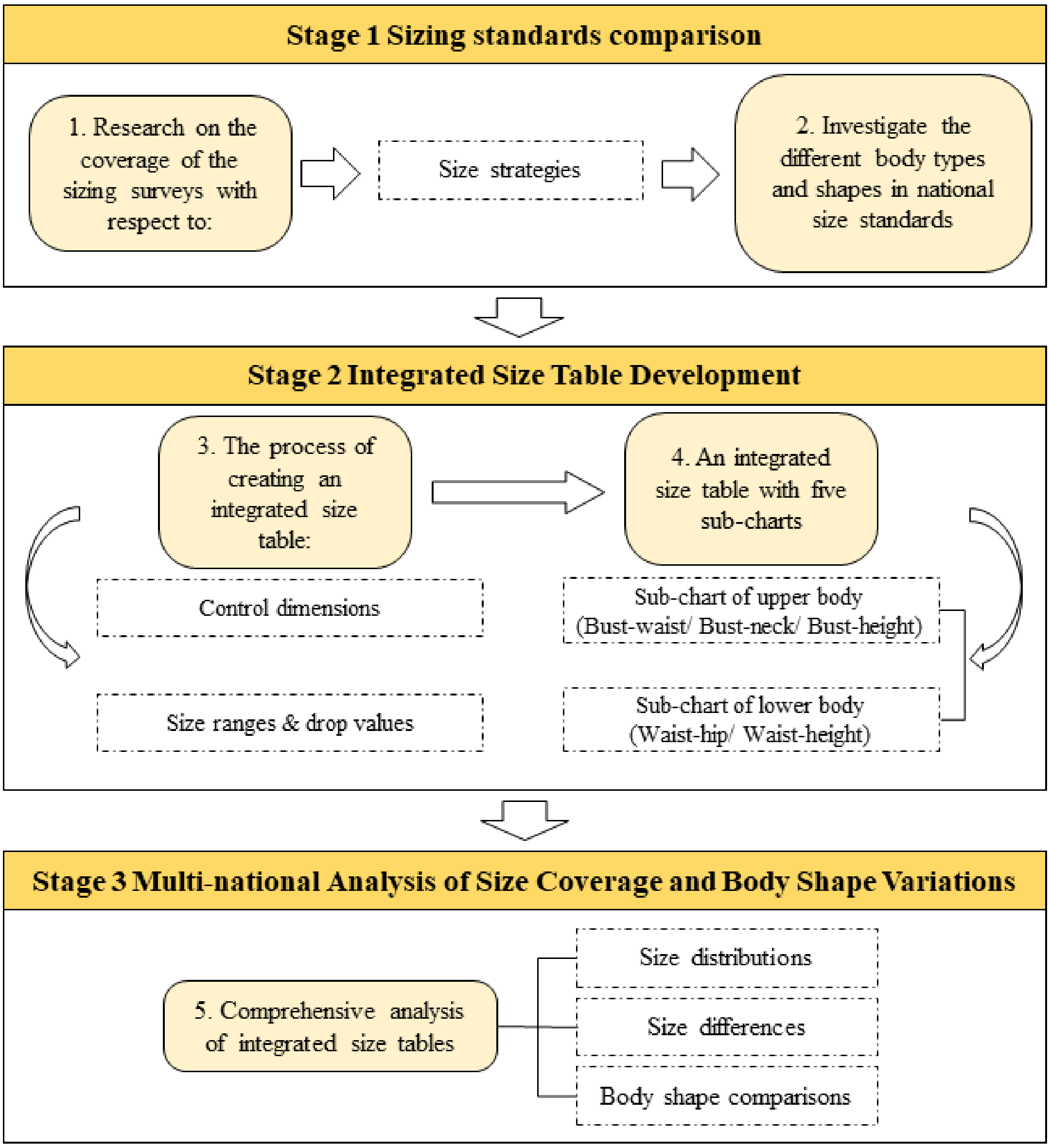


Figure 3-1 Framework of Integrated Size Table Development

3.2 Method

3.2.1 Sizing Standards Comparison

Currently, there are several mainstream sizing standards in the international market, notably in the US, Europe, China and Japan. The sizing standards are based on a large amount of human body data, enabling individuals to identify their body types and find a more suitable size. Due to the differences of defining body types in different countries and regions, the sizing standards in the US, Europe, China, Japan and other countries are compared in this study

3.2.1.1 American sizing standard

The US female sizing standard (ASTM D5585 2021; ASTM D5586 2010; ASTM D7878 2023) is influenced by age, physical development, and body measurements. After long-term analysis and updating of human body data, the hip-bust drop value and body height were used as the discriminant rules to divide the female body type into four types: *Misses, Women, Half-size* and *Junior*. *Misses* type is classified into *Curvy Misses* size and *Straight Misses* size. The bust sizes of the two *Misses* types are the same, but the hip-bust drop value of the *Curvy Misses* size is 7.0 cm – 7.6 cm, while the *Straight Misses* size is 5.1 cm to 5.4 cm. The hip-bust drop value of the *Women* size is between -5.5 cm and 10.0 cm. The other body type is *Half-size*, and the body type difference is obviously different from other body types. The hip-bust drop value is about 2.0 cm – 4.1 cm. The hip-bust drop value of the *Junior* size is fixed at 5.0 cm or 5.1 cm. The US female sizing standard covers a wide range of bust girths, namely from 77.5 cm to 148.0 cm, waist girths, from 61.0 cm to 102.0 cm, hip girths, from 82.5 cm to 158.0 cm, body height, from 162.0 cm to 173.0 cm and neck girth ranges from approximately 33.3 cm to 40.1 cm.

For the US male sizing standard (ASTM D6240 2021), 27 sizes from 34 to 60 are given, while simplified into seven versatile Alpha sizes: *S, M, L,XL, 2XL,3XL* and *4XL* (Chun, 2014). There is a wide range of drop values in the various sizes (Table 3-1). The US male sizing standard covers a wide range, namely chest from 86.4 cm to 152.4 cm, waist from 71.1 cm to 157.5 cm, hip from 85.1 cm to 124.5 cm, neck from 38.4 cm to 49.9 cm, and body height range from 172.0 cm to 187.0 cm.

Table 3-1 The Size Drop Ranges of US Male Sizing Standard

Letter Sizes	Sizes	Chest Girth(cm)	Waist Girth(cm)	Chest-waist Drop Value(cm)
S	34-37	86.4 – 94.0	71.1 – 78.7	15.3
M	38-41	96.5 – 104.1	81.3 – 98.9	15.2
L	42-45	106.7 – 114.3	91.4 – 99.7	14.6 – 15.3
XL	46-49	116.3 – 124.5	102.9 – 112.4	12.1 – 13.3
2XL	50-53	127.0 – 134.6	115.6 – 125.7	8.9 – 11.4
3XL	54-57	137.2 – 144.8	129.5 – 142.2	2.6 – 7.7
4XL	58-60	147.3 – 152.4	147.3 – 157.5	-5.1 – 0.0

3.2.1.2 European sizing standard

The European female sizing standard (BS EN 13402-3:2013) contains a wide range of bust and hip girths and divides the human body into upper body and lower body. Bust girths of the upper body range from 74.0 to 156.0 cm with 4.0 cm or 6.0 cm intervals. For the lower body sizes, and hip girths cover from 74.0 cm to 159.0 cm, with the 4.0 cm intervals. The waist sizes are summarized from sizing standard, ranging from 53.0 cm to 139.0 cm, For European body types, the minimum hip-waist drop is 3.0 cm. The European female sizing standard does not specify body types, and is simplified to 8 sizes and labelled as *C, D, E, F, G, H, J* and *K*. The height covers from 156.0 cm to 188.0 cm.

The European male sizing standard(BS EN 13402-3:2013), there are fourteen chest girths ranging from 84.0 cm to 144.0 cm and waist girths ranging from 72.0 cm to 132.0 cm. Same as the female sizing standard, the male sizing standard also does not define specific body types, and is simplified to 14 sizes and labelled as *C, D, E, F, G, H, J, K, L, M, N, P, Q* and *R*. Seven chest-waist drop values are given, namely -4.0 cm, 0 cm, 4.0 cm, 12.0 cm, 20.0 cm, 22.0 cm and 24.0 cm. The neck girths are explicitly defined in the European male sizing standard ranging from 32.0 cm to 51.0 cm.

3.2.1.3 *Chinese sizing standard*

The Chinese sizing standard (GB/T 1335.1 2008; GB/T 1335.2 2008) divide four body types for females and males labelled as *Y, A, B* and *C*, which are based on the bust/chest-waist drop values. The bust/chest interval is 4.0 cm, and the waist interval is either 2.0 cm or 4.0 cm. The drop values and size ranges are different for the four body types, as shown in Table 3-2, which are illustrated height, neck, shoulder width and sleeve length in detail. Height is classified in 5.0 cm intervals, whereas neck, shoulder width and sleeve length intervals are classified in 0.8 cm,1.0 cm and 1.5 cm, respectively.

Table 3-2 The Size Ranges and Drop Values in the Chinese Sizing Standard

Sizing Standard	Body Type	Bust/Chest Girth(cm)	Waist Girth(cm)	Bust/Chest-waist Drop Value(cm)
Chinese females	Y	72.0 – 100.0	50.0 – 80.0	19.0 – 24.0
	A	72.0 – 100.0	54.0 – 86.0	14.0 – 18.0
	B	68.0 – 108.0	56.0 – 98.0	9.0 – 13.0
	C	68.0 – 112.0	60.0 – 106.0	4.0 – 8.0
Chinese males	Y	76.0 – 104.0	56.0 – 86.0	17.0 – 22.0
	A	72.0 – 104.0	56.0 – 92.0	12.0 – 16.0
	B	84.0 – 112.0	74.0 – 104.0	7.0 – 11.0
	C	76.0 – 116.0	70.0 – 112.0	2.0 – 6.0

3.2.1.4 *Japanese sizing standard*

In the Japanese female sizing standard (JIS L 4005: 2023), four body types are defined according to their height and hip proportions, while four height types: *PP, P, T* and *R*, namely 142.0 cm, 150.0 cm, 158.0 cm and 166.0 cm, respectively. The hip proportion, four types (*A, Y, AB* and *B*) are given, while the hip-bust drop value of the *A* body type ranges from -3.0 cm to 14.0 cm, the *Y* body type has a narrow range, namely -3.0 cm – 8.0 cm. The Hip-bust drop value of the *AB* and *B* body type are 1.0 cm – 16.0 cm and 9.0 cm – 17.0 cm, respectively. The Japanese female sizing standard contains seventeen sizes that cover all height and hip types.

In Japanese sizing standard (JIS L 4004: 2023) for males, ten body types, *J, JY, Y, YA, A, AB, B, BB, BE* and *E*, are defined according to the chest-waist drop values. The drop values of athletic body types, including *J, JY* and *Y* body type are 20.0 cm, 18.0 cm and 16.0 cm, respectively. Average body types are *YA, A* and *AB* with 14.0 cm, 12.0 cm and 10.0 cm, respectively. For full body types *B, BB, BE* and *E*, the drop values are 8.0 cm, 6.0 cm, 4.0 cm and 0 cm, respectively. The chest girths given in Japanese male sizing standard range from 86.0 to 104.0 cm, with 2.0 cm size intervals. The waist girths range from 68.0 cm to 104.0 cm, with 2.0 cm size intervals. The Height range from 155.0 to 190.0 cm. In the Japanese sizing standards. there is no explanation on definition for the neck.

3.2.1.5 Sizing standards of ISO, Germany, France and Korea

Several national and regional sizing standards have also been organized and compared (Chun, 2014). The sizing standard of ISO/TR 10652:1991 contains three body types for women as *A, M* and *H*, all body types, which are classified according to the hip-bust drop values of 12.0 cm, 8.0 cm, and 0 cm, respectively. Five body types are defined for males in the ISO sizing standard, namely *Athletic(A), Regular(R), Portly(P), Stout(S),* and *Corpulent(C)* types, which are defined according to the chest-waist drop values of 16.0 cm, 12.0 cm, 6.0 cm, 0 cm and -6.0 cm, respectively. Nevertheless, this sizing standard has been withdrawn by ISO.

The German sizing standard for females contains nine body types: *SL, SM, SS, RL, RM, RS, TL, TM* and *TS*, which are defined according to height and hip proportion. The height group is divided into *S* (160.0 cm), *R* (168.0 cm) and *T* (176.0 cm). The large-hip type (*L*) has a drop value range of 8.0 cm – 14.0 cm, while the middle-hip type (*M*) has a range of 2.0 cm – 8.0 cm and the small hip type (*S*) has a range of -4.0 cm – 2.0 cm. The German sizing standard covers a bust girth range from 84.0 cm to 128.0 cm and waist girths range from 63.0 cm to 113.0 cm. In the German sizing standard for male, body types are defined according to height and body-build, male types classify into three height groups *Short(S), Medium(M)*, and *Tall(T)* and five body-build types

Athletic(A), *Normal(N)*, *Slim(S)*, *Large(L)* and *Stocky(S)*. The combination of height and body-build are given, namely *TA, TS, MA, MN, ML, MS, MP, SS* and *SP*. The size ranges and drop values are summarized in Table 3-3.

Table 3-3 The Size Ranges and Drop Values Given in the German Sizing Standard for Males

Body Type	Chest Girth(cm)	Waist Girth(cm)	Chest-waist Drop Value(cm)
Tall Athletic (TA)	88.0 – 104.0	72.0 – 92.0	16.0
Tall Slim (TS)	88.0 – 108.0	76.0 – 96.0	12.0
Medium Athletic (MA)	88.0 – 108.0	72.0 – 92.0	16.0
Medium Normal (MN)	88.0 – 116.0	76.0 – 108.0	12.0
Medium Large (ML)	88.0 – 112.0	80.0 – 106.0	6.0 – 8.0
Medium Stocky (MS)	88.0 – 116.0	80.0 – 110.0	6.0 – 8.0
Medium Portly (MP)	92.0 – 112.0	96.0 – 120.0	-4.0 – -8.0
Short Stocky (SS)	88.0 – 116.0	82.0 – 112.0	4.0 – 8.0
Short Portly (SP)	100.0 – 112.0	96.0 – 120.0	-4.0 – -8.0

The French sizing standard for females covers various key body dimensions, bust girths range from 80.0 cm to 128.0 cm and waist girths from 57.0 cm to 101.0 cm, hip girths from 57.0 cm to 101.0 cm, and height from 152.0 cm to 180.0 cm. The sizing standard for males cover the chest girth ranges from 80.0 cm to 120.0 cm, the waist girth ranges from 64.0 cm to 128.0 cm and the height from 156.0 cm to 186.0 cm.

The sizing standard of Korea for females defines three body types (*N, A* and *H*) according to the hip-bust drop value, bust girths cover from 76.0 cm to 103.0 cm, with the 3.0 cm intervals, and hip girths from 82.0 cm to 103.0 cm, with the 3.0 cm intervals. The Korean sizing standard has the hip-waist drop value of 33.0 cm. Four body types are given in the sizing standard of Korea for males, namely *Y, A, B* and *BB*. Male body types are defined by the chest-waist drop values of 21.0 cm, 15.0 cm, 12.0 cm and 9.0 cm, respectively. The standard covers chest girths from 85.0 cm to 109.0 cm and waist girths from 67.0 cm to 97.0 cm.

After summarizing the sizing strategies of the international mainstream countries, it can be found that the strategies for defining body types varies across different countries. Most of female body types were defined by hip proportion, hip - bust drop value, or bust - waist drop value. The chest - waist drop value or height group were commonly used for male body type classification. Therefore, the most typical issues shown in the current sizing standards and related research is that inconsistent strategies of defining body types, and the simple comparison does not provide an accurate and reliable indication of the different body types and are not meaningful for understanding body characteristics in various countries. A solution that overcomes these challenges is to create a more accommodating and integrated size table, with data expressed in terms of the smaller body sizes to cover the majority of body types in mainstream countries for better analysis.

3.2.2 Integrated Size Table Development

As mentioned previously, sizing standards in mainstream countries were analysed to develop an integrated size table that covers all the body types and size ranges defined in the national sizing standards.

The integrated size tables containing five sub-charts for the upper body and lower body can be created. Firstly, the control dimensions, namely body dimensions used to classify the population, bust and waist dimension were used as primary control dimensions for the upper and lower body, respectively. These dimensions are crucial for classifying the body types and are also considered as the most important control dimensions for a specific type of garment. Furthermore, once the primary control dimensions are determined, it is necessary to define additional dimensions to accurately classify individuals into specific body type categories and tabulate the size charts for the specific garment. These additional dimensions are referred to as secondary control dimensions. For example, hip, neck and height dimension are common secondary control dimensions. Then, the range of sizes associated with each dimension was calculated for the upper body and lower body. The drop values between the primary and the secondary control dimensions and upper were also summarized.

With the information collected, an integrated size table, containing five sub-charts, was constructed: (i). Bust (primary) – Waist (secondary); (ii). Bust (primary) – Neck (secondary); (iii). Bust (primary) – Height (secondary); (iv). Waist(primary) – Hip (secondary); (v). Waist (primary) – Height (secondary).

3.3 Multi-national Analysis of Size Coverage and Body Shape Variations

Only the data analysis process of the integrated size table for female is provided in this section since the analysis process of sizing strategy for male is the same. The integrated female size table contains the upper body and the lower body. More specifically, there are three sub-charts for the upper body and two sub-charts for lower body. The control dimensions for five sub-charts are bust, waist, hip, neck, and height. The bust and waist are used as the primary control dimensions for classifying the upper and lower body sub-charts.

Since the aim is to accommodate the sizes of all the mainstream countries, the size ranges for the control dimensions are collected to create the integrated size table. The size ranges of sizing standards in mainstream countries have been calculated, as shown in Figure 3-2. Overall, the national garment sizing standards covered bust girths ranging from 68.0 cm to 159.0 cm, and the waist girths ranging from 50.0 cm to 139.0 cm, and the hip girth range wider, namely from 57.0 cm to 158.0 cm. The different national sizing standards define the different height ranges from 142.0 cm to 188.0 cm. It is worth noting that only the US and China have clear explanations and definitions for neck. Combining the sizing standards of the US and China, the neck ranges from 30.6 cm to 47.1 cm.

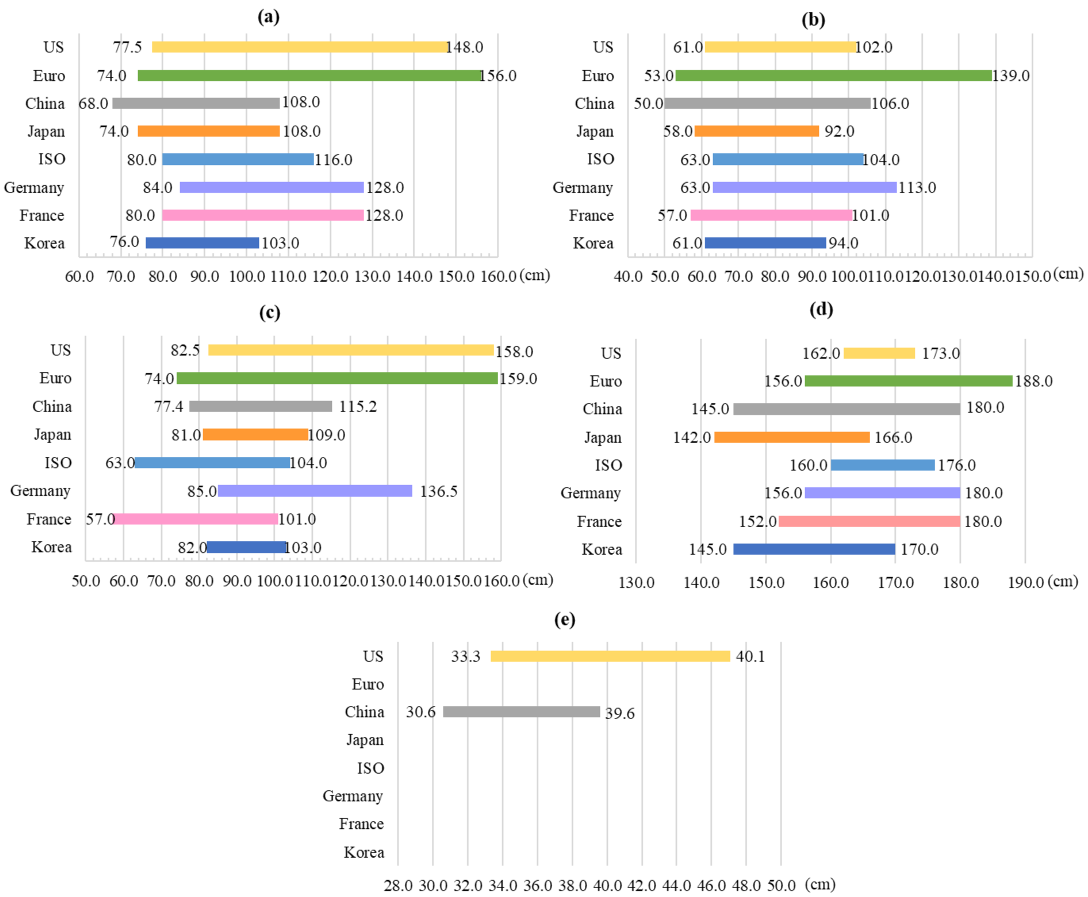


Figure 3-2 Comparison of the Various National Garment Sizing Standards for Females: (a) bust, (b) waist, (c) hip; (d) height; and (e) neck ranges.

Once the key measurements had been identified, body types could be defined by combining the primary and secondary control dimensions, such as the drop values between bust and waist girth, bust and hip girth or hip and waist girth (O'brien, 1941). In this study, the bust-waist drop values and waist-hip drop values were given to classify upper body and lower body, respectively. The corresponding drop values and intervals for the mainstream countries are given in Table 3-4. Taking into account the incomplete size information in some standards, the drop values for the upper body and the lower body size tables were consolidated and derived, with bust-waist drop values ranging from 4.0 cm to 28.6 cm and the hip-waist drop values from 3.0 cm to 33.0 cm, as highlighted in bold in the table.

Table 3-4 Drop Value Ranges and Intervals According to Female Body Type in Various National Garment Sizing Standards.

Standard	Body Type	Bust-Waist Drop Value (cm)	Hip-Waist Drop Value (cm)
US	Curvy Misses	24.8 – **28.6**	17.8 – 21.0
	Straight Misses	19.1 – 22.9	14.0 – 17.2
	Women	9.9 – 16.0	11.8 – 26.0
	Half-sizes	9.6 – 12.4	12.6 – 15.1
	Junior	20.4	25.4
Europe	C	21.0	**3.0** – 15.0
	D	19.0	5.0 – 17.0
	E	17.0	7.0 – 19.0
	F	15.0	9.0 – 21.0
	G	13.0	11.0 – 23.0
	H	11.0	13.0 – 25.0
	J	9.0	15.0 – 27.0
	K	7.0	17.0 – 29.0
China	Y	19.0 – 24.0	24.4 – 27.4
	A	14.0 – 18.0	20.2 – 23.4
	B	9.0 – 13.0	14.0 – 22.4
	C	**4.0** – 8.0	9.2 – 18.4
Japan	A	10.0 – 16.0	9.0 – 29.0
	Y	16.0 – 22.0	9.0 – 28.0
	AB	7.0 – 20.0	13.0 – 29.0
	B	6.0 – 16.0	15.0 – 30.0

ISO	A	/	/
	M	/	/
	H	/	/
Korea	N	/	17.0 – **33.0**
	A	/	/
	H	/	/
Min		**4.0**	**3.0**
Max		**28.6**	**33.0**

The size chart construction rules were slightly different for the sub-charts, Sub-charts (i) Bust -Waist and (iv) Waist - Hip sharing the same rules. In the different national sizing standards, the small intervals of 2.0 cm were used for 3.0 girth measurements, namely bust, waist and hip. As mentioned above, the size ranges for bust, waist, hip, neck, and height can be considered as their upper and lower limits. The size drop value determining the upper and lower limits of the difference between the control dimensions. For example, Sub-chart (i) Bust -Waist, the bust upper limit (BUL) is 159.0 cm and bust lower limits (BLL) is 68.0 cm. For the bust and waist differences, the upper limit (BWUL) is 28.6 cm, and the lower limit (BWLL) is 4.0 cm. For sub-chart standardization, BWUL was adjusted to 30.0 cm due to the 2.0 cm intervals. For hip and waist difference of the Sub-chart (iv) Waist-Hip, the upper limit (HWUL) is 33.0 cm, and the lower limit (HWLL) is 3.0 cm, and its range changed to 2.0 cm – 34.0 cm.

Table 3-5 presents the body type rules applied in sub-chart (i).

Table 3-5 Rules Applied in the Construction of the Sub-charts (i) and (iv)

Sub-chart(i)	BLL	BLL +2	…	BUL
	BLL – BULL	(BLL +2) – BULL	…	BUL – BULL
	(BLL – BULL) +2	(BLL +2) – BULL +2	…	(BUL – BULL) +2
Bust - Waist	(BLL – BULL) +4	(BLL +2) – BULL +4	…	(BUL – BULL) +4
	…	…	…	…
	BWLL	BWLL +2	…	BUL – BWLL

Table 3-6 Rules Applied in the Construction of the Sub-charts (ii), (iii) and (v)

Sub-chart(ii)	BLL	BLL + 2	…	BUL
	NLL	NLL	…	NLL
	NLL + 1	NLL + 1	…	NLL + 1
Bust - Neck	NLL + 2	NLL + 2		NLL + 2
	…	…	…	…
	NUL	NUL	…	NUL

The three rest of sub-charts: Sub-chart (ii) Bust - Neck, (iii) Bust - Height and (v) Waist - Height shared the same size rules except that the neck interval was 1.0 cm while the height interval was 5.0 cm. As summarized in Table 3-5, the neck ranges were from approximately 30.6 cm to 40.1 cm. After standardizing the size rules, neck upper limit

(NUL) was changed to 40.6 cm and the neck lower limit (NLL) to 30.6 cm. The rules construction of Sub-chart (ii) (Bust -Neck) is shown in Table 3-6.

3.4 Results and Discussion

All the combined sub-charts were constructed based on the above analysis. Three sub-charts, namely Bust - Waist, Bust - Neck and Bust-Height were constructed for the upper body, in which the bust was the primary control dimension located in the first row, while waist, neck and height were the secondary control dimension. Each bust dimension has a corresponding range of secondary control dimensions. Therefore, these three sub-charts can be used to describe different body types of the upper body. For the rest two sub-charts, Waist - Hip and Waist - Height, waist was the primary control dimension and hip, as well as height were the secondary control dimension, which related to the body types of lower body.

3.4.1 Integrated Female Size Table

The derived integrated size tables for female are shown in Figure 3-3 and Figure 3-4. The integrated size table was developed and consolidated in the way that covers the size ranges and body types based on the sizing standards of various countries for better multi-country comparison. Previous studies and literature related to sizing standards have indicated the relationship and correlation between sizes of dimensions are not clear. For example, in ISO, Germany, France, and Korea, the bust and waist size ranges and drop values are given, while the bust and waist intervals are not provided. Hence, the multi-national comparison of body types and sizes was analysed based on the available standards in each sub-chart.

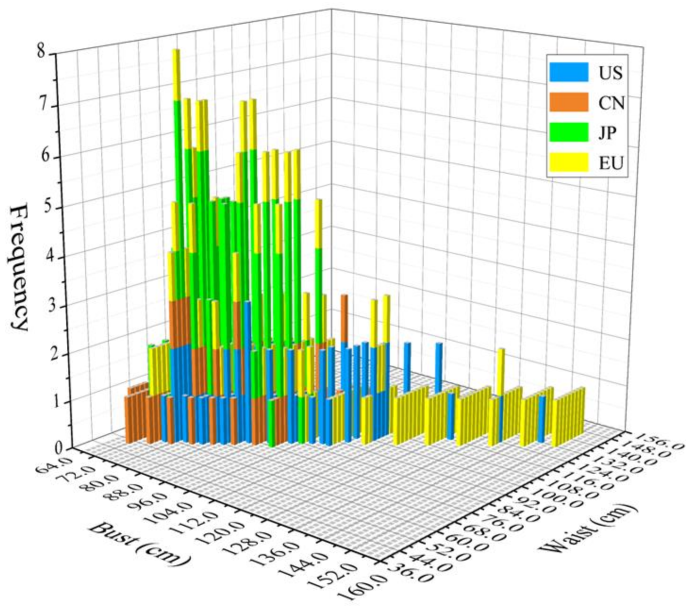
Sub-chart (i) Bust-Waist																													
Bust	**68.0**	**70.0**	**72.0**	**74.0**	**76.0**	**78.0**	**80.0**	**82.0**	84.0	**86.0**	**88.0**	**90.0**	**92.0**	**94.0**	**96.0**	**98.0**	**100.0**	**102.0**	**104.0**	**106.0**	**108.0**	**110.0**	**112.0**	**114.0**	**116.0**	**118.0**	**120.0**	**122.0**	**124.0**
Waist	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0
	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0
	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0
	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0
	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0
	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0
	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0
	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0
	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0
	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0
	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0
	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0
	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0
	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0
Sub-chart (ii) Bust-Neck																													
Neck	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6
	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6
	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6
	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6
	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6
	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6
	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6
	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6
	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6
	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6
	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6
	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6	42.6
	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6
	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6
	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6
	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6
	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6
Sub-chart (iii) Bust-Height																													
Height	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0
	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0
	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0
	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0
	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0
	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0
	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0
	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0
	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0

Figure 3-3 The Upper Body Sub-charts of the Integrated Female Size Table (Partial Table).

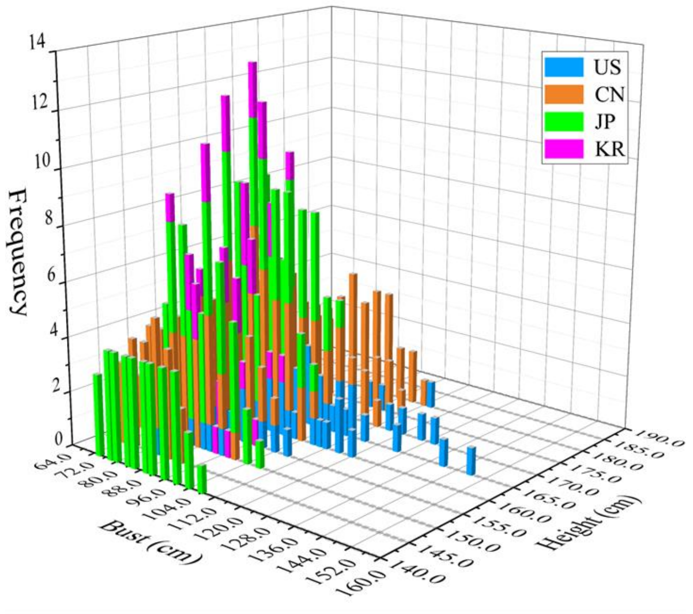
Sub-chart (iv) Waist-Hip																													
Waist	**50.0**	**52.0**	**54.0**	**56.0**	**58.0**	**60.0**	**62.0**	**64.0**	66.0	**68.0**	**70.0**	**72.0**	**74.0**	**76.0**	**78.0**	**80.0**	**82.0**	**84.0**	**86.0**	**88.0**	**90.0**	**92.0**	**94.0**	**96.0**	**98.0**	**100.0**	**102.0**	**104.0**	**106.0**
Hip	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0
	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0
	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0
	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0
	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0
	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0
	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0
	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0
	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0
	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0
	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0
	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0
	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0
	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0
	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0
	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0
	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0
Sub-chart (v) Waist-Height																													
Height	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0
	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0	145.0
	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0
	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0
	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0
	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0
	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0
	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0
	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0

Figure 3-4 The Lower Body Sub-charts of the Integrated Female Size Table (Partial Table).

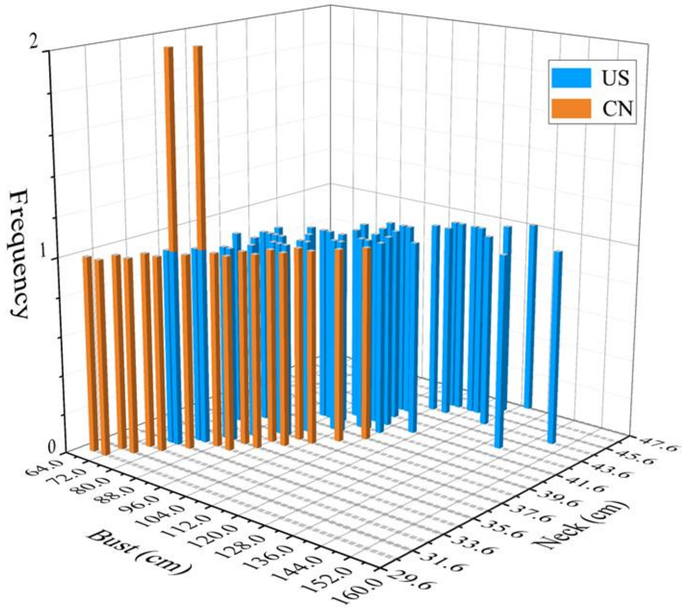
To better visualize and understand the size distribution of different sizing standards in the integrated size table, the size frequency with differences and similarities are labelled in Figure 3-5. The sizes in sizing standards were described by approximation. For example, in the US female sizing standard, bust and waist size were 77.5 cm and 57.1 cm, respectively, and were labelled as 78.0 cm and 58.0 cm in the integrated size table. The 2.0 cm intervals between adjacent sizes were applied to cover more sizes. The distribution of size frequency revealed the separation of the national sizing standards. As shown in Figure 3-5, the separation of the national sizing standards becomes more apparent with increasing distance from the distribution centre.


US
CN
JP
EU
Frequency
Bust (cm)
Waist (cm)

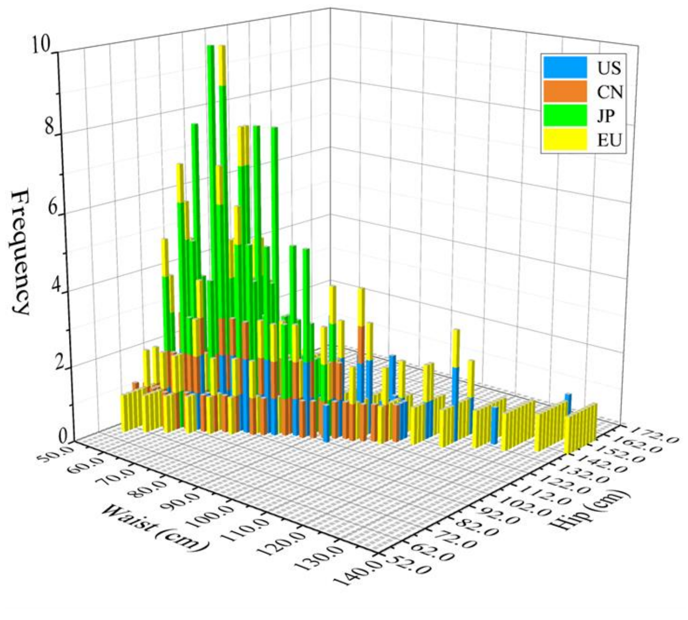
(i)


US
CN
JP
KR
Frequency
Bust (cm)
Height (cm)

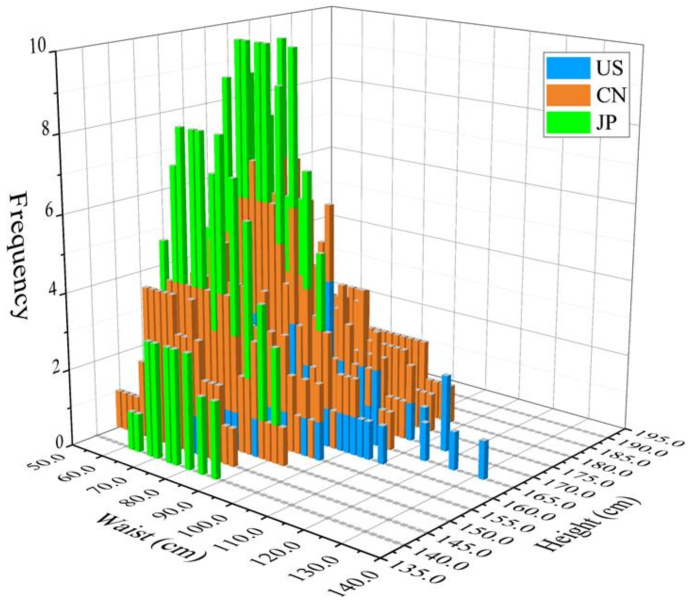
(ii)


US
CN
Frequency
Bust (cm)
Neck (cm)

(iii)


US
CN
JP
EU
Frequency
Waist (cm)
Hip (cm)

(iv)



(v)

Figure 3-5 The 3D Stacked Graph of Size Frequency for Different Sizing Standard in the Integrated Female Size Table: (i) Bust-Waist; (ii) Bust-Height; (iii) Bust-Neck; (iv) Waist-Hip; (v) Waist-Height.

As shown in Figure 3-5 (i) Bust - Waist, it is quite apparent that the majority of sizes of sizing standards in mainstream countries are distributed in the first half of the 3D stacked graph, from which it can be concluded that most of the body sizes and types of the various mainstream countries are covered in this area. According to the frequency of the size labelling, the Chinese and Japanese sizing standards start with the relatively smaller bust size ranges, covering from 68.0 cm – 112.0 cm and 74.0 cm – 104.0 cm, respectively. The ranges of the bust girths in the US and European sizing standards are relatively large, covering 76.0 cm – 148.0 cm and 76.0 cm – 152.0 cm, respectively. From the figure, the majority bust girths fall into the range of 76.0 cm to 104.0 cm, which corresponds to the waist range from 56.0 cm to 98.0 cm. Furthermore, there is a significant difference in body shapes among these people in the same range. For example, according to the frequency of the size labelling, the size region of 84.0 cm for bust and 62.0 cm to 78.0 cm for waist shows a trend of concentration, indicating that body shapes of the US, European, Chinese and Japanese sizing standards are similar in this area. The major body types of the US *Misses*, China *A* and Japan *A* types are assigned to compare the upper body shape differences due to the highest frequency in their respective countries. The mean values of these major body types are calculated using the sizes from the integrated size table, which can be simulated in CLO 3D, as shown in Figure 3-6. The US *Misses* types, including the *Curvy Misses* and *Straight Misses*, referring to the body types with same bust sizes but different waist sizes. According to the US sizing standards, the *Curvy Misses* have a mean value of waist size that is 4.0 cm smaller than the *Straight Misses*. Asian body types, namely the China and Japan A types, differ significantly. In the case of similar bust sizes, the mean waist of the Japan *A* type is 4.0 cm larger than that of the China *A* type. It can be concluded that the body shape of the China *A* type is more slender and petite, with a larger difference between bust and waist, than the Japan *A* type. In addition, the results of statistical analyses of multi-country sizing standards show that the US *Misses types* have a wider range of bust. The body shapes tend to a little plump than the main body types in China and Japan in the upper body.

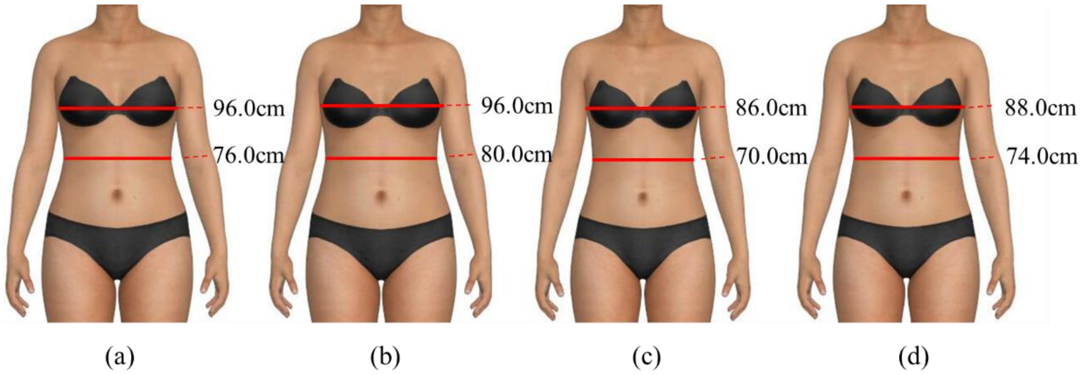


Figure 3-6 The Mean Values of Female Major Upper Body Shapes for US, China and Japan: (a) American Curvy Misses type, (b) American Straight Misses type, (c) Chinese A type, (d) Japanese A Type.

Figure 3-5 (ii) Bust-Neck provides the frequency of bust and neck sizes. Only two standards, the US and Chinese sizing standards, presented the size variation of neck. The neck sizes of Chinese sizing standard are distributed in the first half of the 3D stacked graph, ranging from 30.6 cm to 39.6 cm, while the US neck sizes are relatively large, covering from 33.6cm to 47.6 cm. Similar to the bust and waist in the Sub-chart (i), the neck girths increases with the bust girths, which is found in previous validation (Gupta & Gangadhar, 2004; Sixiang et al., 2011; Su et al., 2015). Due to the diversity of body types, the increments of the neck sizes greatly differ among the various sizing standards. China and the US sizing standards showed a similar trend, but the neck intervals are larger for the same bust sizes. For example, the maximum neck size for China is 5.0 cm smaller than that for the US for a range of 84.0 cm bust size. Different from the bust girths, the increments of the neck sizes are limited. Hence, the neck options covered in the (ii) Bust - Neck can give the majority of neck sizes in terms of body shapes in mainstream countries.

Figure 3-5 (iii) Bust-Height shows the size frequency related to bust and height. It can be observed that the majority height sizes are concentrated in the first half of the 3D stacked graph, indicating that the corresponding bust sizes are relatively small. More specifically, the most of height sizes ranging from 150.0 cm to 170.0 cm, while the bust sizes covering from 76.0 cm to 112.0 cm. For the size distribution of mainstream sizing standards, the bust and height sizes in the Chinese sizing standard are relatively large, namely from 68.0 cm to 112.0 cm and 145.0 cm to 180.0 cm, respectively. The height range in the US is relatively scattered, which are accommodating between 160.0 cm and 175.0 cm. The Japanese sizing standard divides height into four groups, namely 140.0 cm, 150.0 cm,160.0 cm and 165.0 cm. Based on the frequency of the size labelling, 160.0 cm and 165.0 cm are modes, representing they are the most common values among mainstream countries.

Figure 3-5 (iv) Waist - Hip shows the size frequency related to the waist and hip. Th size distribution indicates that the majority of the waist sizes correspond to the larger hip sizes, revealing that the waist and hip difference range of most national sizing standards are relatively concentrated compared to the original defined difference range of 2.0 cm – 34.0 cm. China standard covers a relatively smaller waist range, from 50.0 cm to 114.0 cm, while the US sizing standard starts at a larger waist size and covers the range from 60.0 cm to 106.0 cm, and the European sizing standard covers the largest range of waist size, namely 54.0 cm to 140.0 cm. More specifically, the highest frequency of waist sizes covered in the various sizing standards are 54.0 cm to 98.0 cm. For the major body types, the US *Misses*, China *A* and Japan *A* types, show the diversity of the lower body shapes. As shown in Figure 3-7,there are significant shape differences between the *Curvy Misses* and *Straight Misses*. The *Curvy Misses* type has a very narrow waist and large hip, showing a more curved shape compared to *Straight Misses* type who have a waist size of 78.0 cm and hip size of 98.0 cm. The lower body shapes of the Japan *A* and China *A* types are similar, with both having narrow waist and hip sizes.

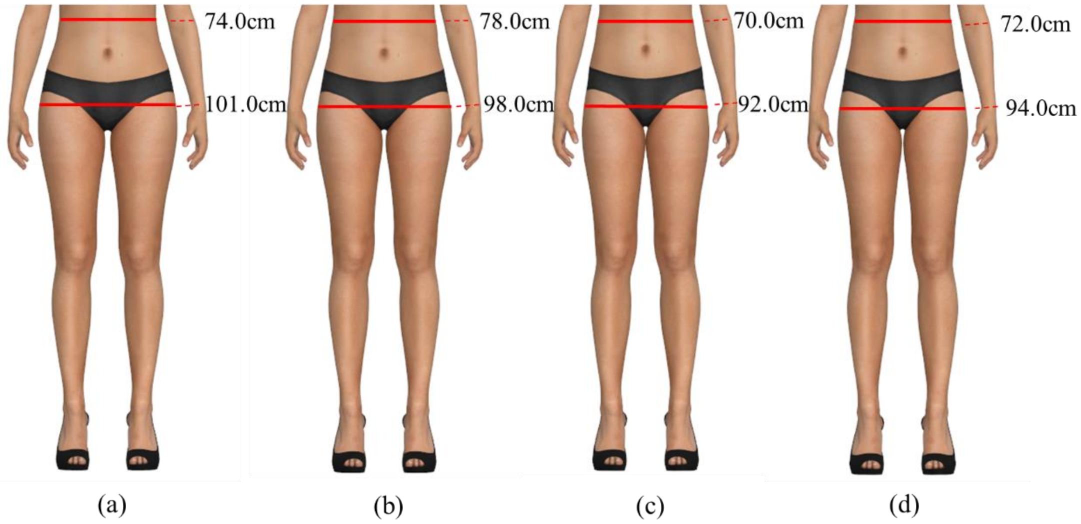


Figure 3-7 The Mean Values of Female Major Lower Body Shapes for US, China and Japan: (a) American Curvy Misses type, (b) American Straight Misses type, (c) Chinese A type, (d) Japanese A type.

Figure 3-5 (v) Waist - Height shows the frequency of waist and height sizes. Majority sizes are located in the first half of the 3D stacked graph, indicating that the smaller waist sizes cover most of the height ranges, generally concentrated in the waist size range of 60.0 cm to 100.0 cm and height size range of 145.0 cm to 175.0 cm. The Chinese sizing standard account for the largest number of sizes and the have a more concentrated size distribution, while the US sizing standard starts at a relatively large waist and covers the widest range. The Japanese size standard is unconcentrated, as height sizes are divided into four groups: 140.0cm, 150.0 cm, 160.0 cm, and 165.0 cm.

3.4.2 Integrated Male Size Table

The five sub-charts of the integrated male size table are derived using the same construction rules as those for the integrated female size table. After size sorting and classifying, the five male sub-charts are prepared, as shown in Figure 3-8 and Figure 3-9. In the various sizing standards, most male body types are classified according to the chest-hip drop values, while the chest-waist and waist-hip drop values are applied in integrated male size table to better describe the body shapes of upper and lower body. Most of the countries are reflected in the size table, with the exception of the ISO and France.

The size ranges covered in the sizing standards for chest, waist, hip, neck, and height are 72.0 cm – 152.0 cm, 56.0 cm – 158.0 cm, 72.0 cm – 124.5 cm, 32.0 cm – 51.0 cm, and 150.0 cm – 200 .0 cm, respectively. The chest-waist drop values range from -16.0 cm to 24.0 cm and the waist-hip is from 17.0 cm – 24.0 cm. In Sub-chart (i) Chest-waist and Sub-chart (iv) Waist-hip are developed using 2.0 cm intervals. The interval of Sub-chart b) Chest - neck is 1.0 cm. An interval of 5.0 cm is used for Sub-chart (iii) Chest - height and Sub-chart (v) Waist - height. As shown in Figure 3-10, the size frequency with differences and similarities was presented to compare the size distribution among mainstream countries.

Sub-chart (i) Bust-Waist

Chest	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0
Waist	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0
	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0
	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0
	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0
	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0
	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0
	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0
	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0
	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0
	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0
	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0
	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0
	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0
	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0
	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0
	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0	142.0
	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0	142.0	144.0
	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0	142.0	144.0	146.0
	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0	142.0	144.0	146.0	148.0
	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0	142.0	144.0	146.0	148.0	150.0
	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0	136.0	138.0	140.0	142.0	144.0	146.0	148.0	150.0	152.0

Sub-chart (ii) Bust-Neck

Neck	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0
	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0
	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0
	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0
	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0
	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0
	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0

Sub-chart (iii) Bust-Height

Height	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0
	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0
	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0
	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0
	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0
	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0
	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0
	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0
	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0
	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0
	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0

Figure 3-8 The Upper Body Sub-charts of the Integrated Male Size Table (Partial Table).

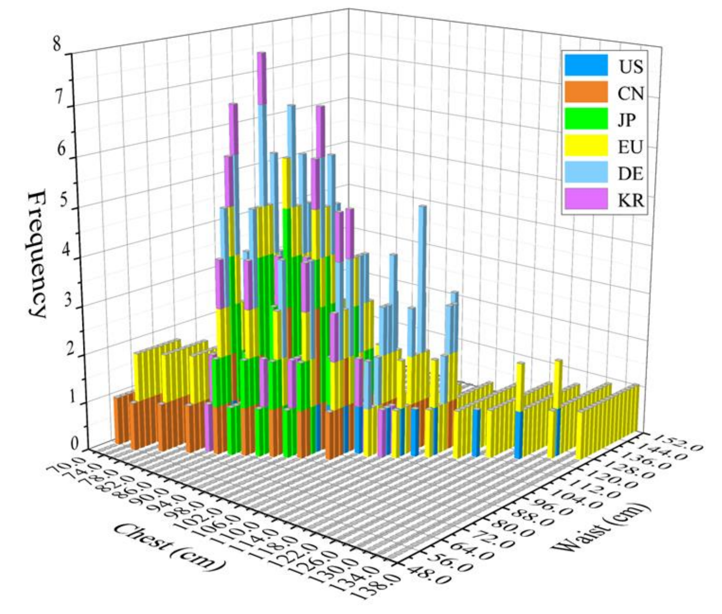
Sub-chart (iv) Waist-Hip

Waist	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	112.0	114.0	116.0	118.0	120.0
Hip	39.0	41.0	43.0	45.0	47.0	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0
	41.0	43.0	45.0	47.0	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0
	43.0	45.0	47.0	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0
	45.0	47.0	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0
	47.0	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0
	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0
	51.0	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0
	53.0	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0
	55.0	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0
	57.0	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0
	59.0	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0
	61.0	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0
	63.0	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0
	65.0	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0
	67.0	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0
	69.0	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0
	71.0	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0	135.0
	73.0	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0	135.0	137.0
	75.0	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0	135.0	137.0	139.0
	77.0	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0	135.0	137.0	139.0	141.0
	79.0	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0	135.0	137.0	139.0	141.0	143.0
	81.0	83.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0	99.0	101.0	103.0	105.0	107.0	109.0	111.0	113.0	115.0	117.0	119.0	121.0	123.0	125.0	127.0	129.0	131.0	133.0	135.0	137.0	139.0	141.0	143.0	145.0

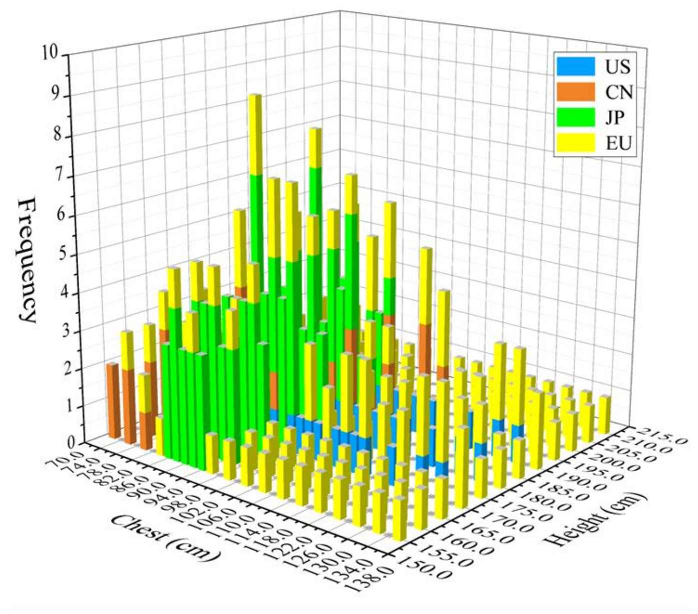
Sub-chart (v) Waist-Height

Height	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0	155.0
	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0
	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0
	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0
	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0	175.0
	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0	185.0
	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0
	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0
	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0
	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0	205.0
	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0	210.0

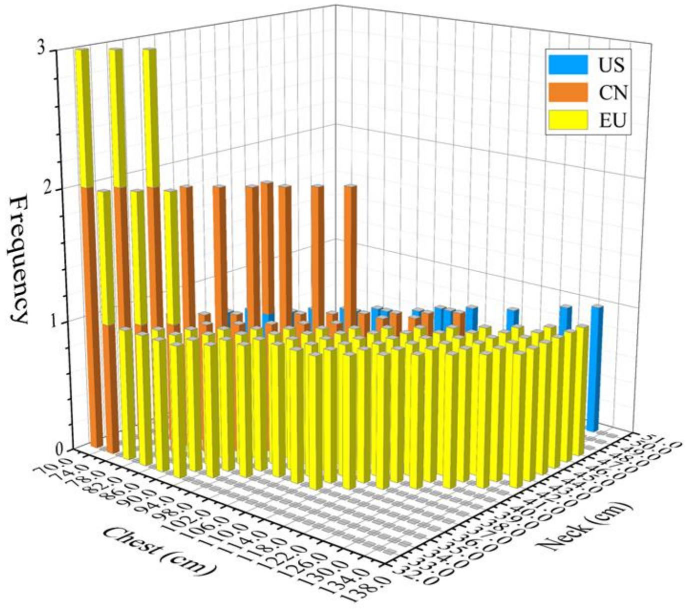
Figure 3-9 The Lower Body Sub-charts of the Integrated Male Size Table (Partial Table).


Frequency
Chest (cm)
Waist (cm)
US
CN
JP
EU
DE
KR

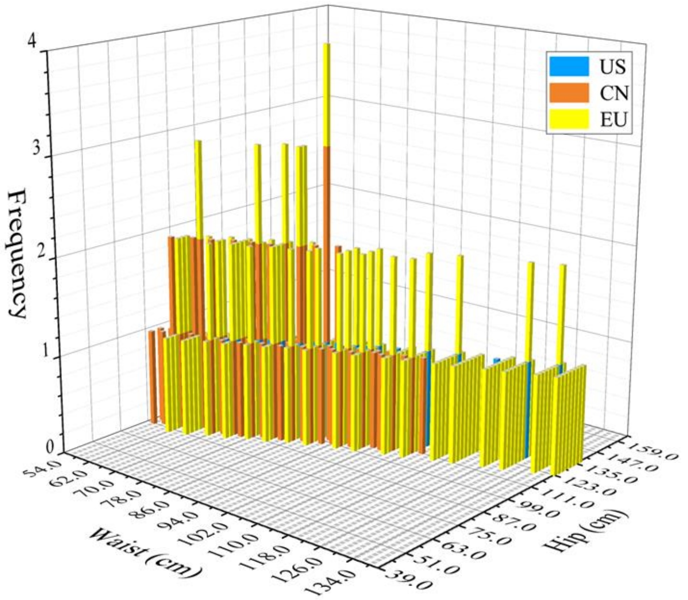
(i)


Frequency
Chest (cm)
Height (cm)
US
CN
JP
EU

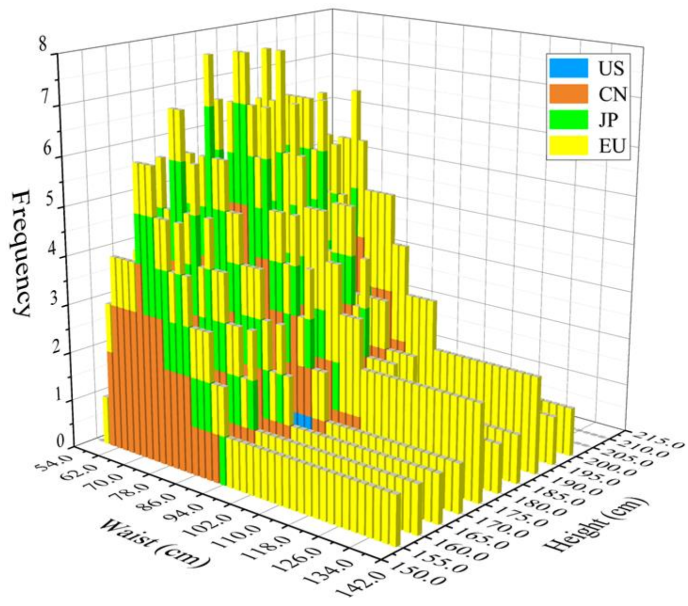
(ii)


US
CN
EU
Frequency
0
1
2
3
Chest (cm)
70.0
74.0
78.0
82.0
86.0
90.0
94.0
98.0
102.0
106.0
110.0
114.0
118.0
122.0
126.0
130.0
134.0
138.0
Neck (cm)

(iii)


US
CN
EU
Frequency
0
1
2
3
4
Waist (cm)
54.0
62.0
70.0
78.0
86.0
94.0
102.0
110.0
118.0
126.0
134.0
Hip (cm)
39.0
51.0
63.0
75.0
87.0
99.0
111.0
123.0
135.0
147.0
159.0

(iv)



(v)

Figure 3-10 The 3D Stacked Graph of Size Frequency for Different Sizing Standard in the Integrated Male Size Table: (i) Chest-Waist; (ii) Chest-Height; (iii) Chest-Neck; (iv) Waist-Hip; (v) Waist-Height.

Figure 3-10 (i) Chest-Waist shows the frequency of chest and waist sizes. The majority of sizes are distributed on the left side of the 3D stacked graph, with chest sizes ranging from 88.0 cm to 104.0 cm, corresponding to a waist range from 70.0 cm to 100.0 cm. According to the labelling of the size frequency, the Chinese sizing standard starts with a relatively small chest and waist sizes, covering from 72.0 cm to 116.0 cm and 56.0 cm to 112.0 cm. The Germany and Korean sizing standards define a small number of sizes and cover the relatively concentrated ranges. Both the sizing standards of Japan and the US start at 86.0 cm, the US sizing standards show a relatively large chest and waist range of 86.0 cm to 132.0 cm and 72.0 cm to 124.0 cm, respectively, while the

Japanese sizing standard covers a relatively small range of chest and waist, namely, 86.0 cm to 100.0 cm and 56.0 cm to 86.0 cm. According to the size distribution in 3D stacked graph, the European sizing standard has the highest frequency of sizes. To compare body shapes of the major body types in mainstream countries, the mean values were calculated using the sizes from the integrated male size table. The mean values of the US average body types are calculated based on size *34* to *45*, which are defined as well-proportioned in the US sizing standards (Chun, 2014). The Japanese average body types are *YA*, *A* and *AB* (Chun, 2014). As illustrated in Figure 3-11, the China *A*, Korea *A* and Japan average body types, tend to have narrow torsos with the larger chest-waist drop value, in which the torso of the China *A* type tends to a little slim than those of other groups. Japan and Korea have the same mean sizes of chest and waist. For the US and Germany, the mean chest sizes are larger than those of other national body types. Germany *MN* type has a relatively wide range of chest and waist size with a smaller chest-waist drop value, namely 10.0 cm. In addition, according to the labelled size frequency, the size region of 100.0 cm for chest and 82.0 cm to 96.0 cm for waist tends to concentrate, which indicates the consistency of body sizes in mainstream countries exists in this area.

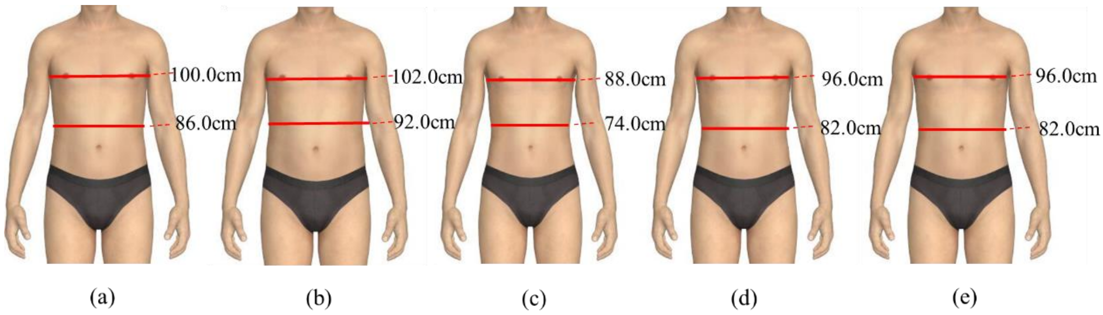


Figure 3-11 The Mean Values for Male Major Upper Body Types for Given Sizing Standards of the US, Germany, China, Korea and Japan: (a) the US Average Type; (b) Germany MN type; (c) China A type; (d) Korea A Type; (e) Japan Average Type

Figure 3-10 (ii) Chest - Neck contains the chest and neck size information, ranging from 72.0 cm to 136.0 cm and 33.0 cm to 50.0 cm, respectively. The neck sizes increase as the chest sizes increase. Among the size frequency between the various standards, China and the US show a similar rate of increase, which is higher than those of Europe. The European sizing standard defines the relatively specific neck sizes for the corresponding chest sizes and occupies and highest size frequency. Neck sizes tend to differ between certain sizes. For example, in the size region of 100.0 cm for chest, the upper and lower limits for the neck sizes are different in Europe, the US and China. In Europe, neck sizes range from 35.0 cm to 37.0 cm, while China neck sizes range from 39.0 cm to 41.0 cm. The US has a relatively large size at 42.0 cm.

Figure 3-10 (iii) Chest - Height gives the size frequency of chest and height. The standards of China and Japan show a relatively smaller range of chest and height sizes, namely from 72.0 cm to 116.0 cm and 155.0 cm to 190.0 cm, respectively. The Europe sizing standard shows the largest chest and height range, namely from 76.0 cm to 132.0 cm and 155.0 cm to 210.0 cm, respectively. The US sizing standard divides the height sizes into three ranges, namely below 170.0 cm, around 178.0 cm and above 188.0 cm, which covers the chest sizes from 86.0 to 132.0 cm. According to the labelling of the height sizes, 170.0 cm height sizes under each country make up the highest frequency, indicating that the 170.0 cm range is the most common height size in the national sizing standards.

In Figure 3-10 (iv) Waist - Hip, three mainstream sizing standards are depicted to compare the size distribution of lower body types, the most of waist sizes are concentrated between the range of 62.0 cm to 110.0 cm, covering the hip sizes from 73.0 cm to 119.0 cm. The Chinese sizing standard shows a relatively small waist range, namely from 56.0 cm to 112.0 cm, while the US sizing standard has a large waist range, namely form 72.0 cm to 124.0 cm. The European sizing standard covers the largest range for waist sizes, namely from 62.0 cm to 140.0 cm. According to the 3D stacked graph, the differences between hip and waist decreases as the waist increases, indicating that the larger waist sizes correspond the smaller hip sizes. More specifically, according to the size distribution, the waist size of 100.0 cm corresponds to the hip size of 99.0 cm, indicating that the body shape with a belly may occur from 100.0 cm onwards. Figure 3-12 compares the mean values of waist and hip sizes for the major body types in the US and China. Europe is excluded from this comparison because body types are not clearly defined. It is concluded that the US average body type has the large waist and hip sizes than the China A type.

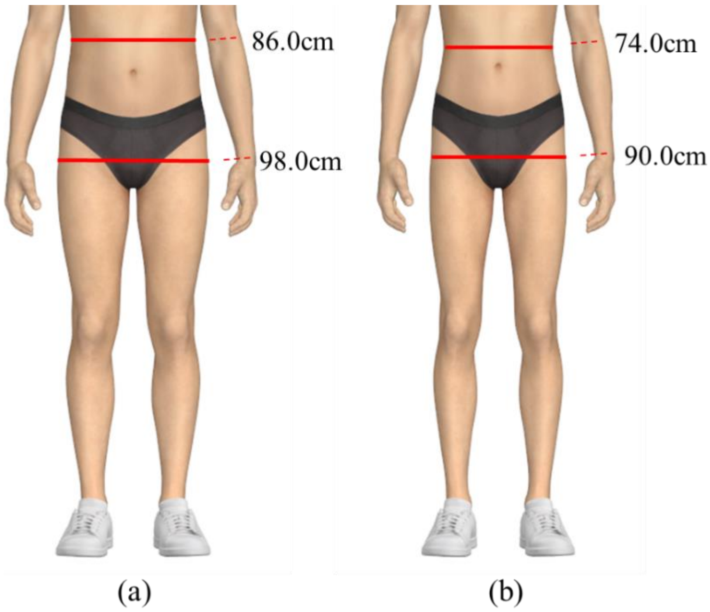


Figure 3-12 The Mean Values for Male Major Lower Body Types for Given Sizing Standards of the US, and China: (a) the US Average Type; (b) China A Type.

Figure 3-10 (v) contains the waist and height size information. The European sizing standard defines a large number of height sizes and covers the large waist sizes, ranging from 155.0 cm to 200.0 cm and 58.0 cm to 140.0 cm, respectively. The height sizes of

US sizing standards are distributed in three size regions: 170.0 cm, 180.0 cm and 190.0 cm. The Chinese and Japanese sizing standards have the same concentrated height area, covering from 155.0 cm to 190.0 cm.

3.5 Chapter Summary

This chapter provides a comprehensive analysis on the body types in various countries using the most recent national sizing standards. A set of integrated and internationally compatible size tables are then derived, which provide a valuable reference for analysis of body shape variation. This study covers both female and male sizing standards of the US, Europe, China, Japan, and some other countries. The 3D stacked graphs of size frequency were developed based on the integrated size table to conduct the comprehensive analysis of various body types and shapes. The statistical analysis showed that size frequency varies from various countries with significant differences in body types and shapes. The standards of China and Japan covered the smaller body dimensions and sizes, as reflected in the relatively narrow torso and hips. The Europe and US standards covered the relatively large body dimensions and size ranges, the body shapes are plumper and wider than those of other countries. As mentioned above, the integrated size table with high size frequency is valuable for designing ergonomic products and providing size references for international customers.

In sum, this study contributes to the body size related literature by filling gaps in multi-national comparison of body types and shapes, and also provides a detailed reference for designing and producing ergonomic products related to body types. Furthermore, it will benefit consumers as it provides an integrated size table that they can use as a reference table to identify sizes in fashion brands from different countries and provide size references for garment pattern grading to produce ready-to-wear (RTW) garment for consumers in different countries.

CHAPTER 4. A NOVEL SIZE RECOMMENDATION MODEL

4.1 Introduction

Clothing fit has been proven to be crucial in determining overall customer satisfaction with garments (Abdulla & Borar, 2017). Generally, the ill-fit issue and inappropriate sizes will result in returns. More and more online platforms are addressing this issue by implementing size recommendation features. Current methods of online size recommendations typically rely on one or two primary dimensions to estimate the appropriate size for an individual, often leading to ill-fitting results (Meunier, 2000). One of the main reasons is that the limited number of dimensions used only offer a basic approximation of body shape and size, which may not be adequate for all garments. Based on this method, customers may be recommended a size that is very tight and ill-fitting on certain body sections. Furthermore, customers seldom wear a single size when it comes to different styles or even within the same brand. It is common for individuals to alternate between two or three different sizes, influenced by personal preferences or the specific style of the garment. The proposed novel size recommendation model helps customers select appropriate sizes from unclear options by examining the correlation between human body measurements and garment sizes. Additionally, it offers clear information regarding the fit of specific areas within recommended sizes. This method aims to address the existing issue, recommending better-fitting garments for customers while reducing garment return rates.

Figure 4-1 serves as a roadmap in the development of size recommendation model, highlighting the underlying rationale and key concepts of the proposed size recommendation method. The proposed model involves four steps: Step 1. Mapping body measurement onto garment size, where first determine the size of each fit model and establish the correspondence between body measurement and garment size at each key fit points. Step 2. The mapping function is used to calculate the garment ease and ideal ease in each key fit point, which can help to explore the importance of each dimension in terms of its influence on the overall fit of the garment. In the third step, the overall fit error is derived as a fit score, by taking into account all the regional fit. The fit scores of all sizes are sorted to recommend the top three size options for customers. Finally, the proposed size recommendation model is validated by experiments on female and male shirts in Step 4.

Analyzing the correlation between body measurement and garment size is a prerequisite for the successful development of the method. An essential indicator in quantifying the correlation is the garment ease in each body section. The proposed model presents the concept of *Ideal ease*, which indicates the optimal fit between the garment and the human body. Importantly, the *Ideal ease* is not a fixed value; rather, it varies and depends on the specific garment style and different requirements in the particular area. To obtain the optimal fit, the proposed method combines garment ease, dimensional weighting, fit error score calculation, and size ranking to determine the ideal ease in each body section and generate an optimal size recommendation for the individual, as well as provide users with a more convenient and effective approach for determining their suitable sizes from any size chart. In addition, the proposed method provides fitting information on key areas to assist customers in understanding the fit level in each specific area, making informed decisions about garment selection.

To validate the superiority of the proposed method, it was tested on two different databases comprising different styles of shirts designed for both females and males. By conducting experiments on these datasets, the proposed method has demonstrated surpassing traditional techniques in terms of performance and accuracy. Furthermore, the shirt experiment focused on four key dimensions, namely bust, waist, shoulder and height, that significantly contribute to the overall fit of the garment. In Chapter 3, a detailed explanation of the importance of these four key dimensions is provided, emphasizing the importance of selecting the appropriate number of dimensions. Finally, a thorough comparison with the methods outlined in previous studies is conducted, and the results consistently demonstrated superior recommendation performance of the proposed method.

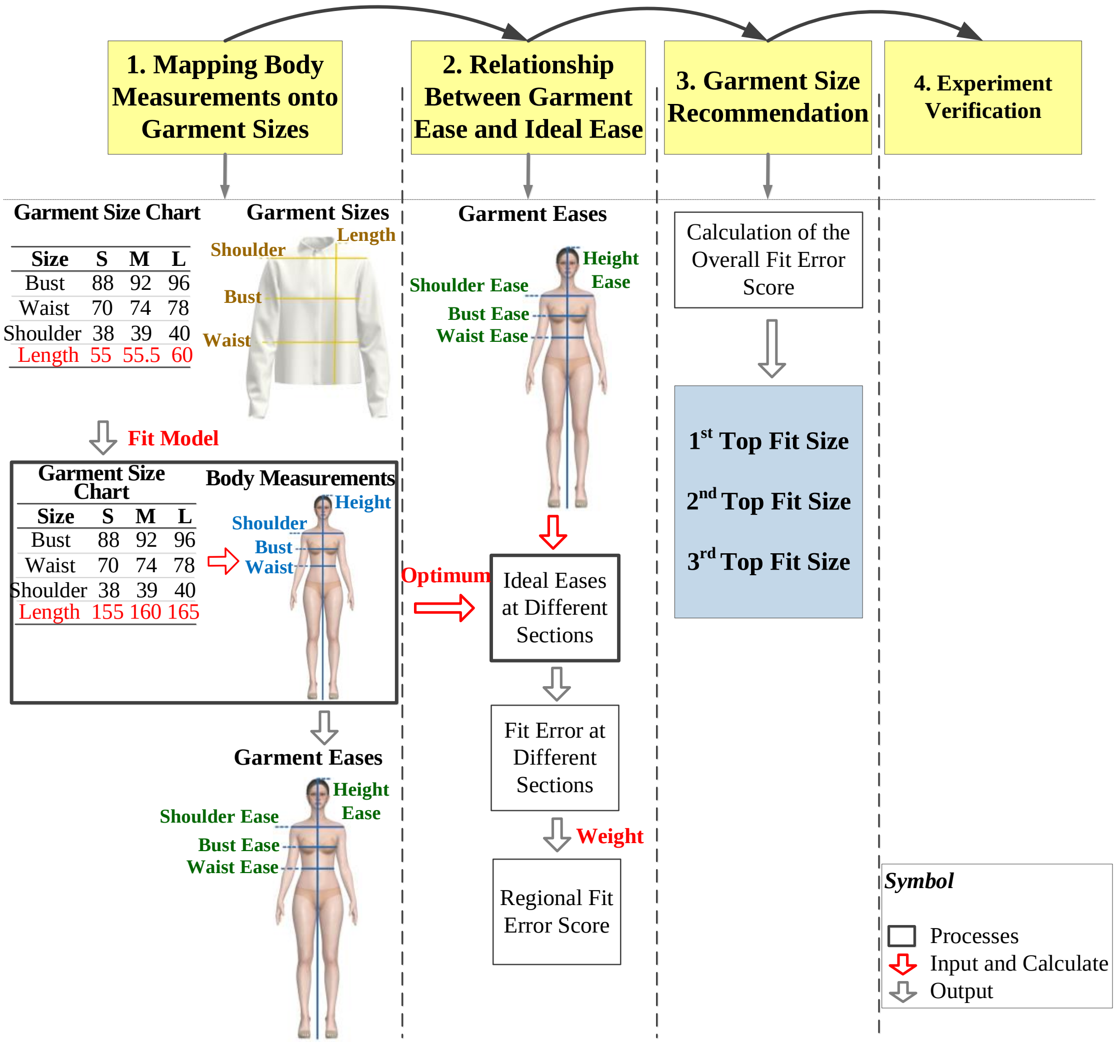


Figure 4-1 The Rationale and Key Concepts of the Proposed Size Recommendation Model

4.2 Method

4.2.1 Mapping Body Measurements onto Garment Sizes

Garment fit is largely determined by garment ease, which is a key factor affecting size selection and refers to the increase differ amount beyond body size at different body sections (Daanen & Reffeltrath, 2007; Gupta, 2020; Petrova, 2007). Garment ease can be analyzed by fit mapping, which effectively involves mapping the body measurements onto a garment of the appropriate size, in order to determine how well the garment size accommodates the user's body section (Bougourd, 2007; Daanen & Reffeltrath, 2007). Two datasets are required be provided for fit mapping: one containing the body measurements of the user wearing light form fitting clothing or underwear (Yu, 2004a), and the other containing the garment sizes selected by customers from specific garment size charts. The mapping relationship of body measurements (*BM*) and garment sizes (*GS*) can then be established: $BM \rightarrow GS$, in which:

$$f\left(BM_i\right) = GS_i \tag{4.1}$$

where *i* represents body sections, such as bust (*b*), waist (*w*), shoulder (*s*), height (*h*), etc. Take an example to illustrate, BM_b indicates the bust measurement of human body, GS_b denotes the bust size of the garment.

Various companies have developed their own sizing system based on a large number of body measurements generated by traditional anthropometric surveys and using sophisticated statistical methods to divide the population into groups of similar body measurements (Petrova, 2007). To represent the target market, idealized body shapes are chosen as the human fit models for each group (Chun, 2007; Loker et al., 2005; Taylor, 1998). Based on their human fit models, garment fit models are then created by adding an ease allowance. Equation (4.1) shows the correspondence of each fit point between human body and garments. It is noteworthy that among all the correspondences, the body height (BM_h) and garment length (GS_l) require conversion for computation. BM_h and GS_l having been shown to be highly correlated previously (Gupta & Gangadhar, 2004; Hsu & Wang, 2005; Liu, Zeng, Wang, et al., 2018; Yuan & Huh, 2019). The correspondence between BM_h and GS_l can be used to calculate the height of the garment fit model versus that of the human fit model. Garment ease (GE) at each fit point is given in Eq. (4.2). As an example, a customer with the bust girth (BM_b) of 84.0 cm selects the S size of a specific garment, such as a shirt, so as to have an optimum wearing comfort. The bust size (GS_b) of the shirt is 90.0 cm, bust ease (GE_b) = GS_b - BM_b =6.0 cm. The ease of garment waist (GE_w), shoulder (GE_s) and height (GE_h) can also be calculated.

$$GE_i = GS_i - BM_i \tag{4.2}$$

where i= b, w, s, h, etc. For example, GE_b indicates the bust ease between GS_b and BM_b.

4.2.2 Relationship Between Garment Ease and Ideal Ease

4.2.2.1 Garment fit prediction with garment ease and ideal ease

The calculation of the garment ease can help customers to quantify the exact ease allowance at each specific section of the garment. In garment size charts, garment fit models are derived from the human fit models by adding an ease. Such an extra ease as the *Ideal ease*, which represents the optimum fit between the human body and the garment. Another concept, *Fit error* (*FE*), is introduced in this section, which represents the difference between the garment ease and the ideal ease, it is hypothesized that the difference is absolute value, indicating a smaller *Fit error* means better fit. Generally, garment fit is not related to the garment ease, that is, garment fit does not necessarily peak as the garment ease increases or decreases. For example, when a customer tries a garment on, larger or smaller does not mean a better fit; rather, the garment is deemed most suitable when the customer's figure is closest to the human fit model of the select of size. The *FE* can be therefore used to quantify garment fit. The *FE* at different fit points can be computed as follows:

$$FE_i = GE_i - GI_i, \tag{4.3}$$

where i= b, w, s, h, etc. For example, FE_b and GI_b represent the bust fit error and bust ideal ease, respectively.

4.2.2.2 *Weighting of fit error according to its effect on garment fit*

The proposed size recommendation model involves an ease segment weighting feature that assigns varying weights to the *FE* of different body dimensions, according to their impact in determining the overall fit. Weightings are varied according to the different ease range of each dimension to obtain the optimum *Fit error score* (*FS)* for each fit point. *FS* in each fit point can be extracted according to the appropriate constraints on the garment ease, defined as follows:

$$FS_i = \begin{cases} FE_i \times W_{i1}, & GE_i < P_{i1} \\ FE_i \times W_{i2}, & P_{i1} \le GE_i < P_{i2} \\ \quad \cdots \quad , & \quad \cdots \\ FE_i \times W_{in}, & P_{in} \le GE_i < P_{in+1} \\ FE_i \times W_{in+1}, & P_{in+1} \le GE_i \end{cases}, \tag{4.4}$$

where i= b, w, s, h, etc. More specifically, FS_i represents the *Fit error score* in different fit points, including bust fit error score (FS_b), waist fit error score (FS_w), etc.; W_{i1}, W_{i2}…W_{in+1} denote different weightings assigned for FE_i; P_{i1}, P_{i2}… P_{in+1} represent the ease segment derived based on theoretical garment ease allowances.

4.2.2.3 *Application of garment ease segment for generating optimal size suggestions*

Garment ease allowances play a crucial role in the generation of optimal size recommendations. In the novel size recommendation model, the ease segments are refined and derived from theoretical garment ease allowances. These derived ease segments are then utilized to compute the *FS* by assigning appropriate weightings to different ease groups. The finetuning of ease segments takes into account the ideal ease between human and garment fit models, as well as specific garment styles, thereby ensuring flexibility and adaptability across different styles and categories of garments.

According to the Eq. (4.4), thresholds are assigned to the garment ease in various ease segments for the calculation of the *FS*. Weighting (Wi_n) was introduced to give priority to different body dimensions, recognizing that not all dimensions have the same impact on garment fit. For instance, individuals often prioritize bust dimensions over other measurements when selecting garment sizes, while some prioritize height (garment length). Wi_n is used not only to prioritize dimensions but also within each dimension to determine the importance of the garment ease (GE_i) in relation to the ideal ease (GI_i). GE_i that closely aligns with GI_i should have a smaller Fit Error Score (FS_i), indicating a good fit. To achieve this, sets of ease range were established to assign different weightings based on where GE_i falls within the ranges. As an example, for a garment with an ideal bust ease of 6cm, the lowest weighting of 0.8 is assigned to the range of 4 to 8cm (6 ± 2cm) (as shown in Figure 4-2). As the range deviates further from the ideal ease, the assigned weighting increases, resulting in a larger FS_i for poor fit.

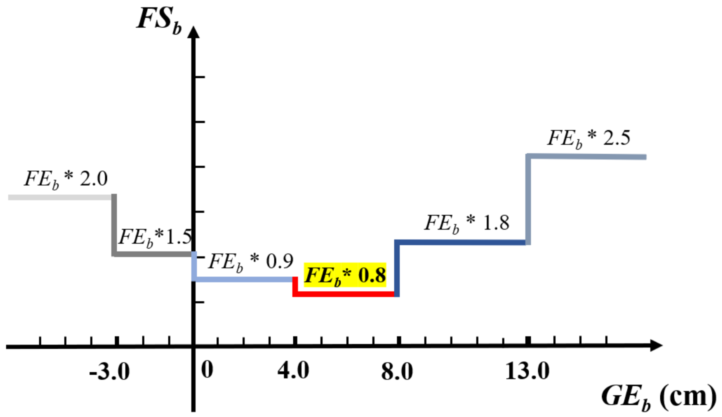


Figure 4-2 Weighting Distribution to Calculate the FS_b by Bust Ease Range

4.2.3 Garment Size Recommendation

The overall fit error score (*Ofs*) is computed for each fit point and analysed for every size in the size chart, providing a comprehensive overview of the overall fit of each size. The *Ofs* takes into account fit of all the body sections with the condition for assessing the overall fit perception of a garment derived as follows:

$$Ofs = FS_{i1} + FS_{i2} + ... + FS_{in} \tag{4.5}$$

The *Ofs* of all size options in the size chart are calculated and put into ascending order. The 3 size options with the best *Ofs* s are recommended to the customer.

4.3 Experimental Verification

4.3.1 Experiment for Female

4.3.1.1 Garments

Two female shirts, differing style in size and garment ease, were selected to verify the accuracy of the proposed method. Each subject tried on two shirts, a regular-fit shirt (shirt A) with 11 sizes ranging from S01 to S11, a tight-fit shirt (shirt B) with 7 sizes ranging from 34 to 40.

4.3.1.2 Subjects

Experimental verification involved a dataset of 52 female participants from Hong Kong rowing team and Hong Kong fencing team. Their body measurements were collected by means of a 3D body scanner. Table 4-1 lists the basic measurements for the four body dimensions that correspond to those in the shirt size charts.

Table 4-1 Basic Measurements of Subjects

Gender	N	Body dimensions	Mean± SD (cm)
Female	52	Height	167.0±6
		Bust	88.6±6
		Waist	76.5±6
		Shoulder	43.1±3

4.3.1.3 Size recommendation implementation

Experiment 1:

In this experiment, all subjects tried on shirt A and the garment size selected by each subject was recorded as the ground truth, also defined as the preferred size.. The essence of this method is to assign weighting based on the impact of the *FE* at each fit point on the overall fit of the garment so as to recommend the optimum sizes ranked in the first three for each customer. The difference between the recommended sizes and the preferred size is also compared.

1.) determining the Fit Model

The key issue for accurately mapping the body measurements onto the garment sizes is to establish the relationship between body and garment in each fit point. Since the subjects have already been grouped according to their size, the distribution of body measurements within each size can be derived. To avoid bias due to the skewness of the distribution, the median value of the body measurements in each group is used as the representative value for each human fit model. The median height of the subjects within the same size is calculated to represent the body height of the human fit model. The complete sizes of the garment fit model for shirt A are shown in Table 4-2.

Table 4-2 The Sizes of the Fit models for Shirt A

Size	Bust (cm)	Waist (cm)	Shoulder (cm)	Height (cm)
S01	82.0	72.0	42.3	158.6
S02	86.0	72.0	41.9	168.0
S03	88.0	76.0	40.6	161.0
S04	90.0	78.0	41.7	168.0
S05	94.0	82.0	43.6	164.0
S06	94.0	82.0	44.5	172.0
S07	98.0	84.0	44.2	168.0
S08	100.0	88.0	43.4	168.0
S09	98.0	88.0	44.6	164.0
S10	104.0	98.0	45.8	168.0
S11	110.0	98.0	44.7	172.0

2.) calculating garment ease.

The garment eases for each fit point of the subject were calculated based on the corresponding sizes, in order to evaluate the variance in garment eases across all sizes of shirt A for the subject (Eq. (4.2)).

3.) calculating Fit errors.

By calculating the differences between the human body and the corresponds garment fit model, the ideal ease can be obtained. The optimal eases at different fit points are

GI_b= 5.0, GI_w=4.5, GI_s=0, GI_h=0, and *FE* at each point was calculated according to Eq. (4.3).

4.) assigning weighting to Fit errors.

This step involves adjusting the ease range of the theoretical garment ease according to the garment fit. For the regular-fit shirt A, the upper and lower limits of each segment finetuned to achieve the best fit performance, with Table 4-3 giving derived garment ease segments for each body section. Compared with the theoretical ease, the ranges of ease allowance for each segment also changed accordingly. Taking into account the different effects of fit error scores for the different body sections on the garment overall fit, the algorithm assigned different weights to those *FE* in determining the recommended optimum sizes, also as based on Eq. (4.4).

Table 4-3 Derived Garment Ease Segments for Shirt A

Sections	Segment 1 (cm)	Segment 2 (cm)	Segment 3 (cm)	Segment 4 (cm)	Segment 5 (cm)	Segment 6 (cm)
Bust (b)	b <-3.0	-3.0≤b< 0	0≤b< 4.0	4.0≤b< 8.0	8.0≤b< 13.0	13.0≤ b
Waist (w)	w <-3.0	-3.0≤w< 0	0≤w< 8.0	8.0≤w< 12.0	12.0≤w< 17.0	17.0≤w
Shoulder (s)	s <-4.0	-4.0≤s<-2.0	-2.0≤s< 2.0	2.0≤s<3.0	3.0≤s<6.0	6.0≤ s
Height (h)	h <-10.0	-10.0≤h<-5.0	-5.0≤h< 0	0≤h<5.0	5.0≤h<10.0	10.0≤ h

Table 4-4 Ease Segment Weighting for Different Dimensions of Shirt A

Dimensions	Fit Score	Ease Segment					
		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
Bust	FS_b	FE_b* 2.0	FE_b* 1.5	FE_b* 0.9	FE_b* 0.8	FE_b* 1.8	FE_b* 2.5
Waist	FS_w	FE_w* 3.0	FE_w* 1.2	FE_w* 0.6	FE_w* 0.9	FE_w* 1.5	FE_w* 2.0
Shoulder	FS_s	FE_s* 1.5	FE_s * 1.2	FE_s * 0.7	FE_s * 1.1	FE_s * 1.3	FE_s * 2.5
Height	FS_h	FE_h* 2.5	FE_h* 2.0	FE_h* 1.5	FE_h* 0.6	FE_h* 0.8	FE_h* 1.0
Overall Fit Score	*Ofs*						

The model generates *FS* for different ease segments at each dimension so as to obtain the *Ofs* (as shown in Table 4-4). When the garment ease closely matches the ideal ease, assigning a smaller weight to *FE* in order to achieve a smaller *Ofs,* thereby obtaining a higher ranking in the subsequent overall score ranking.

5.) calculating Overall fit scores

Using Eq. (4.5) and considering the *FS* for the different fit points, the *Ofs* can be calculated for each subject. In addition, the relationship between the individual subject and the various shirt sizes can be obtained so that further detailed and targeted analysis of body sections can be done for subjects. By ranking the corresponding 11 size options in the size chart, the system can automatically recommend the top 3 sizes for each customer.

Experiment 2:

To validate the effectiveness of the developed algorithm, the same method as for shirt A was adopted for shirt B. The fit model sizes are shown Table 4-5. The ease ranges and intervals of garment ease segments have been finetuned for shirt B (Table 4-6). *FS* formulas developed for each fit point are defined, the ease segment weights are illustrated in Table 4-7.

Table 4-5 The Size of Fit Models for Shirt B

Size	Bust (cm)	Waist (cm)	Shoulder (cm)	Height (cm)
34	84.0	71.0	41.0	156.3
35	88.0	74.0	42.0	159.0
36	92.0	77.0	42.0	161.8
37	96.0	80.0	42.0	167.3
38	98.0	83.0	45.0	170.0
39	100.0	86.0	43.0	175.5
40	106.0	89.0	44.0	197.4

Table 4-6 Derived Garment Ease Segments for Shirt B

Sections	Segment 1 (cm)	Segment 2 (cm)	Segment 3 (cm)	Segment 4 (cm)	Segment 5 (cm)	Segment 6 (cm)
Bust (b)	b <-3.0	-3.0≤b< -1.0	-1.0≤b< 3.0	3.0≤b< 5.0	5.0≤b< 14.0	14.0≤ b
Waist (w)	w <-4.0	-4.0≤w< -1.0	-1≤w< 7.0	7.0≤w< 10.0	10.0≤w< 15.0	15.0≤w
Shoulder (s)	s <-4.0	-4.0≤s<-3.0	-3.0≤s< -1.0	-1.0≤s< 0	0≤s< 2.0	2.0≤ s
Height (h)	h <-10.0	-10.0≤h<-2.0	-2.0≤h< 0	0≤h< 3.0	3.0≤h< 15.0	15.0≤ h

Table 4-7 Ease Segment Weighting for Different Dimensions of Shirt B

Dimensions	Fit Score	Ease Segment					
		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
Bust	FS_b	FE_b* 2.0	FE_b* 1.5	FE_b* 1.0	FE_b* 0.8	FE_b* 0.2	FE_b* 3.0
Waist	FS_w	FE_w* 2.0	FE_w* 0.5	FE_w* 0.6	FE_w* 0.8	FE_w* 1.2	FE_w* 3.0
Shoulder	FS_s	FE_s* 2.5	FE_s * 2.0	FE_s * 1.0	FE_s * 0.5	FE_s * 1.1	FE_s * 1.3
Height	FS_h	FE_h* 2.0	FE_h* 0.8	FE_h* 0.2	FE_h* 1.2	FE_h* 1.5	FE_h* 2.5
Overall Fit Score	*Ofs*						

The values derived for shirt B are different from those for shirt A due to differences in the garment style and fit level, as well as fit perception of subjects wearing the various garments.

4.3.2 Experiment for Male

The same method and process were adopted by a group of 73 male participants who tried on two different styles of shirts, namely shirt C and shirt D. The experimental results are presented in the following section.

4.4 Results and Discussion

4.4.1 Validation of the Accuracy of Novel Model

In garment e-commerce platforms, consumers lack the chances of physically testing a product. Instead, they must depend on visual images and size specifications to select the item, resulting in a large percentage of returns due to size and fit (Z. Wang et al., 2021). As a result of this gap, this study proposed a novel size recommendation model based on the fit analysis between body measurements and garment sizes that assist customers quickly locate appropriate sizes. Two female and male shirts with different styles and fit levels were selected to evaluate the effectiveness of the size recommendation algorithm, in terms of (1) the number of subjects whose preferred size fell within the sizes assigned by the recommendation model; (2) the difference between the subjects' preferred size and that assigned by the recommendation model; (3) the accuracy and application of the recommendation model.

An example of Experiment 1 of female shirt is given here to illustrate the process of optimal size identification of the size recommendation model. In Experiment 1, the newly model used the body measurements of shirt A to establish the mapping relationships with 11 size options in the size chart. The size recommendation model can output the fit scores at each section and computes the *Ofs* for all sizes. Table 4-8 calculates the *Ofs* of 11 sizes for subject I. The top three best fit sizes, with smallest *Ofs*, are shown on the right. The reason for recommending three sizes is that people often wear more than one size, the suitable size chosen by customers may not fit perfectly in all body sections, like waist, length, and shoulder. By providing customers with a choice of three sizes, the method can help them identify the size that fits them optimally. Furthermore, the method provides detailed fitting information and how the subject fits in each body section. For instance, the three top-ranking sizes, S03, S01 and S02, are optimal sizes for subject I. For the first one, the misfit dimension is the waist, with a very loose ease allowance of 9.5cm. The second fit size is S01, the most misfit dimension is at the bust area, with an ease value of 11.5cm. The third best size, S02, is looser than both S03 and S01, with garment eases of 13.5cm and 13 cm for bust and waist, respectively.

Table 4-8 An Example of a Subject I 's Size Recommendations

S.	Size	GE_b	GE_w	GE_s	GE_h	FE_b	FE_w	FE_s	FE_h	FS_b	FS_w	FS_s	FS_h	Ofs
I	**S03**	**7.5**	**9.5**	**0.0**	**-1.4**	**2.5**	**5.0**	**0.0**	**1.4**	**2.0**	**2.8**	**0.0**	**2.1**	**6.9**
I	**S01**	**11.5**	**9.5**	**-0.4**	**8.0**	**6.5**	**5.0**	**0.4**	**8.0**	**11.7**	**2.8**	**0.8**	**6.4**	**22.4**
I	**S02**	**13.5**	**13.0**	**-1.7**	**1.0**	**8.5**	**9.0**	**1.7**	**1.0**	**21.3**	**9.1**	**3.4**	**0.6**	**37.7**
I	S04	15.5	15.5	-0.6	8.0	10.5	11.0	0.6	8.0	26.3	11.1	1.2	6.4	46.1
I	S05	19.5	19.5	1.3	4.0	14.5	15.0	1.3	4.0	36.3	25.2	2.6	2.4	69.1
I	S07	19.5	19.5	2.2	12.0	14.5	15.0	2.2	12.0	36.3	25.2	2.6	12.0	80.5
I	S09	23.5	21.5	1.9	8.0	18.5	17.0	1.9	8.0	46.3	28.6	3.8	6.4	88.8
I	S08	25.5	25.5	1.1	8.0	20.5	21.0	1.1	8.0	51.3	35.3	2.2	6.4	97.3
I	S06	23.5	25.5	2.3	4.0	18.5	21.0	2.3	4.0	46.3	35.3	2.8	2.4	91.3
I	S10	29.5	35.5	3.5	8.0	24.5	31.0	3.5	8.0	61.3	52.1	2.8	6.4	129.5
I	S11	35.5	35.5	2.4	12.0	30.5	31.0	2.4	12.0	76.3	52.1	2.9	12.0	148.0

In the novel size recommendation model, 3 metrics are used to access fit performance, that is, top 1 accuracy, top 2 accuracy, and top 3 accuracy. If the preferred size of the subjects aligns with the first size in recommended sizes, the matching rate is defined as the first accuracy, also refers to the top 1 accuracy. If the preferred size is matched with second size in the recommended sizes, it is defined as the second accuracy. Top 2 accuracy contains first accuracy and second accuracy. Likewise, the top3 accuracy including first, second and third accuracies. For example, Table 4-8 presents the ranked sizes for Subject I, with the top three recommended sizes having the lowest overall fit scores. The known preferred size for the Subject I is S03, which is calculated as the top 1 accuracy (first accuracy). If the preferred size is S01, the match rate is the second accuracy. The first and second accuracy rates are included in the calculation of the overall top 2 accuracy. Similarly, when the preferred size is S02, the match rate is the third accuracy. The top 3 accuracy for all subjects incorporates the first, second, and third accuracies.

In Experiment 1 of female shirt, the matching results are compared with the customers' preferred size, and it was found that the accuracy of the new model was 61.5% for the top 1accuracy, 80.8% for top2 accuracy and 90.4% for the top3 accuracy. In Experiment 2, the matching rates are 56.9% for the top1 accuracy, 80.4% for the top2 accuracy and 96.1% for the top3 accuracy. For male shirt experiments, the matching rates of shirt C are 66.2% for top 1 accuracy, 78.4% for top 2 accuracy and 89.2% for top 3accuracy. The matching rates of shirt D are 62.2%, 81.1% and 90.5%, respectively.

The size recommendation model provides a breakdown of how well each body dimension is accommodated with each selected size, providing customers with invaluable insights into how well the garment will fit before they actually try it on. It is critical in improving customer's shopping experience and satisfaction, as well as reduce product return rates. In this model, when the garment ease between the customer's body measurements and the garment size is infinitely close to the ideal ease, a smaller weight will be assigned to defining *FS* and it will be filtered out when calculating the *Ofs*. The *Ofs* is computed based on fit score at each fit point and is used as above to analyze every size in the chart, providing a comprehensive overview of each size's level of fit.

In the two experiments, some subjects demonstrated different size adaptation, resulting in different accuracies. The reasons can be summarized: (1) different style of garments. Each subject has individual fit problems with the different garments what could not be quantified; (2) body measurement errors and garment tolerances. In the current model, the recommendation constraint is that when the bust and waist ease is greater than -1 cm, as well as the size being ranked first according to the overall fit score, the size can be recommended to the subject. In the actual fitting, the acceptable ease of the shirt for subjects is less than -1 cm. For instance, in the shirt A experiment, the bust ease for subject 39's preferred size was -3.2 cm. However, when the bust or waist ease was -1cm, and garment sizes would be eliminated in order to provide reliable fit perceptions. For subject 39, the negative for bust ease values may be due to body and garment size measurement errors; (3) the preferences of individual customers. The personal preferences of customers can be attributed to various reasons, such as age, lifestyle, body shape, etc. In addition, prediction errors are not uncommon, complete accuracy being rarely achieved when predicting a person's clothing size based on his or her body measurements (Bradtmiller, 2015).

4.4.2 Influence of Key Indicator Selection on Size Recommendation Accuracy

In the size recommendation model, key measurements commonly used in the size table serve as important indicators that significantly impact the overall fit of the garment. For instance, the measurements of bust, waist, shoulder, and height collectively contribute to the recommendation of shirt sizes in female shirt experiments. The key indicators selection will be influenced on the size recommendation accuracy. To comprehensively demonstrate the influence of indicator selection, comparative experiments using various combinations of indicators were conducted in two shirts. Based on the sizes listed in the female shirt size chart, the indicator combinations are divided into two clusters: 3 indicators and 2 indicators, to assess the size recommendation accuracy. Table 4-9 shows the recommendation accuracy of different indicator combinations in the comparison experiments.

Table 4-9 Comparative Results of the Recommendation Accuracy for Different Combinations of Indicators

Garment	Clusters	Combinations	Top1 Accuracy	Top2 Accuracy	Top3 Accuracy
Shirt A	**4 indicators**	**Bust & Waist & Shoulder & Height**	**63.5%**	**82.7%**	**90.4%**
	3 indicators	Bust & Waist & Shoulder	38.5%	67.3%	80.8%
		Bust & Waist & Height	59.6%	82.7%	86.5%
		Bust & Shoulder & Height	55.8%	75.0%	88.5%
		Waist & Shoulder & Height	50.0%	71.2%	84.6%
	2 indicators	Bust & Waist	38.5%	61.5%	76.9%
		Bust & Shoulder	32.7%	59.6%	75.0%
		Bust & Height	53.8%	75.0%	88.5%
		Waist & Shoulder	28.8%	55.8%	63.5%
		Waist & Height	46.2%	63.5%	76.9%
		Shoulder & Height	42.3%	55.8%	69.2%
Shirt B	**4 indicators**	**Bust & Waist & Shoulder & Height**	**56.9%**	**80.4%**	**96.1%**
	3 indicators	Bust & Waist & Shoulder	52.9%	80.4%	90.2%
		Bust & Waist & Height	52.9%	72.5%	92.2%
		Bust & Shoulder & Height	47.1%	64.7%	84.3%
		Waist & Shoulder & Height	49.0%	78.4%	90.2%
	2 indicators	Bust & Waist	51.0%	76.5%	90.2%
		Bust & Shoulder	35.3%	70.6%	86.3%
		Bust & Height	45.1%	66.7%	86.3%
		Waist & Shoulder	52.9%	78.4%	86.3%
		Waist & Height	37.3%	70.6%	92.2%
		Shoulder & Height	27.5%	52.9%	66.7%

As shown in the table, among the two female shirts with different levels of fit, the top 3 accuracies of different clusters are lower than the accuracy achieved by the combination of 4 indicators, namely bust, waist, shoulder, and height. However, it should be noted that a higher number of indicators does not necessarily guarantee higher accuracy. The experimental comparative results suggest that 2 indicators yield superior predictive accuracy compared to 3 indicators. For instance, in the female shirt A experiment, the combination of bust and height demonstrates the highest performance among the 2 indicators, surpassing the accuracy achieved by many of the 3 indicators with an overall accuracy of 88.5%. The accuracy of size recommendation varies depending on the combination of different indicators, which reflects the influence of different dimensions on overall fit. In the experiment of regular-fit shirt A, it can be seen that the significant role of bust and height in determining the accuracy of size recommendation. In the experiment of tight-fit shirt B of female, waist has the highest accuracy with any combination of indicators. The weighting feature of the size recommendation model assigns different weights to garment ease of each dimension based on its importance, as well as the garment style.

According to the experimental results, the combination of 4 indicators, namely bust, waist, shoulder, and height, achieved the highest accuracy, which can respectively cover the applicability of clothing in terms of circumference and length. Based on the comparative results of the experiment, it is recommended that customers provide their body measurements as comprehensively and accurately as possible in order to improve the accuracy of size recommendations.

4.5 Inter-method Comparative Evaluation

A comparative evaluation of the proposed new size recommendation method was carried out, utilizing a commonly used traditional size recommendation method for the same category.

Two rounds of comparison have been conducted between the proposed new method and the traditional method. The basic principle of traditional size recommendation is comparing one or two body measurements with the corresponding sizes in the relevant size chart of a particular garment style (Hajjar et al., 2021; Meunier, 2000; Pierola et al., 2016). This simple heuristic recommendation method is still commonly used during current online shopping. In traditional online purchasing, customers often choose a garment size based on more generally available data information. They usually considered height to be the key dimension and combined it with one of other measurement, such as that of bust, waist or shoulder to select their garment size. In order to be consistent in other comparative experiments, three combinations, namely height with bust, height with waist, height with shoulder, have been collected so as to provide size options for the target customers. Look the size chart, if the customer's measurements belong to the assigned size of a combination of any two key dimensions, the corresponding sizes are selected, with the subjects wearing all available sizes and then choose the preferred size. The same subjects and garments are used in for both method with comparative evaluation so as to avoid bias. According to the experimental results, the accuracy of the female shirt A recommendation by the traditional simple heuristic recommendation method was 25.0% for top1, 42.3% for top2 and 59.6% for Top3. Using the same process is for female shirt B, the accuracy results were 19.3% for top1, 39.7% for top2 and 43.5% for top3. Similarly, the experimental results of male shirt (shirt C & D) are also listed (Table 4-10).

The main issue observed in this study regarding current online size recommendation is the low rate of garments purchased online matching the customers' expected size, which leads to a high return rate. To address this issue, a novel method has been developed that provides higher accuracy in size recommendation. The experiment results of two round comparisons are shown in Table 4-10, from clearly demonstrating that the size recommendation method outperforms a commonly used simple heuristics method in three metrics, specifically in terms of production accuracy. Furthermore, as shown in the table, the experiment results for female shirt A indicate that the proposed method achieves a matching rate as high as 90.4%, whereas the comparative simple heuristics model only achieves a matching rate of 59.6%. Meanwhile, for female shirt B, the size recommendation method outperformed the simple heuristic method in terms of top 1, top 2, and top 3 accuracies, with an overall accuracy rate of approximately 96.1%. For male shirts, the size recommendation methods have outperformed simple heuristics. In addition, the simple heuristic method cannot provide on misfitting information and requires customers to choose fit size by trial and error, which leaves customers uncertain about which size they should buy.

Table 4-10 Comparative Results Between Our Size Recommendation Method and a Traditional Simple Heuristic Method

Gender	Garment	Method	Top1 Accuracy	Top2 Accuracy	Top3 Accuracy
Female	Shirt A	New Method	63.5%	82.7%	**90.4%**
		Simple Heuristics	25.0%	42.3%	59.6%
	Shirt B	New Method	56.9%	80.4%	**96.1%**
		Simple Heuristics	19.3%	39.7%	43.5%
Male	Shirt C	New Method	66.2%	78.4%	**89.2%**
		Simple Heuristics	29.1%	37.0%	57.9%
	Shirt D	New Method	62.2%	81.1%	**90.5%**
		Simple Heuristics	35.3%	43.5%	61.2%

4.6 Chapter Summary

This chapter presents a novel method that can assist customers in identifying appropriate sizes based on vague and uncertain size information and which provides customers with the fit evaluation bases as to how each body dimension is accommodated within each recommended size, thereby improving accuracy and ease of use. This study broken down into three steps: (1) Analyze the impact of key body measurements on garment size and explore the relationship between human body and garment fitting dimensions. (2) Prioritize key measurements based on their influence on the overall fit of the garment. (3) Suggest the best three fitting sizes, while offering customers an optimal fitting garment evaluation of each recommended size.

This chapter examined the influence of key indicator selection on the accuracy of sizing predictions, thereby emphasizing the importance for consumers to provide comprehensive body measurements when shopping in order to enhance the accuracy of sizing recommendations. In addition, comparative experiments involving two different styles of shirts, showed that the proposed new model outperformed traditional size recommendation methods.

In the slow progress of online shopping and e-commerce, such a study can resolve the ongoing problem of ill-fitting garments due to the inappropriate size of the online selection, enabling online shoppers to purchase better fitting clothing, as well as increase online sales and reduce product return rates.

CHAPTER 5. AUTOMATIC CUSTOM PATTERN GENERATION

5.1 Introduction

Grading is an integral and inseparable component of garment production when creating patterns in multiple sizes (M. M. Islam et al., 2020). In apparel manufacturing, numerous methods have been developed to ensure precise pattern grading. However, many traditional grading systems have inherent drawbacks. One prominent issue is the use of uniform grading increments, which can result in fit problems for individuals who do not conform to the average size (Bye et al., 2008b). By relying on such proportional grading techniques, the pattern may overlook the unique variations in body shapes and sizes among individuals. Building upon the understanding on the relationship between body measurements and garment sizes, the development of IPP system is to improve garment fit. In Chapter 4, development II introduces a groundbreaking size recommendation method designed to determine the most appropriate size for RTW garments. Building upon this foundation, Chapter 5 delves into the implementation of an optimized grading method, aiming to automatically generate customized clothing patterns tailored to individual customers' diverse body shapes, thereby ensuring an optimal fit that aligns precisely with market demands.

The framework of automatic custom pattern generation is shown in Figure 5-1. Four main steps are involved in this development to optimize the grading rules and realize auto-grading techniques. By inputting the body measurements of the base body and garment sizes of the base pattern, as well as the measurements of the target body sizes, the graded garment sizes for the target populations can be calculated. In current RTW grading techniques, the grading increment is obtained from a garment size chart and is evenly distributed at key grading points. The proportional grading method is applied across all body types in garment production. However, not all customers have ideal body shapes, so the current grading distribution may not be suitable, leading to dissatisfaction and fitting issues with RTW garments. Based on the limitations of proportional grading techniques, this study emphasizes the alteration of graded patterns and grading distributions at key grading points to better accommodate the fit requirements of customers with diverse body shapes. Two sets of grading rules are established: proportional grading rules for average body shapes and new grading rules for non-average body shapes. The results undergo rigorous testing through virtual try-on and real sample trial on different datasets that encompass diverse body shapes, sizes, and garment styles.

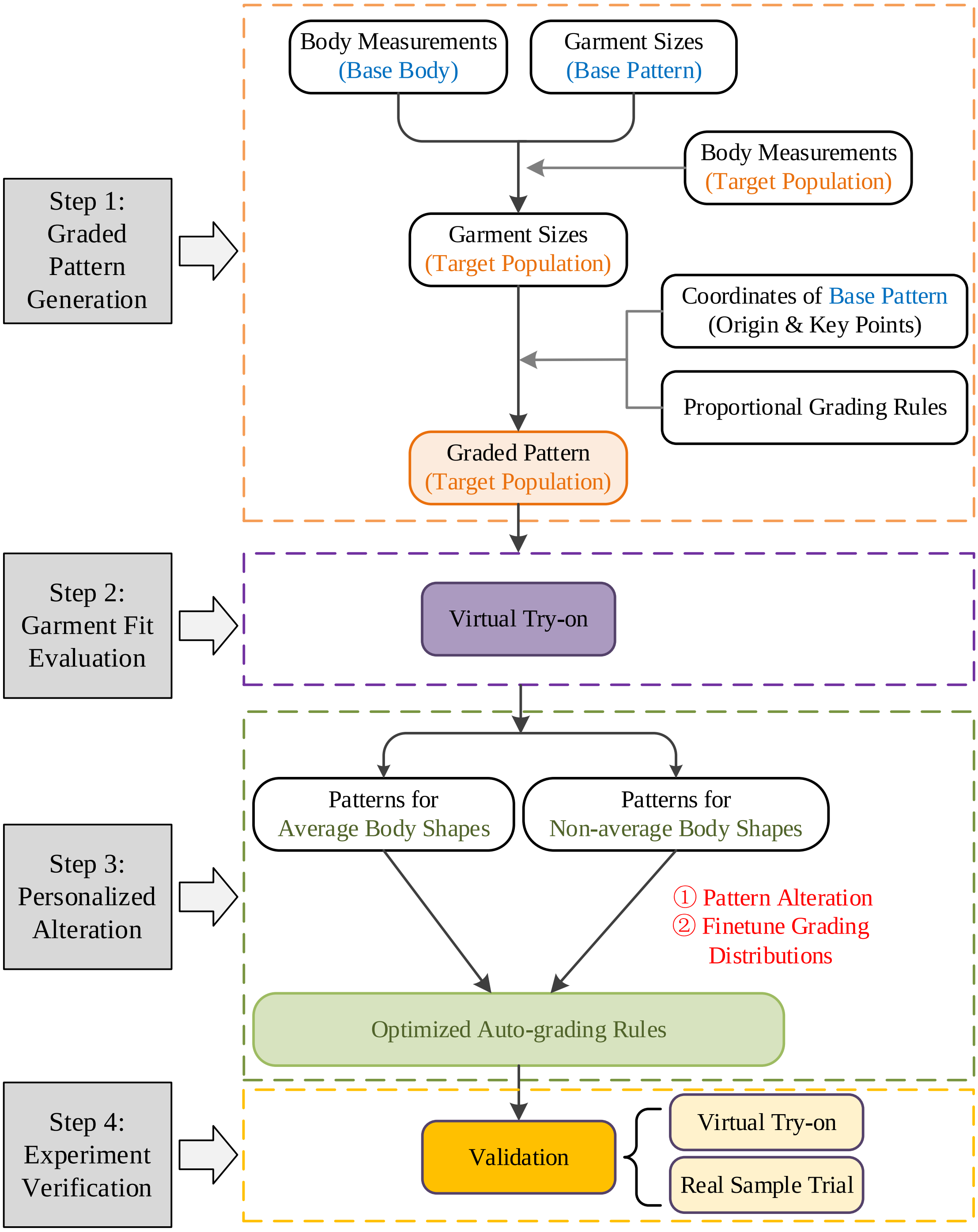


Figure 5-1 The Framework of Automatic Custom Pattern Generation

5.2 Method

This proposed method seeks to enhance grading techniques to conform with the demands of the current market. The development of this method involves four main parts: Firstly, evaluating the effectiveness of proportional grading techniques in accommodating various body sizes and shapes. Secondly, identifying and consolidating fitting issues by garment fit evaluation. Thirdly, finetuning the pattern based on the fit issues, while redefining the grading distributions at key points for non-average body shapes. Finally, testing the proposed optimized grading method on different datasets that comprise varied body shapes, sizes, and garment styles while conducting quantitative and qualitative evaluations to gauge the validity and reliability of the methodology.

In this study, two proportional grading techniques that commonly used in garment production were utilized to assess fit problems (Handford, 2003; Jeanne Price, 1996).The grading results undergo rigorous testing in VStitcher to evaluate the fitting effect on different shapes and sizes. Subsequently, produced real samples were employed to validate and evaluate the proposed method.

Base Pattern & Fit Model

This study focuses on using female shirts as an example to demonstrate the process of optimized automatic grading method. The garment sizes of the based shirt M and measurements of corresponding based fit model Women 34 are shown in Figure 5-1.

Table 5-1 The Garment Sizes of Female Shirt and Body Measurements of Fit Model

Garment	Bust (cm)	Waist (cm)	Across Shoulder (cm)	Sleeve length (cm)	Back length (cm)	Height (cm)
Base Shirt M	92.5	90.2	39.4	60.1	58.7	\
Fit Model	**Bust (cm)**	**Waist (cm)**	**Shoulder Width (cm)**	**Armlength (cm)**	**SNP*-Back Waist (cm)**	**Height (cm)**
Women 34	86.0	72.0	38.5	56.0	43.4	164.0

*SNP: Side Neck Point

Target Population

In order to evaluate the effectiveness of proportional grading techniques in accommodating various body sizes and shapes. Five representative forms (*Missy10, Women Intimate/Swim 40C, Plus Straight 16, Plus Straight 20* and *Plus Straight 38*) were selected from Avalon Body Platform to generate the graded patterns, comprising a diverse range of sizes and shapes across various regions (as displayed in Figure 5-2). The body size specifications of five body forms are shown in Table 5-2.

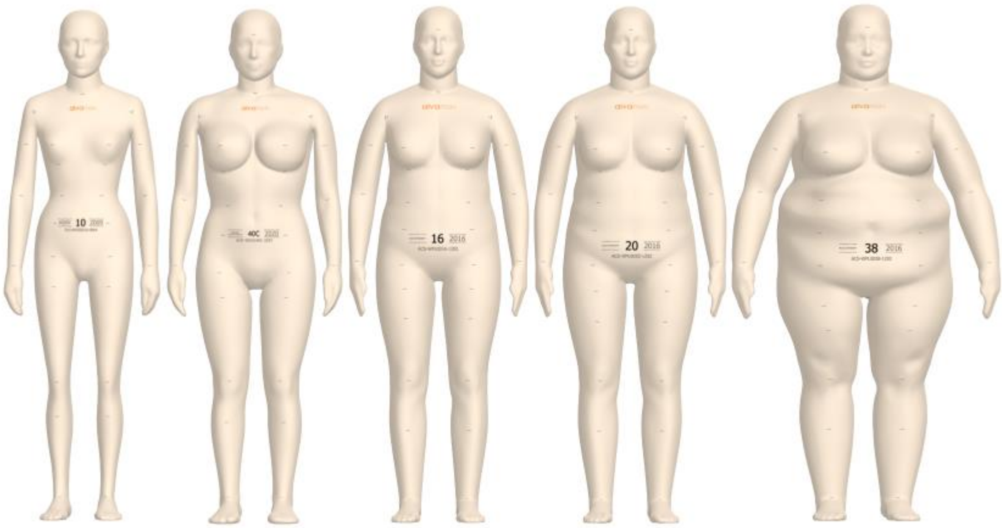


Figure 5-2 Five Representative Body Forms: Missy10, Women Intimate/Swim 40C, Plus Straight 16, Plus Straight 20 and Plus Straight 38

Table 5-2 The Body Size Specifications of Five Avatars

Avatars	Bust (cm)	Waist (cm)	Shoulder Width (cm)	Armlength (cm)	SNP-Back Waist (cm)	Height （cm）
Missy10	82.5	60.0	38.0	58.0	40.5	164.0
Women Intimate/ Swim 40C	108.5	80.0	40.0	58.6	44.9	170.0
Plus Straight 16	110.0	98.0	41.0	58.1	43.5	165.0
Plus Straight 20	119.5	110.0	43.0	58.9	44.0	165.0
Plus Straight 38	165.1	161.3	47.5	62.8	49.2	164.0

5.3 Experiment

5.3.1 Definition of Coordinate and Key Points

Pattern grading is the process of adjusting a garment pattern to different sizes in industrial production (Cui, 2015; Schofield & LaBat, 2005a; Taylor & Shoben, 1984). The basic principle of pattern grading is to calculate the size increments for both girth and length directions of the pattern based on the size rules for a particular style. These increments are then distributed proportionally at key points (Liu & Harlock, 1995; Schofield, 2000). In the proportional grading rules, the distribution of corresponding grading points on both the front and back pieces is consistent. For example, bust points on front and back pieces are graded with a consistent 1/4 girth increment. The proportional grading process ensures that a design can be scaled up or down to create multiple sizes while maintaining the overall proportions and style elements of the original pattern.

The grading process involves creating a mathematical model that consists of straight lines, curves, and points. This model is derived from the geometric variations observed in similar patterns. To generate patterns of varying sizes, the origin point is established on the base pattern, and then the X-coordinate and Y-coordinate are determined. New points are obtained by calculating the grading increments in each grading point and applying them to the X and Y axes accordingly. These new points are connected to form patterns for garments in different sizes. All the increases and decreases in the different-sized pattern pieces are based on the point movements on the base pattern within the axis. The grading points used for grading increments are corner points, dart points, key dimensions points, etc. (Moore et al., 2001; Taylor & Shoben, 1984). The coordinate axis, the origin and grading points are set for female shirt M, as shown in Figure 5-3.

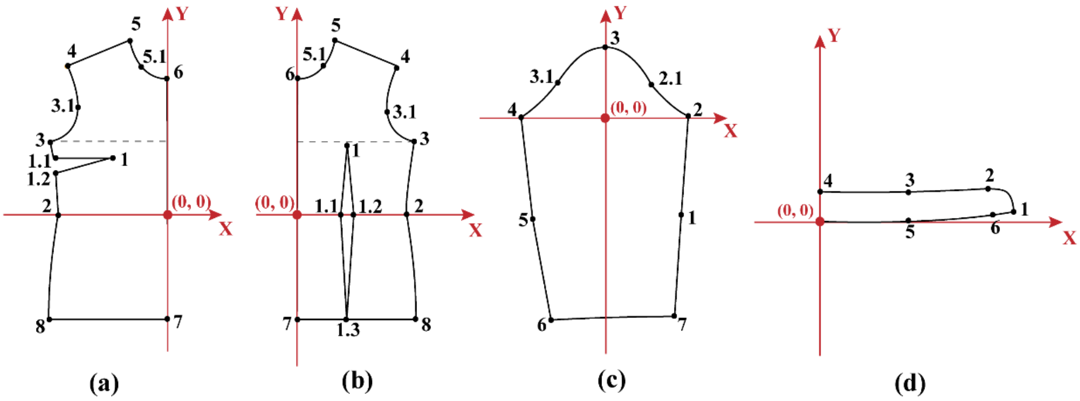


Figure 5-3 The Coordinate Axes and Grading Points for Pattern Pieces of Female Shirt M: (a) Front Piece; (b) Back Piece; (c) Sleeve; (d) Collar.

5.3.2 Calculation of the Grade Increment

This step involves determining the key dimension, grading increments between different sizes and grading distributions across the pattern piece. In general, the three key body girth measurements that are commonly used are the bust, waist, and hip. For the vertical grade, back length, height and arm length are important for length variations. These measurements are taken into consideration to ensure the appropriate changes in the patterns. Grading increments are derived from the difference between garment sizes. When the base garment sizes and the corresponding body measurements of the human fit model are known, the body measurements of the target population are inputted to compute the graded garment sizes. Consequently, the graded increment ($g^n{}_i$) can be obtained. The specific formulas are as follows:

$$\begin{aligned} & Gx^n.GS_i = B.GS_i + (Bx^n.BM_i - B.BM_i) \\ and & \\ & g^n{}_i = Gx^n.GS_i - B.GS_i \end{aligned} \tag{5.1}$$

where $Gx^n.GS_i$ represents the garment size of target population; $B.GS_i$ represents garment size of base pattern; $Bx^n.BM_i$ indicates the body measurements of target population; $B.BM_i$ is body measurements of human fit model for base pattern.

Take an example to illustrate, $B.GS_b$ is 92.5 cm, $B.BM_b$ is 86 cm, $Bx^1.BM_b$ of Missy 10 is 82.5 cm, the bust size of the new pattern for *Missy 10* ($Gx^1.GS_b$) can be obtained $Gx^1.GS_b$ = 92.5 + (82.5 - 86)= 89 cm. $g^1{}_b$ can be calculated as $g^1{}_b$ =89 - 92.5 = - 3.5 cm. The graded sizes of shirts for other avatars are calculated in Table 5-3. Therefore, the bust increments between base bust size and graded bust sizes can be obtained as -3.5 cm, 22.5 cm, 25.0 cm, 33.5 cm and 79.1 cm.

Table 5-3 The Graded Shirt Sizes and Bust Grade Increments for Five Avatars

Garment Sizes	Bust (cm)	Waist (cm)	Sleeve length (cm)	Back length (cm)
Missy10	89.0	86.7	62.1	55.8
Women Intimate/ Swim 40C	115.0	112.7	62.7	60.2
Plus Straight 16	117.5	115.2	62.2	58.8
Plus Straight 20	126.0	123.7	63.0	59.3
Plus Straight 38	171.6	169.3	66.9	64.5

5.3.3 Transformation of grading increments.

The calculation of grade increments can be used to assign distributions to various parts of the pattern pieces in this step. From grading increments to grading distributions, the data must be transformed into grading points. Identifying the grading principle of each point is a crucial step in grading practice. In this study, one of the purposes was to assess the garment fit developed from proportional graded patterns to improve the grading distributions at each key points. Therefore, two different specification grading methods that commonly used in current apparel market were collected (Handford, 2003; Price et al., 1996). The two grading methods specify the different distributions of the grade within the pattern block (Figure 5-4). Totals are based on 1 1/2-inch grade. In grading practice, this may be converted to a 1 ratio grade for convenience. The grading points for circumference and length follow the same grading distributions, which involves using the bust grading amount. The grading distributions of female shirt M are displayed in Figure 5-5 with a 1/4 ratio grade.

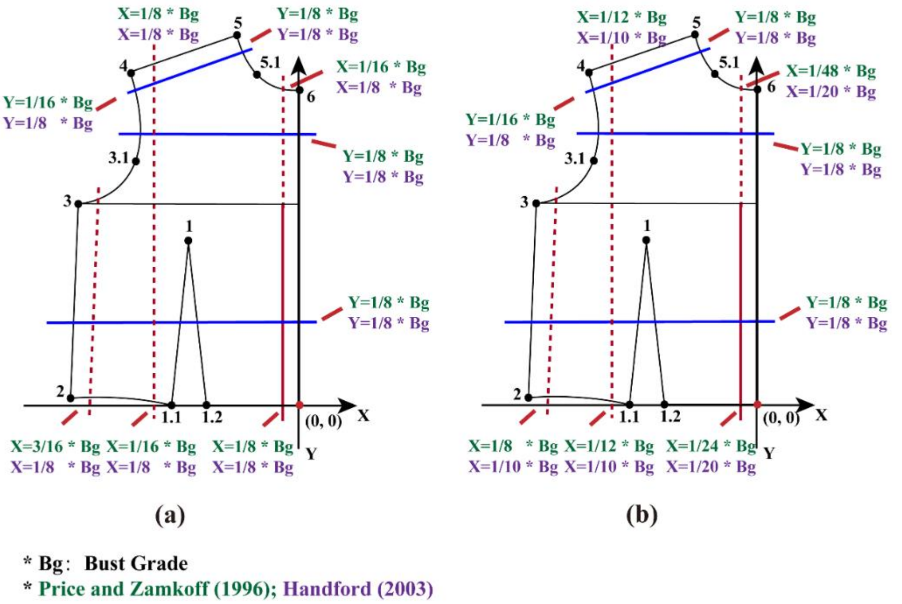
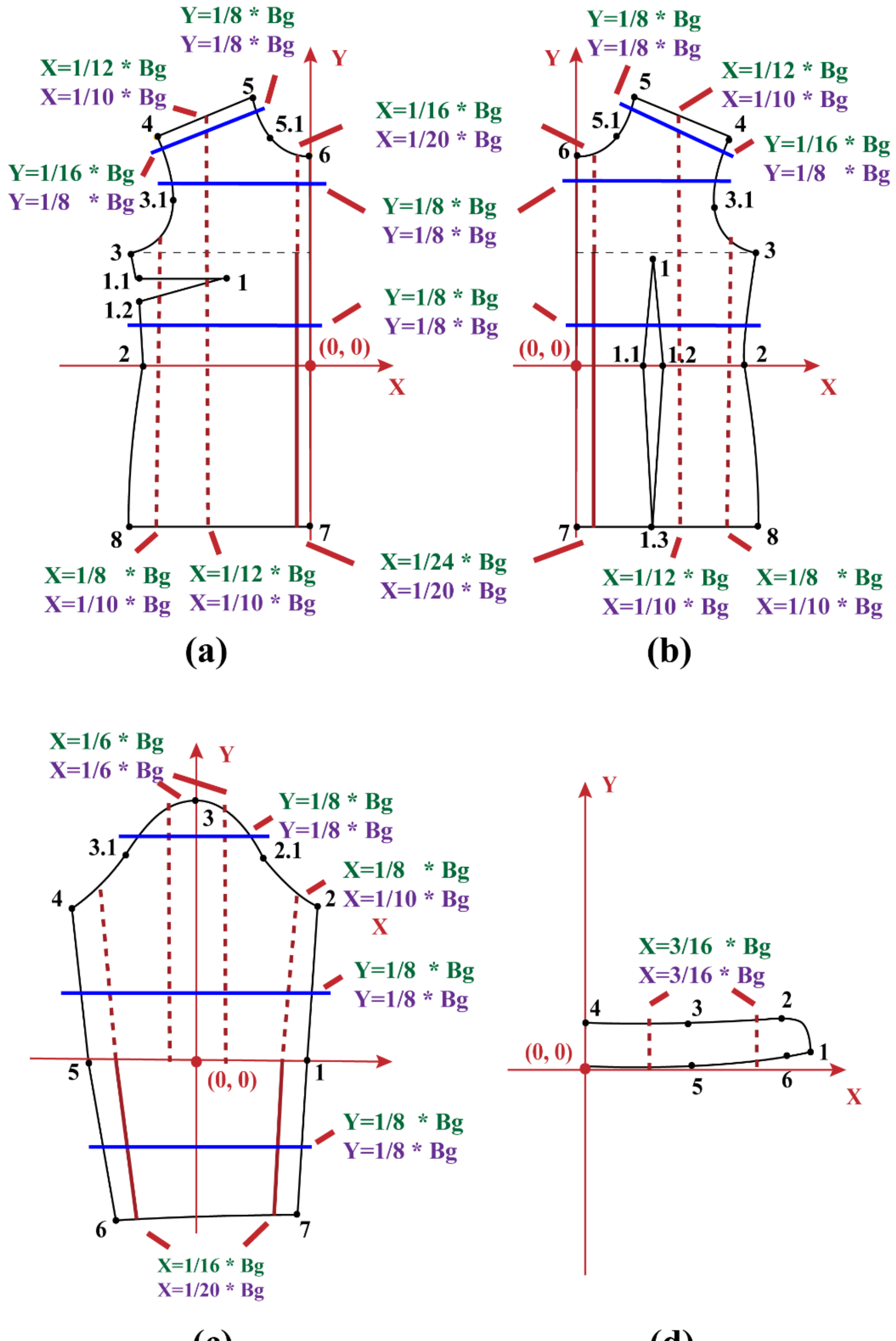


Figure 5-4 Traditional Grading distributions of the Basic Bodice: (a) 1 1/2 Ratio Grade; (b) 1/4 Ratio Grade (Price et al., 1996) & (Handford, 2003).



* Bg: Bust Grade

* Price and Zamkoff (1996); Handford (2003)

Figure 5-5 Two Proportional Grading distributions for Female Shirt M (Price et al., 1996) & (Handford, 2003)

Based on the distributions of two grading principles, the movement of each grading point in the X and Y axis can be obtained. All point movements in the pattern grading process are determined by the distribution ratios specified in the reference lines of grading principles. It is important to note that each point's movement is not considered independently but rather in relation to the position and increments of adjacent points. Moreover, all movements are executed in alignment with or perpendicular to the original grain line of the pattern (Han et al., 2015b; N. A. Schofield, 2007). This maintains the overall integrity and consistency of the pattern, resulting in accurate and proportional size variations.

Points share consistent movement rules within the area of the same reference line of the pattern, ensuring that the point movements maintain proportional within a specific area of the pattern to prevent distortion. Each grade ratio represents the cumulative effect of the successive shifts made to reach a particular point in the grading process (N. A. Schofield, 2007), reflecting the combined influence of the incremental movements performed during shifting. It's important to note that the signs used for the coordinates (horizontal and vertical) may vary depending on the orientation of the pattern piece. For instance, in the grading principle proposed by Price et al. (1996), point 2 and point 3 share the same horizontal increment of 1/4 * *Bg,* but different vertical increment of 0 and 1/8 * *Bg*, respectively. Similarly, point 3 and point 3.1 have the same vertical increment of 1/8 * *Bg* but differ in horizontal increment with 1/4 * *Bg* and 1/8 * *Bg*. Therefore, suppose that P^n is the grading point in the base pattern and the total increments are *a* and *b* in X and Y axis. Different ratios in horizontal and vertical are defined as: $R = \{R^h{}_1, R^h{}_2, R^h{}_m\}$ and $R = \{R^v{}_1, R^v{}_2, \ldots R^v{}_m\}$, respectively. The increments in X ($N.dx^n$) and Y($N.dy^n$) axis of the new point $N.\ P^n$ can be defined by Eq. (5.2):

$$
\begin{aligned}
&N.\,dx^n = a \times (R^h{}_1 + R^h{}_2 + \ldots + R^h{}_m) \\
&and \\
&N.\,dy^n = b \times (R^v{}_1 + R^v{}_2 + \ldots + R^v{}_m)
\end{aligned}
\tag{5.2}
$$

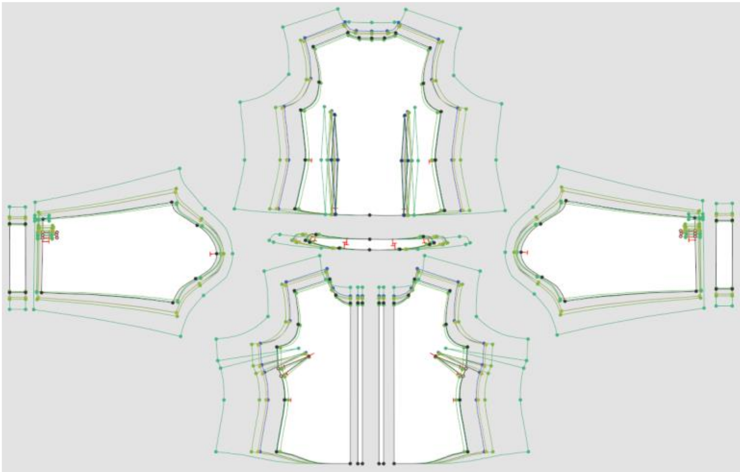
According to Eq. (5.2), the movements of all grading points in the X and Y directions can be summarized. Table 5-4 shows the movements of grading points in front piece. Once the coordinate, grading points and grade increment are determined, the amount of decrease and increase in the X and Y directions can be calculated for all grading points.

Table 5-4 The Movements of Grading Points in Front Piece for Graded Shirts

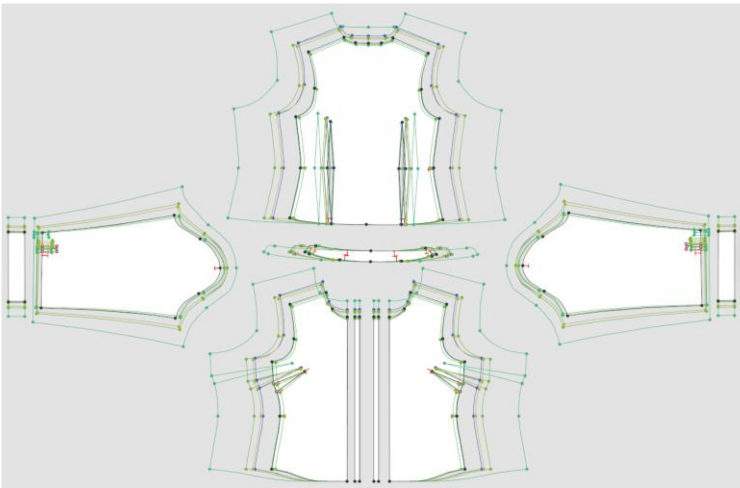
Points	Axis	Missy10 (cm)	Women Intimate/ Swim 40C (cm)	Plus Straight 16 (cm)	Plus Straight 20 (cm)	Plus Straight 38 (cm)
1	X	0.4	-2.8	-3.1	-4.2	-9.9
	Y	-1.0	0.5	0.1	0.2	1.9
1.1	X	0.9	-5.6	-6.3	-8.4	-19.8
	Y	-1.0	0.5	0.1	0.2	1.9
1.2	X	0.9	-5.7	-6.3	-8.4	-19.8
	Y	-1.0	0.5	0.1	0.2	1.9
2	X	0.9	-5.6	-6.3	-8.4	-19.8
	Y	0.0	0.0	0.0	0.0	0.0
3	X	0.9	-5.6	-6.3	-8.4	-19.8
	Y	-1.0	0.5	0.1	0.2	1.9
3.1	X	0.4	-2.8	-3.1	-4.2	-9.9
	Y	-1.0	0.5	0.0	0.2	1.9
4	X	0.4	-2.8	-3.1	-4.2	-9.9
	Y	-2.4	1.3	0.1	0.5	4.8
5	X	0.2	-0.9	-1.0	-1.4	-3.3
	Y	-2.9	1.3	0.1	0.6	5.8
5.1	X	0.1	-0.5	-0.5	-0.7	-1.7
	Y	-1.9	1.0	0.1	0.4	3.9
6	X	0.0	0.0	0.0	0.0	0.0
	Y	-1.1	1.0	0.1	0.42	3.9
7	X	0.0	0.0	0.0	0.0	0.0
	Y	0.0	0.0	0.0	0.0	0.0
8	X	0.9	-5.6	-6.3	-8.4	-19.8
	Y	0.0	0.0	0.0	0.0	0.0

5.3.4 Graded Pattern Generation

Two proportional grading techniques are graded based on bust increments and applied in the X and Y directions. The graded patterns were generated for five body forms, as shown in Figure 5-6.



(a)



(b)

Figure 5-6 Graded Pattern Generation by Two Proportional Grading Techniques: (a) Proportional Grading Techniques Developed by Price et al. (1996); (b) Proportional Grading Techniques Developed by Handford (2003).

5.4 Results and Discussion

5.4.1 Automatic Pattern Generation for Female Shirt

5.4.1.1 Garment fit evaluation

The grading process was conducted digitally using VStitcher software on 2D patterns, incorporating various shapes and sizes of the five Alvanon female forms and enabling the visualization of the pattern simulation in a virtual environment to achieve precise and consistent results, as displayed in Figure 5-7.

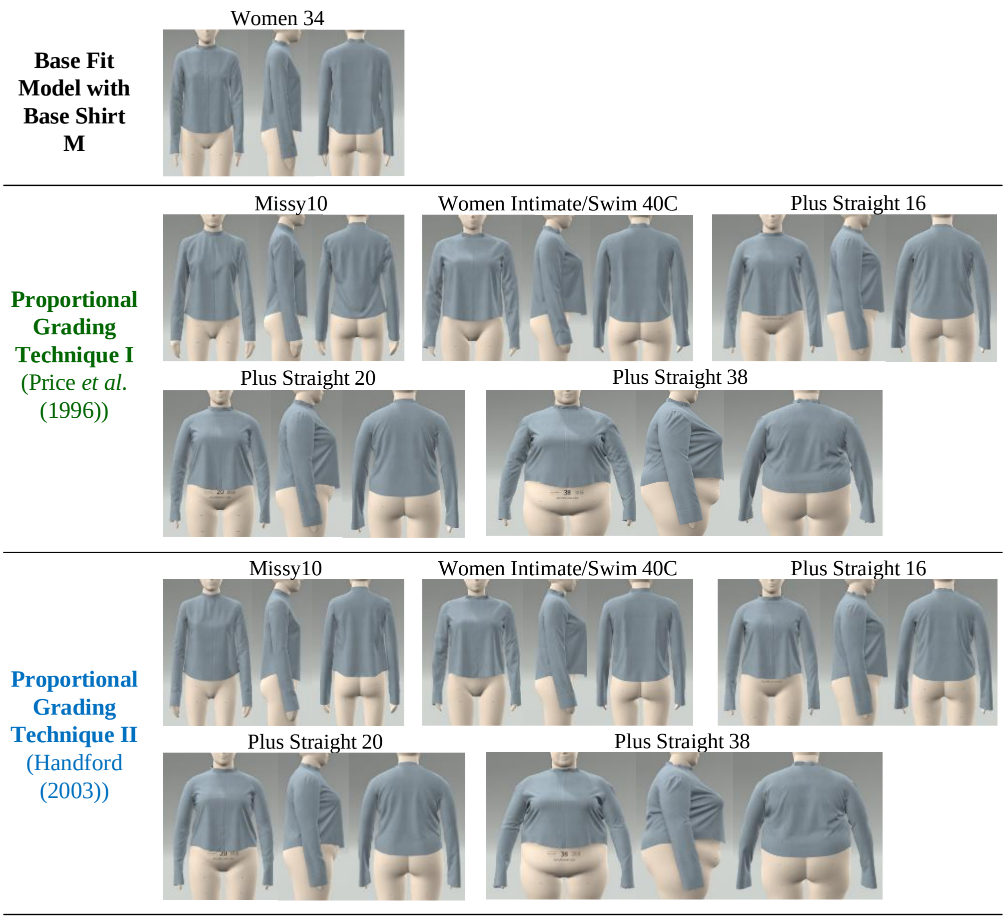


Figure 5-7 Virtual Fitting Results of Female Shirt with Two Proportional Grading Techniques (upper: Price et al. (1996); lower: Handford (2003))

According to the comparisons of grading distributions, the two grading techniques of Price et al. (1996) Handford (2003) had some limitations. Firstly, relying solely on bust size for determining both horizontal and vertical grading is not a reliable approach. Due to the fact that individuals with different heights may have the same bust measurement. For instance, consider two individuals with heights of 170 cm and 150 cm, both having a bust measurement of 100 cm. The grading method assigned them the same size and the garment would be too short for the person with a height of 170 cm. Therefore, it is crucial to consider other dimensions such as garment length and sleeve length in the vertical grading of both garments and sleeves, which is consistent with the previous research (Muhammad Sayem et al., 2014; Schofield & LaBat, 2005b). Secondly, the inconsistent grading distribution of the upper and lower parts of the pattern leads to twisted distribution proportions. In the Price's technique, the grading ratios differ for the upper and lower areas based on the bust datum line in front-centre part of the main bodice, which can lead to distortions in the garment patterns. Finally, there is a discrepancy between the grading ratios used for collar and the neck in the main body of the pattern in Handford's technique, which leads to a misalignment issue.

In terms of virtual try-on, the graded patterns of both Price et al. (1996) and Handford (2003) techniques illustrated poor fitting on larger forms with low bust-to-waist ratios or larger bust girth, such as *Women Intimate/Swim 40C, Plus Straight 16, Plus Straight 20* and *Plus Straight 38*. More specifically, the discrepancies between these two techniques were evident around the shoulder area, resulting in longer sleeve lengths. Price's technique distributed more grading around the middle torso, leading to wider shoulders than Handford's method. This issue was more prominent on larger forms because grading amounts are greater for larger sizes, making distribution discrepancies more noticeable. Meanwhile, due to the larger and more prominent of the female bust, the front piece tended to arch at the bust area, resulting in the accumulation of folds in the underarm and subsequently leading to a shorter front length. In addition, even grading distributions lead to extra folds. The virtual try-on results indicated that larger forms with larger busts experience a tighter fit in the front piece. Additionally, there is an accumulation of extra folds in the back waist, and tightness is observed at the hem position. In fact, in the side view of the human body, it becomes apparent that larger body forms exhibit variations in the back protrusion, back waist point, and hip protrusion compared to the average body shape. The differences can be observed and reflected in the virtual try-on. It is important to take into account these specific body characteristics during the pattern grading process to ensure a proper and comfortable fit for individuals with non-average body shapes and sizes.

Hence, the personalized alteration step will focus on the adjustments of grading distributions at key points in terms of five aspects to achieve optimal fit. 1) Consider the impact of length, such as back length and sleeve length, on vertical grading; 2) Ensuring uniform grade distribution based on the same baseline throughout the pattern; 3) Aligning the grade edge lines to maintain the consistency (armhole – sleeve, neck – collar, front side seam-back side seam); 4) Modifying the grading distribution in key sections of the pattern to address specific body features and proportions and 5) Increasing the front length to accommodate bust variations or body types with a lower bust-to-waist ratio.

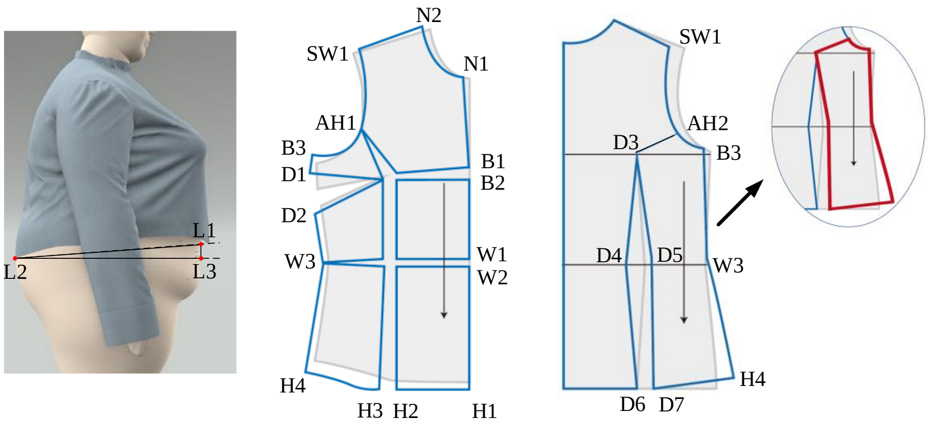
5.4.1.2 Personalized alteration

Considering the above limitations, this section aims to finetune the graded patterns for the personalized fit. Through the pattern fine tuning, the adjustments' differences are summarized and generated to establish distribution ratios applicable to other patterns. The ultimate goal is to optimize and improve the grading distributions at key points. Notably, the differences between the two distribution ratios are most apparent in the extreme sizes because the change is cumulative across the size range (Mullet, 2015). As a result, the pattern for *Plus Straight 38* is chosen as the prototype for adjustment. The principle of fine-tuning is to maintain the integrity of key grade dimensions such as bust, back length and sleeve length while adjusting the pattern to accommodate specific body characteristics and ensure the individual fit.

The adjustment reference is the fitting effect of base fit model in base shirt M. Firstly, the across shoulder was adjusted based on the shoulder width of *Plus Straight 38*. It was observed that the sleeve length in a reasonable position due to the decrease of the across shoulder. Then, to address the upward shift of bust line and shortening of the front length caused by the bust protrusion, the focus is primarily on adjusting the front pieces. By analysing the virtual fitting results of the base fit model, the front and back lengths align along the same line. Consequently, take the Price' technique as an example, for the fit model of *Plus Straight 38*, the $\triangle L_1L_2L_3$ are established. By measuring the distances L_1L_2 and L_2L_3, the length of L_1L_3 is calculated, which represents the amount of increase required for the front piece's length (as shown in Figure 5-8). The length increase L_1L_3, was then applied to the B1B2 area of the front piece, which can effectively accommodate the bust protrusion and ensure a better fit and enhanced comfort for individuals with larger bust sizes. At the same time, the width of the dart was increased to alleviate the problem of underarm folds accumulation. In the vertical area from AH1 to H2H3, the width of the front piece is increased to solve the problem of tightness in this area.

The adjustment of the back piece was relatively minor. After observing that the fitting results of other larger forms resulted in upward-trending creases in the back piece at the underarm position., by connecting the auxiliary line AH2D3, and this shifted the red area of the figure upward by the appropriate distance with D3 as the centre of the circle while also lowering the shoulder point in order to eliminate the underarm folds. Furthermore, when adjusting the front piece to increase the overall distribution ratio of the front piece, the difference was calculated and the appropriate ratio in the back piece was reduced to maintain the overall balance of the proportion. In addition, the width of hem length, namely D4H4, was also increased to alleviate tightness of hem area.

By carefully considering and adjusting both the front and back pieces, a well-fitting garment can be achieved that accommodates individual body characteristics while maintaining a balanced and aesthetically pleasing silhouette. The adjustments in both X and Y directions were recorded to calculate the new ratio so as to improve traditional grading distributions.



(a) (b)

Figure 5-8 Schematic Diagram of the Female Shirt Prototype Adjustment for the Special Body Shape: (a) Front Piece Fine-tuning; (b) Back Piece Fine-tuning.

5.4.1.3 Development of automatic grading method

Optimized grading methods were developed to cater to different body shapes, which can be categorized into two types: standard grading rulers for average body shapes and new grading rules for non-average body shapes. As shown in Table 5-5 and Table 5-6, the distributions at key points vary significantly**.** In general, individuals are close to the fit model standard, standard grading rulers are utilized. Standard grading rules are appropriately finetuned based on proportional grading techniques that suitable for average body shapes. On the other hand, non-average body shapes require a different rule. New grading rules are developed specifically to address the unique characteristics and proportions of these body shapes, which takes into account variations such as larger busts, lower bust-waist ratio, or other specific features that deviate from the average body shape. By incorporating these new grading rules, patterns can be adjusted and customized to fit non-average body shapes more accurately and comfortably.

Table 5-5 Standard Grading rules of Female Shirt for Average Body Shapes

	Front Piece		Back Piece		Sleeve				Collar		
Points	X (Bg)	Y (Gl)	X (Bg)	Y (Gl)	X (Bg)	X (Gl)	Y (Gl)	Y (Al)	X (Bg)	X (Gl)	Y (Gl)
1	-0.125	0.333	0.042	0.333	/	/	/	/	0.040	0.291	0.000
1.1	-0.250	0.333	0.042	0.000	/	/	/	/	/	/	/
1.2	-0.250	0.333	0.042	0.000	/	/	/	/	/	/	/
1.3	/	/	0.042	0.000	/	/	/	/	/	/	/
1.4	/	/	0.042	0.000	/	/	/	/	/	/	/
2	-0.250	0.000	0.250	0.000	0.240	0.180	-0.167	0.500	0.040	0.291	0.000
2.1	/	/	/	/	0.120	0.100	-0.167	0.500	/	/	/
3	-0.250	0.333	0.250	0.333	0.000	0.000	0.300	0.500	0.020	0.146	0.000
3.1	-0.120	0.333	0.100	0.333	-0.050	-0.050	-0.200	0.500	/	/	/
4	-0.125	0.950	0.125	0.833	-0.400	-0.300	-0.167	0.500	0.000	0.000	0.000
5	-0.010	1.000	0.010	1.000	/	/	/	/	0.000	0.000	0.000
5.1	-0.010	0.800	0.010	0.800	/	/	/	/	/	/	/
6	0.000	0.800	0.000	0.800	-0.200	-0.150	0.167	-0.500	0.020	0.146	0.000
7	0.000	0.000	0.000	0.000	0.120	0.090	0.167	-0.500	0.040	0.291	0.000
8	-0.250	0.000	0.250	0.000	/	/	/	/	/	/	/

Table 5-6 New Grading rules of Female Shirt for Non-average Body Shapes

	Front Piece			Back Piece			Sleeve					Collar		
Points	X (Bg)	Y (Gl)	Y (Bg)	X (Bg)	Y (Gl)	Y (Bg)	X (Bg)	X (Gl)	Y (Gl)	Y (Al)	Y (Bg)	X (Bg)	X (Gl)	Y (Gl)
1	-0.015	0.333	0.015	0.042	0.333	0.000	/	/	/	/	/	0.050	0.667	0.200
1.1	-0.250	0.333	0.050	0.042	0.000	0.013	/	/	/	/	/	/	/	/
1.2	-0.250	0.333	-0.050	0.060	0.000	0.016	/	/	/	/	/	/	/	/
1.3	/	/	/	0.042	0.000	0.013	/	/	/	/	/	/	/	/
1.4	/	/	/	0.080	0.000	0.020	/	/	/	/	/	/	/	/
2	-0.250	0.000	0.000	0.266	0.000	0.045	0.150	0.167	-0.167	0.500	0.000	0.050	0.667	0.200
2.1	/	/	/	/	/	/	0.070	0.090	-0.167	0.500	0.000	/	/	/
3	-0.250	0.333	0.100	0.252	0.333	0.040	0.000	0.000	0.167	0.500	0.040	0.025	0.333	0.100
3.1	-0.085	0.333	0.065	0.087	0.333	0.025	-0.080	-0.083	-0.167	0.500	0.020	/	/	/
4	-0.050	0.833	0.070	0.085	0.833	0.040	-0.180	-0.167	-0.167	0.500	0.000	0.000	0.000	0.000
5	-0.010	1.000	0.045	0.045	1.000	0.025	/	/	/	/	/	0.000	0.000	0.000
5.1	-0.015	0.600	0.045	0.023	0.667	0.025	/	/	/	/	/	/	/	/
6	0.000	0.500	0.045	0.000	0.667	0.025	-0.090	-0.083	0.167	-0.500	0.040	0.025	0.333	0.100
7	0.000	0.000	0.000	0.000	0.000	0.013	0.075	0.083	0.167	-0.500	0.040	0.050	0.667	0.200
8	-0.250	0.000	0.000	0.290	0.000	0.050	/	/	/	/	/	/	/	/

In the optimized grading method for shirts, the primary and secondary grading dimensions for both horizontal and vertical grading were established. For horizontal sizing, the primary grading dimension is the bust size, while the secondary dimension is the waist size. After grading, it is important to verify if the graded waist size is suitable for the corresponding fit model's waist measurement. If the waist ease (the difference between the garment's waist size and the fit model's waist measurement) is less than 0cm, a basic ease of 2cm will be added to the waist position. This additional ease ensures comfort during daily activities. The 2cm ease will be evenly distributed within the waist portion of the pattern. In vertical grading, the primary dimension is the back length, while the secondary dimension is the sleeve length. These dimensions are adjusted accordingly to achieve the desired fit and proportions for different sizes.

To realize the automatic grading technique, computer-aided technology (CAD) is adopted to facilitate the generation of customized patterns. Through CAD technology, the required measurements can be inputted and processed to generate graded patterns tailored to individual sizes. It is significant as it reduces the time of pattern development and while also improving the accuracy and consistency of the grading process.

The entire process was automated using the following steps:

- Recognizing the garment style and its pattern pieces, allowing for a targeted grading process
- Defining the grading origin and coordinates for each piece, followed by marking the grading points.

- Screening the average body shape and non-average body shape, utilizing corresponding grading rules and distributions. New coordinates were automatically generated for each point to produce the graded pattern for a target body size and shape.
- Checking the graded waist size is suitable for the corresponding fit model's waist measurement. If not, additional ease will be evenly distributed within the waist portion of the pattern.

By automating these steps, the grading process becomes more efficient, accurate, and consistent, enabling the production of graded patterns that cater to a wide range of body sizes and shapes.

5.4.1.4 Validation of the fitting of the proposed optimized grading method

To validate the effectiveness of the optimized grading method for female shirts across different body shapes, virtual try-on simulations and real garment tests were conducted. Figure 5-9 depicts the comparison of the virtual fitting results for the proportional grading techniques (Price's technique) and the optimized grading methods. Figure 5-9 shows real garment samples for four physical mannequins, serving as typical examples: *Missy10, Women Intimate/Swim 40C, Plus Straight 16*, and *Plus Straight 20.* The figure highlights significant reductions in creases around the waist area, indicating improved fitting compared to traditional grading techniques. Moreover, the shoulder area and sleeve length also witnessed noticeable enhancements. The optimized grading method adequately considers the variations in these regions, leading to a more accurate fit for diverse body shapes.

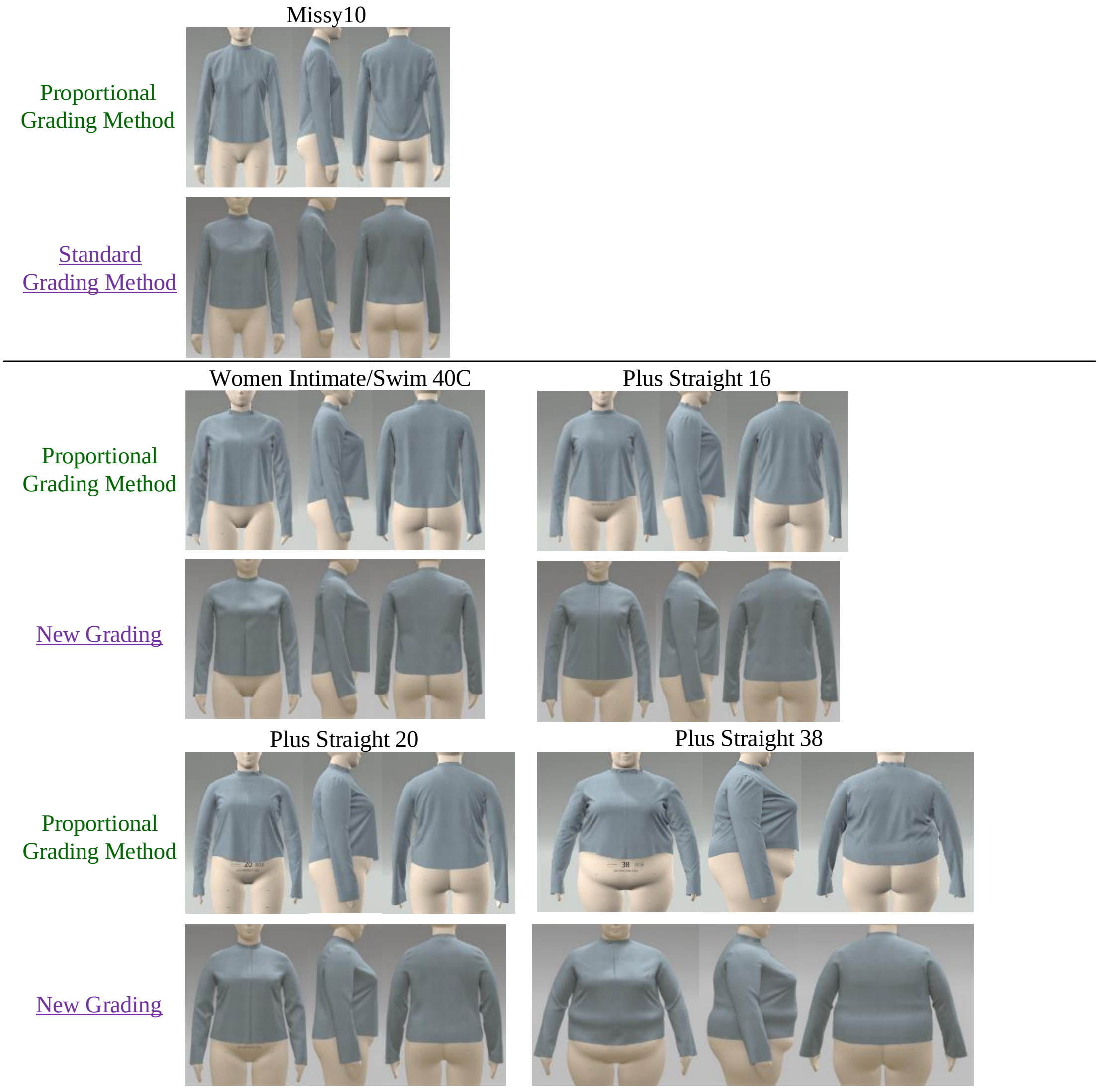


Figure 5-9 Comparison of the Virtual Fitting Results for Female Shirt

By conducting virtual try-on, the validated results affirm the effectiveness of the optimized grading method of female shirts for achieving improved fitting and addressing the fitting issues of non-average body shapes.

In addition, the outcomes of virtual fitting and real sample fitting for each size are juxtaposed against the grading technique commonly employed within the apparel company to underscore the impact and reliability of optimized grading developed in this study. Due to page limit, two distinct sizes for female body forms are selected to present the fitting results. As shown in Figure 5-10, it can be seen that garments graded in VStitcher exhibit consistent results with those produced using the apparel company's grading technique, thus affirming the reliability of virtual fitting. Also, garments graded through the optimized grading method reduce the presence of creases, particularly in larger sizes.

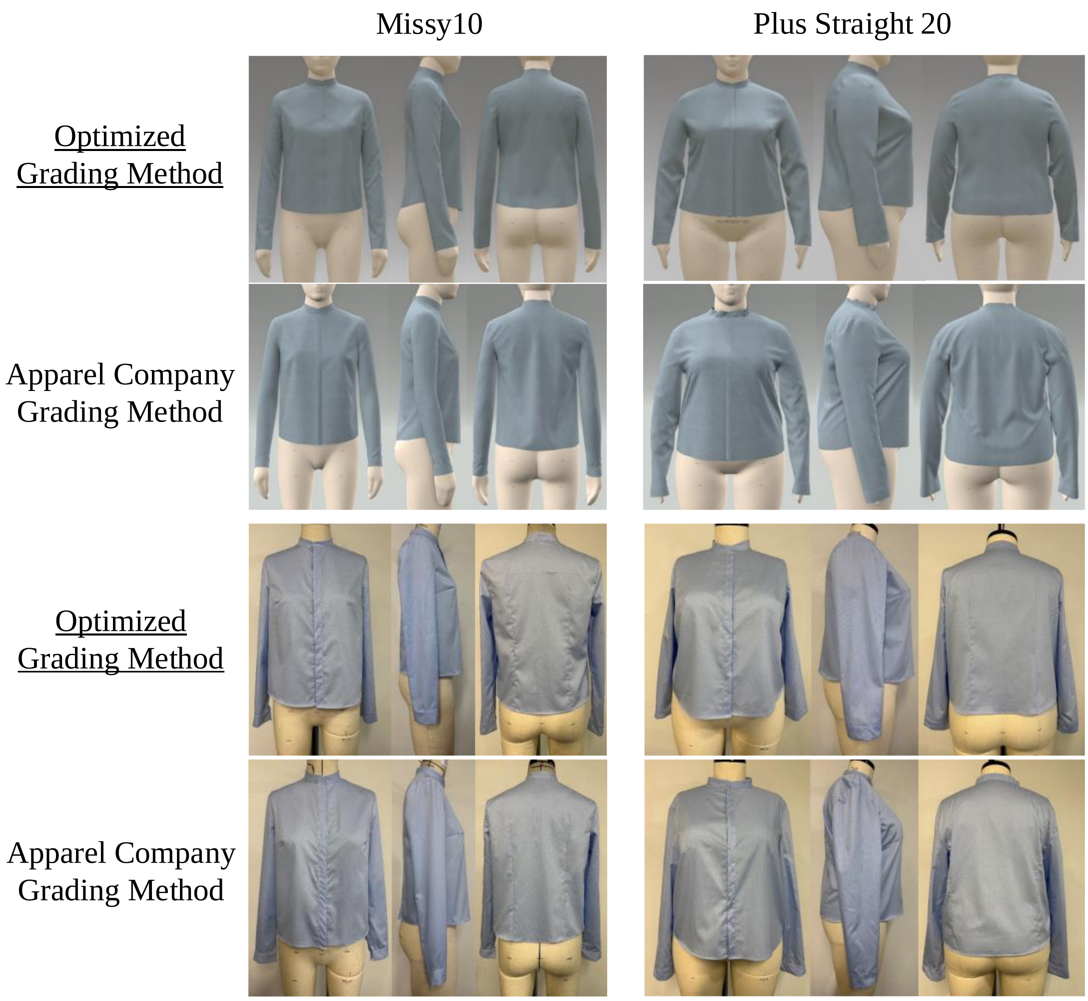


Figure 5-10 Female Shirt Comparison of Size Missy 10 and Plus Straight 20

5.4.2 Automatic Pattern Generation for Male Shirt

The same method and process were adopted for male body forms to develop the male shirt grading method. The base pattern utilized for this purpose is the Male Shirt M, with the corresponding fit model (*EU Men 48*, sourced from the Avalon Body Platform) serving as the foundation for the grading process. Four representative forms (*ASTM 46, ASTM 52, ASTM 58, ASTM 64*) are selected as the target population to represent a range of body sizes and proportions commonly encountered in the male population. The body measurements of the base model and four avatars are listed in Table 5-7. By inputting base information, the relationship between the base size and the body can be studied and used to calculate graded sizes for each target body size (according to Eq(5.1)), as shown in Table 5-8.

Table 5-7 The Body Size Specifications of Five Avatars

Avatars	Bust (cm)	Waist (cm)	Shoulder Width (cm)	Armlength (cm)	SNP-Back Waist (cm)	Height （cm）
EU Men 40	101.6	86.6	40.1	60.3	40.9	174.3
ASTM 46	116.8	103.5	47.6	64.1	47.6	177.8
ASTM 52	132.1	119.4	51.1	64.1	47.0	177.8
ASTM 58	147.3	136.4	53.0	64.1	47.9	177.8
ASTM 64	162.6	150.8	55.2	64.1	48.9	177.8

Table 5-8 The Graded Shirt Sizes for Five Avatars

Garment Sizes	Bust (cm)	Waist (cm)	Sleeve length (cm)	Back length (cm)
Male Shirt M	108.0	94.0	65.5	95.0
ASTM 46	123.3	109.3	69.3	80.4
ASTM 52	138.5	124.5	69.3	81.1
ASTM 58	153.7	139.7	69.3	82.0
ASTM 64	169.0	155.0	69.3	83.0

Based on the graded garment sizes, the bust increments can be calculated as 15.3 cm, 30.5 cm, 45.7 cm, and 61 cm between base bust size and graded bust size, which represents the additional measurement added to the base bust size to achieve the graded bust size for each respective garment size. Then, the grading origin and coordinates for each piece, as well as grading points are defined as Figure 5-11.

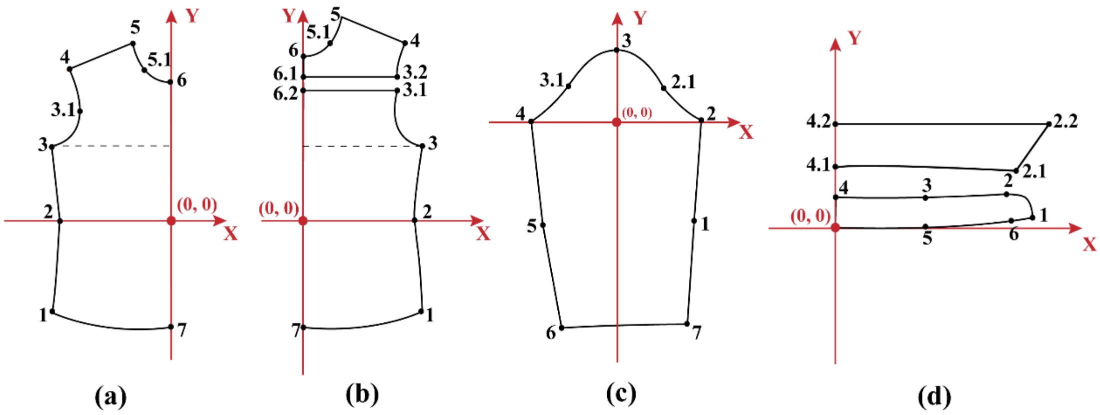


Figure 5-11 The Coordinate Axes and Grading Points for Pattern Pieces of Male Shirt M: (a) Front Piece; (b) Back Piece; (c) Sleeve; (d) Collar.

Two proportional grading techniques, methods developed by Price and Handford, were adopted for grading male shirt. To determine the movements of each grading point, Eq.(5.2) is employed to take into account the grading ratio at each specific point. Therefore, the patterns for four avatars were graded, as displayed in Figure 5-12.

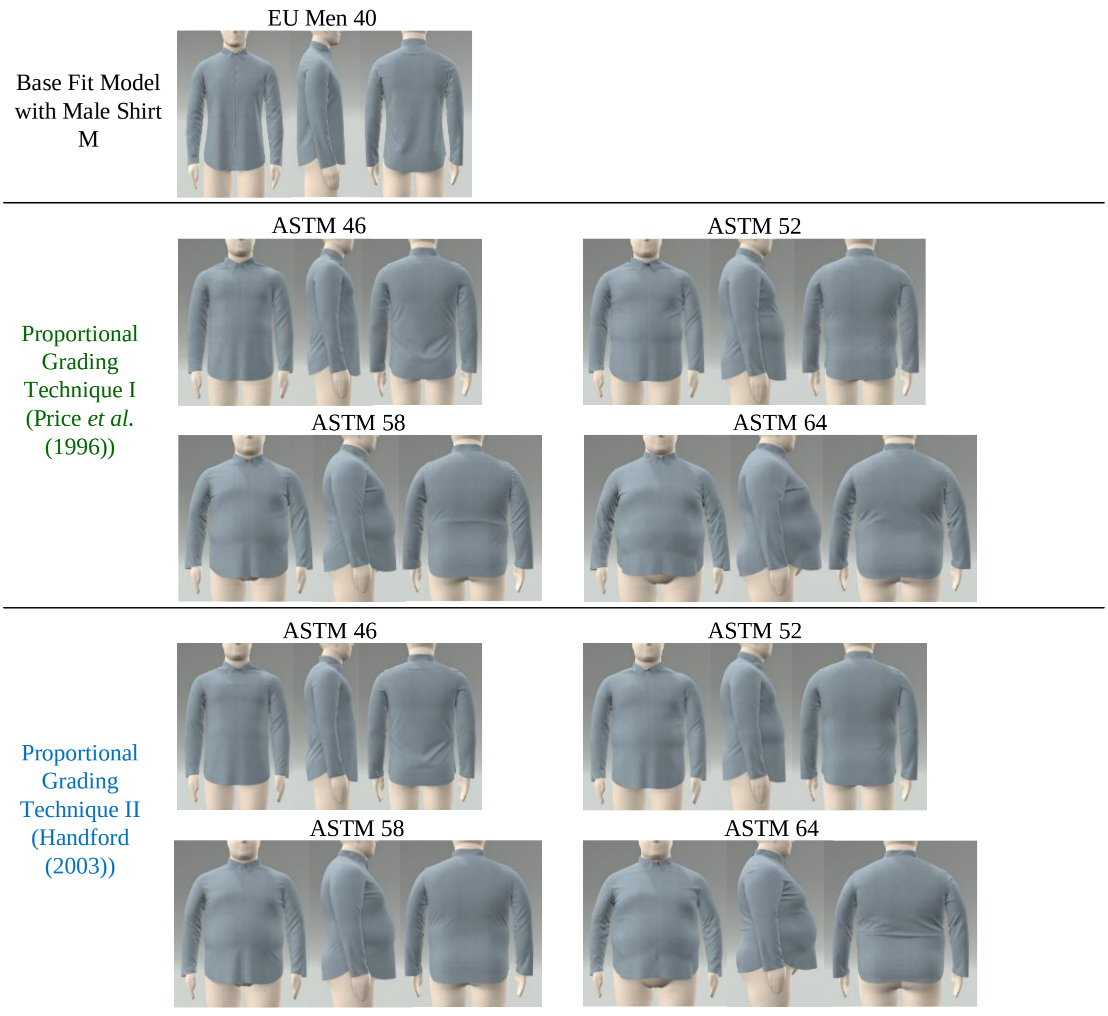
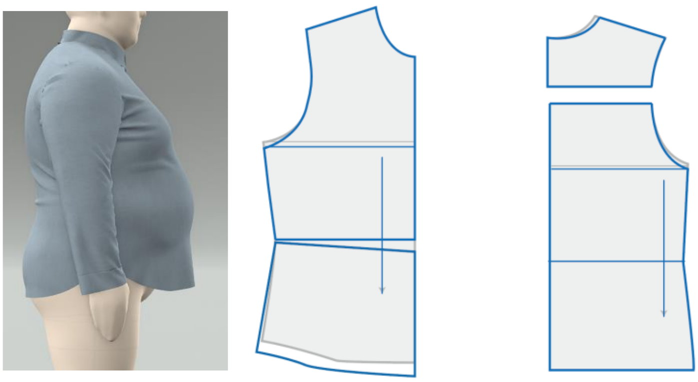


Figure 5-12 Virtual Fitting Results of Male Shirt with Two Proportional Grading Techniques (upper: Price et al. (1996); lower: Handford (2003))

According to the fitting results of male shirts, it is obvious that as the chest-waist difference becomes smaller or the waist measurement increases, the front piece of the garment tends to arch at the waist, causing the waistline to rise. Based on the fit results of the men's shirt, a noticeable trend can be observed: Additionally, tight fit around the underarm area results in constricted arm movement. Furthermore, the collar is also smaller in size and very tight. Therefore, based on the fit issues observed in male shirts, the following adjustments are recommended to address these concerns: 1) Lower the waistline: It is crucial to adequately lower the waistline to accommodate the protrusion of the waist and prevent the issue of the garment shifting upward; 2) Decrease the armhole height, ensuring that there is sufficient ease for arm movement.; 3) Increase the neck width to provide a more comfortable fit. As shown in Figure 5-13, the schematic diagram of male shirt was adjusted for special body shapes.



(a) **(b)**

Figure 5-13 Schematic Diagram of the Male Shirt Prototype Adjustment for the Special Body Shape: (a) Front Piece Fine-tuning; (b) Back Piece Fine-tuning.

The optimized grading methods were developed for diverse body shapes based on the pattern alteration. As displayed in Figure 5-11, grading points are established for male shirts. Standard grading rules and new grading rules for each point were summarized in Table 5-9 and Table 5-10.

Table 5-9 **Standard Grading Rules of Male Shirt for Average Body Shapes**

	Front Piece		Back Piece		Sleeve				Collar		
Points	X (Bg)	Y (Gl)	X (Bg)	Y (Gl)	X (Bg)	X (Gl)	Y (Gl)	Y (Al)	X (Bg)	X (Gl)	Y (Gl)
1	-0.250	-0.750	0.250	-0.750	0.143	-0.250	0.000	0.000	0.083	0.667	0.000
2	-0.250	-0.500	0.250	-0.500	0.189	-0.500	-0.167	0.500	0.083	0.667	0.000
2.1	/	/	/	/	0.143	-0.250	-0.167	0.500	/	/	/
3	-0.250	-0.500	0.250	-0.500	0.000	0.250	0.167	0.500	0.042	0.333	0.000
3.1	-0.143	-0.250	0.250	-0.500	-0.143	-0.250	-0.167	0.500	/	/	/
3.2	/	/	0.167	-0.500	/	/	/	/	/	/	/
4	-0.143	0.250	0.143	0.250	-0.189	-0.500	-0.167	0.500	0.000	0.000	0.000
5	-0.063	0.250	0.063	0.250	-0.143	-0.250	0.000	0.000	0.042	0.333	0.000
5.1	-0.031	0.667	0.031	0.250	/	/	/	/	/	/	/
6	0.000	0.250	0.000	0.500	-0.094	-0.500	0.167	-0.500	0.083	0.667	0.000
6.1	/	/	0.000	-0.500	/	/	/	/	/	/	/
6.2	/	/	0.000	-0.500	/	/	/	/	/	/	/
7	0.000	-0.750	0.000	-0.750	0.094	-0.500	0.167	-0.500	/	/	/

Table 5-10 New Grading Method of Male Shirt for Non-average Body Shapes

	Front Piece		Back Piece		Sleeve				Collar		
Points	X (Bg)	Y (Gl)	X (Bg)	Y (Gl)	X (Bg)	X (Gl)	Y (Gl)	Y (Al)	X (Bg)	X (Gl)	Y (Gl)
1	-0.250	-0.750	0.250	-0.750	0.143	-0.250	0.000	0.000	0.083	0.667	0.000
2	-0.250	-0.500	0.250	-0.500	0.189	-0.500	-0.167	0.500	0.083	0.667	0.000
2.1	/	/	/	/	0.143	-0.250	-0.167	0.500	/	/	/
3	-0.250	-0.658	0.250	-0.658	0.000	0.250	0.167	0.500	0.042	0.333	0.000
3.1	-0.143	-0.250	0.250	-0.500	-0.143	-0.250	-0.167	0.500	/	/	/
3.2	/	/	0.167	-0.500	/	/	/	/	/	/	/
4	-0.143	-0.250	0.143	0.250	-0.189	-0.500	-0.167	0.500	0.000	0.000	0.000
5	-0.063	-0.250	0.063	0.250	-0.143	-0.250	0.000	0.000	0.042	0.333	0.000
5.1	-0.031	-0.250	0.031	0.250	/	/	/	/	/	/	/
6	0.000	-0.250	0.000	-0.250	-0.094	-0.500	0.167	-0.500	0.083	0.667	0.000
6.1	/	/	0.000	-0.500	/	/	/	/	/	/	/
6.2	/	/	0.000	-0.500	/	/	/	/	/	/	/
7	0.000	-0.750	0.000	-0.750	0.094	-0.500	0.167	-0.500	/	/	/

To validate the effectiveness of the optimized grading method for male shirts on various body shapes, virtual try-on simulations were performed. The graded pattern was generated using the automatic grading technique system. In Figure 5-14, the comparison of virtual simulation results is displayed. The results show that the optimized grading method demonstrates an improved fit compared to proportional grading techniques.

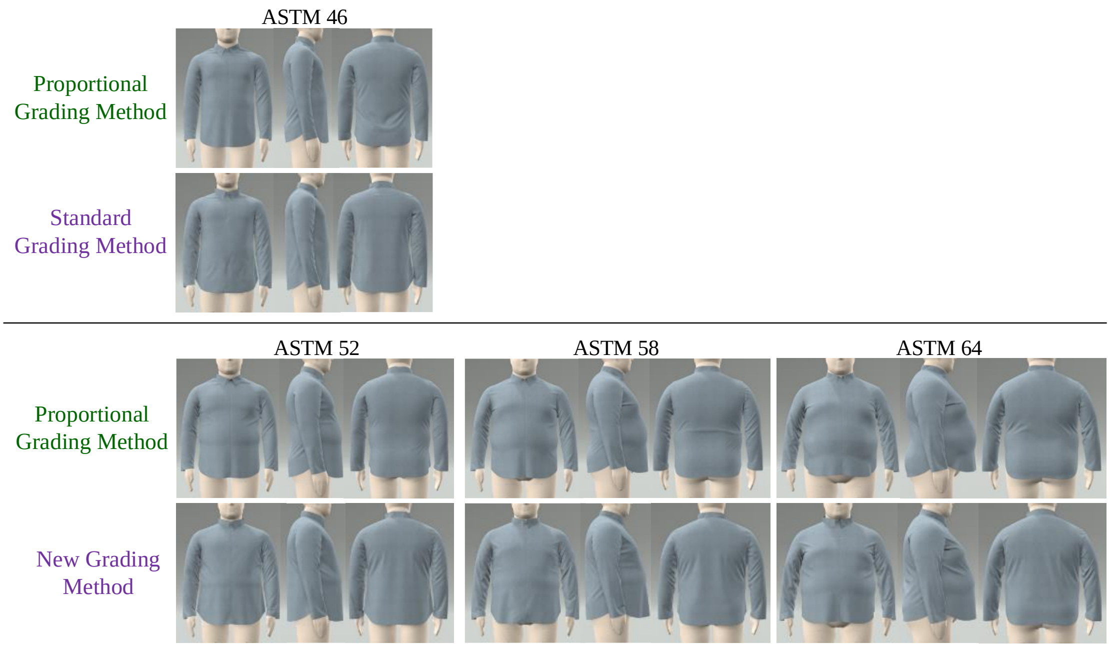


Figure 5-14 Comparison of the Virtual Fitting Results for Male Shirt

The fitting results between optimized grading method and apparel company's grading method are also presented. Notably, the male shirt fitting evaluations clearly reveal that the optimized grading method exhibits significantly superior fit results compared to the apparel company's grading practices, as shown in Figure 5-15.

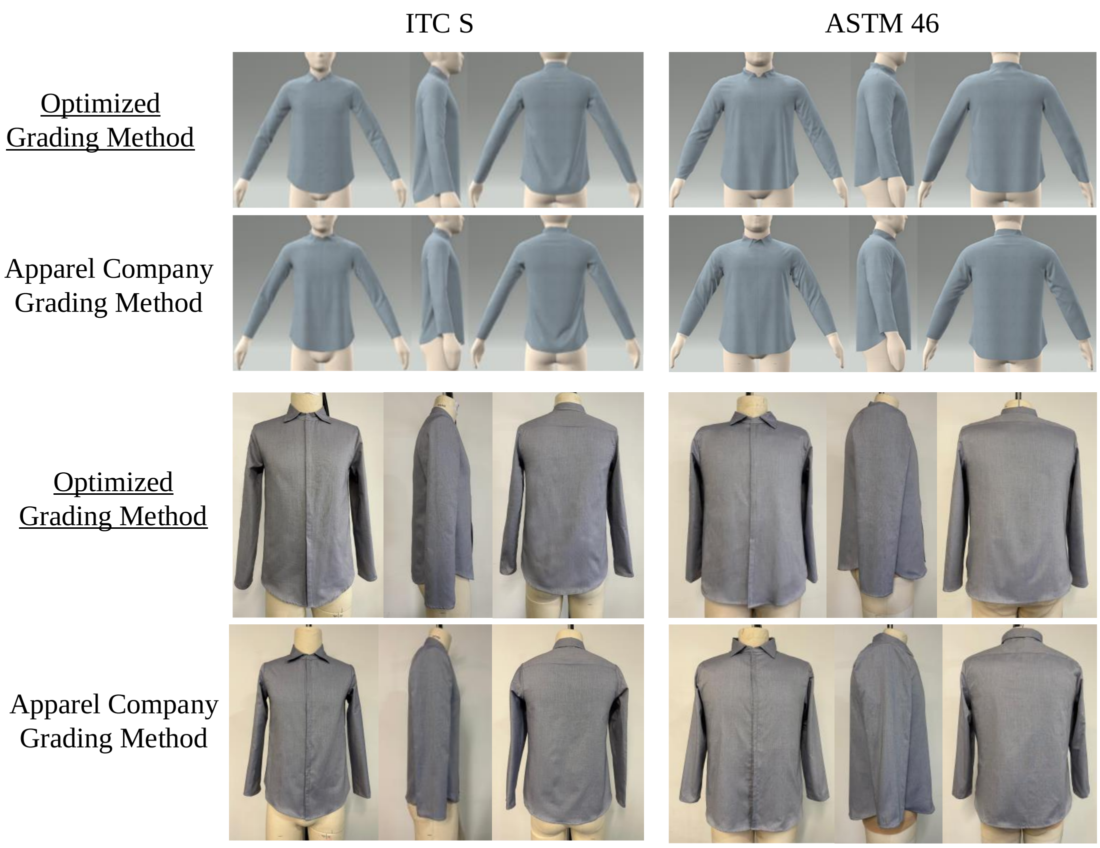


Figure 5-15 Male Shirt Comparison of Size ITC S and ASTM 46

5.5 Chapter Summary

This chapter aims to improve grading techniques to meet the requirements of the current market. The development of this method consists of three key aspects. Firstly, it involves evaluating the effectiveness of proportional grading approaches in accommodating different body sizes and shapes. Secondly, fitting issues are identified and consolidated by virtual try-on in VStitcher. Thirdly, pattern alteration is based on fitting issues, while redefining the grading distributions at key points for diverse body shapes. Lastly, the proposed method is tested on various datasets that encompass a wide range of body shapes, sizes, and garment styles. Virtual fitting and physical sample evaluations are conducted to assess the validity and reliability of the methodology.

The results revealed that proportional grading, a widely utilized traditional approach, was unable to meet the fitting requirements of non-average body shapes, which corroborates similar findings by (Bye et al., 2008a). Overall, the proposed automatic optimized grading methods significantly reduce the manual effort and time usually required for pattern development, while also enhancing accuracy and consistency in the grading process. Meanwhile, it also can achieve customization in producing garments that cater to diverse body shapes and sizes.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 Conclusions

In the current era of e-commerce, purchasing clothing products over the internet has become an important trend for international customers. However, since customers cannot try on clothing before online purchase, size and fit issue is a special challenge to apparel e-commerce. To address this issue, this study proposes and develops an intelligent personalized patternmaking system (IPP system), which consists of three developments: The development of an integrated size table accommodating the diversity of body types and sizes; The development of a novel size recommendation model; and the development of automatic custom pattern generation. A brief structure of the IPP system is reviewed in Figure 6-1.

This study has fulfilled the nine research objectives discussed in section 1.3 of Chapter 1. Among the nine objectives, the fulfilment of the objective (i) has been reported in Chapter 2. Section 1.4 of Chapter 1 provides detailed explanations of how objective (ii) was realized. Chapter 3 specifically focuses on objectives to (iii) to (iv), and the objectives (v) to (vi) have been accomplished in the proposed size recommendation model reported in Chapter 4. The rest of objectives (vii) to (ix) have been completed in

Chapter 5. Specifically, the results of this study are summarised as follows:

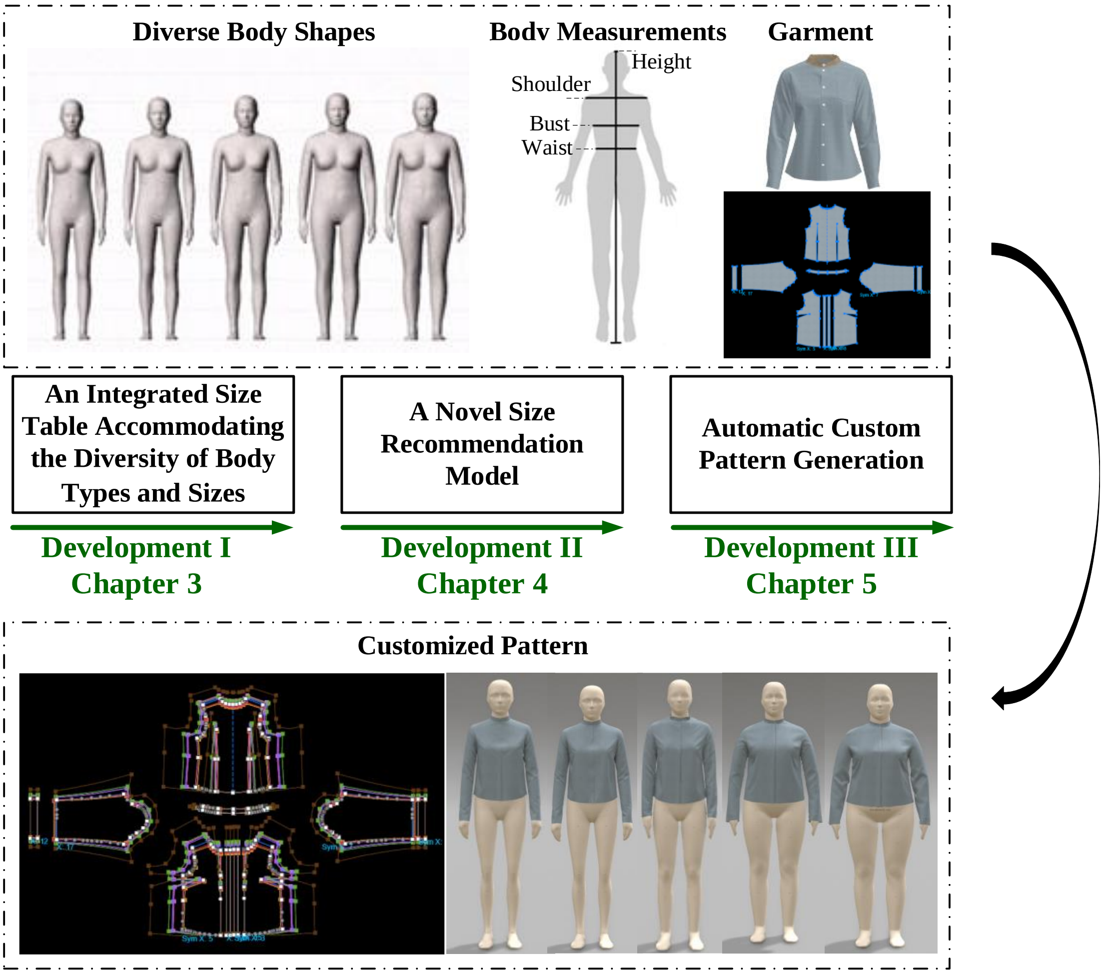


Figure 6-1 Brief Structure Review of the IPP System

6.1.1 An Integrated Size Table Accommodating the Diversity of Body Types and Sizes

Chapter 3 provides a reliable and exhaustive analysis of body types and shapes in various countries, using consistent criteria based on the most recent national sizing standards. Integrated size tables were developed to eliminate the differences in sizing strategies between the national sizing standards, incorporating all body types from various sizing standards considered. The integrated size tables enable a standardized sizing approach and serve as a comprehensive reference for designing and producing internationally applicable human-related products in response to the rising global demand for fashion items. By reducing the inconvenience caused to consumers by inconsistent sizing strategies, this approach benefits both the fashion industry and customers alike. Contributions of this section are summarized as follows:

First, a systematic analysis of the national sizing standards was undertaken to give a clear understanding of body types and shapes in various countries. Research in related fields was summarized in terms of the various ways of defining body type, control dimensions, size range and intervals. The development of integrated size tables for both females and males referenced all the major national body sizing standards, redefined control dimensions, size ranges and intervals to provide the best accommodate for body sizes in various countries. All the sizing information was consolidated into five sub-charts of the integrated size table, which contains three sub-charts for the upper body and two for the lower body. The size ranges of each standard in the integrated size table had different overlaps and differences between the standards of the different countries. In the integrated female size table, the China and Japan sizing standards covered smaller sizes, while the European and US sizing standards generally covered larger sizes and wider ranges. For the upper body, 76.0 cm to 104.0 cm bust range and 54.0 cm to 98.0 cm waist range were dominant, while the size region of 84.0 cm for bust size and 62.0 cm to 78.0 cm for waist size presented the highest frequency. The US *Curvy Misses* type had the same bust size, but a smaller waist compared to *Straight Misses* type. The US *Misses* type had the wider bust than China female *A* and Japan female *A* types. The China female *A* type was relatively slender and petite with a larger difference between bust and waist than the Japan female *A* type. For female height sizes, 160.0 cm and 165.0 cm occupied a high percentage. For the lower body of female, the Chinese and Japanese sizing standard occupied the relatively small waist sizes, while the US and European sizing standard started at larger waist sizes. The waist size range of 54.0 cm to 98.0 cm was dominant. The US *Curvy Misses* type has a very narrow waist and large hip, showing a more curved shape compared to the US *Straight Misses* type. The lower body shapes of Japan *A* and China *A* types are similar, with both having narrow waist and hip sizes.

As for the male body size analysis, the distribution of male body sizes in China and Japan were more concentrated. The male body sizes in Europe were generally large and covered a large range. The torso of the China *A* type tended to a little slimmer than those of the other groups, while the Japan and Korea had the same mean sizes of chest and waist. For the US and Germany, the mean chest sizes were larger than those of the other countries. Furthermore, the Germany *MN* male body type had a wider torso with the smaller chest-waist drop value than the American average types. The height of 170.0 cm presented the highest percentage in all countries, indicating that it is the most common height size in the various national sizing standards. For the lower body of male, waist sizes of 62.0 cm to 110.0 cm occupied the concentration area. The waist size of 100.0 cm corresponds to the small hip size, indicating the belly body shape should be considered in this waist size region. In addition, the US average body type has the large waist and hip sizes than the China A type.

6.1.2 A Novel Size Recommendation Model

Chapter 4 reports on the development of a novel size recommendation model that provides users with a convenient and more precise approach to determine their ideal sizes from any size chart, which overcomes the common issue of inappropriate sizes and inaccurate sizing recommendations in online garment purchases. By incorporating dimensional weighting, fit score calculation, and size ranking, the model generates optimal size suggestions tailored to each online shopper. The new model involved analyzing the correlation between body measurements and garment sizes, considering multiple key body measurements, and assigning them different weights based on their impact on the overall fit of the garment. The fit error score is introduced to quantify the overall fit of each size in the size chart and to guide consumers in selecting well-fitting garment sizes during online shopping. The ranking feature enables all sizes to be ranked on the basis of their overall fit score and provides users with the top three size options as well as body section fit information, making it easier for customers to understand how well and in what respect each size fits them.

This section examined the influence of key indicator selection on the accuracy of sizing predictions, thereby emphasizing the importance for consumers to provide comprehensive body measurements when shopping in order to enhance the accuracy of sizing recommendations. In addition, comparative experiments involving two different styles of shirts showed that the proposed new model outperformed traditional size recommendation methods. The outcome of this study may save time and enhance satisfaction for customers in terms of selecting appropriate garment sizes without having to try on numerous items. Further fine-tuning of the garment can be done based on the fit information in body sections provided by the recommended sizes to generate a personalized pattern.

6.1.3 *Automatic Custom Pattern Generation*

In Chapter 5, an automatic grading method is proposed by using CAD technology, aiming to address the fitting issues for diverse body shapes and sizes and achieve personalized garment fit. The section covers graded pattern generation, garment fit evaluation, personalized alteration, and experiment verification. Optimized grading methods were developed by addressing the fit issues commonly encountered in garments produced using proportional grading techniques prevalent in the market. Both female and male shirts were considered in this study. Virtual try-on simulations were conducted to illustrate the limitations of proportional grading techniques and the effectiveness of the optimized grading method developed in this study. By optimizing the grading distribution at key points, the improvements were evident in areas such as the bust/chest-waist ratio, sleeve length, collar size, and overall garment proportions.

The optimized grading methods were also compared against the apparel company's grading technique. The comparative evaluation serves to further demonstrate the optimal fitting performance achieved through the proposed grading methods. Through virtual try-on simulations, Avalon bodies were utilized to visualize how the graded shirts fit on different body shapes, allowing for a comprehensive assessment of fit and appearance. Real garment tests involved producing physical samples of the graded patterns and conducting fittings on actual mannequins to evaluate the actual fit and comfort. The results indicated that the optimized grading method yielded better-fitting shirts compared to apparel company's grading techniques. In sum, this research contributes to enhancing the accuracy and efficiency of grading techniques using CAD technology, ultimately benefiting the production process by saving time and cost.

6.2 Limitations and Recommendations for Future Work

The current study has developed an IPP system consisting of three modules aiming at enhancing the compatibility of body types and sizes, the fit of the garment, and the speed and efficiency of garment production. The three modules can work independently or be integrated as one system. In the proposed system, the integrated size table serves as a size dataset that aids customers in specifying key sizes and assists manufacturers in achieving accurate grading for the target population in mass production. Meanwhile, our system can recommend the best-fit sizes for customers to address the issue of inaccurate size selection in current RTW market, and the intelligent auto-grading algorithms can be used to alter garment patterns from RTW sizes to customized patterns to achieve optimal fit.

The current study has a number of limitations:

1. The development of integrated size tables has certain limitations due to inconsistent published data and lack of detailed anthropometric data. Future works need to summarize the sizing standards of other countries to incorporate more diverse body shapes and to verify and validate the accuracy of the integrated size table.
2. One limitation of size recommendation method development is that it only examined the effectiveness of the size recommendation method in shirt size recommendations. Further work will investigate the applicability of the recommendation method to other types of garments and develop customized algorithms for different categories.
3. In the development of automatic custom pattern generation, the bust and waist area relationship presented a significant challenge during the grading process. Thus, thoroughly comprehending the target body shape and size is essential to provide customized grading rules to attain optimal fit. In a word, the challenge in intelligent grading lies in achieving a balance between adjusting the grading rules to accommodate varying body shapes while preserving the original garment shape. Further research will focus on refining the grading distribution and testing automatic grading algorithms for diverse garments.

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