A two-step strategy to reduce garment volumes and improve garment structural fit for everyone

by

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ABSTRACT

This research elaborated a two-step strategy to reduce garment volumes and improve garment structural fit for everyone. The strategy is based on data from semi-structured discussions and a comprehensive literature review. Step 1 is a conceptual concerted minimal custom wardrobe model that is composed of a minimal number of custom garments that structurally fit a person's unique body shape and are concerted to efficiently relate to one another and, over an extended period of time, to the person's unique style, social and climate profiles. Step 2 is the automation of custom structural fit. That is, the ability of a computer-aided design (CAD) system to draft, for each and every body shape and directly from inputted formulas and body shape data, patterns that structurally fit without alterations. Such automation gives more people, professionals, and companies the ability to create, with less skills and training, custom garments that structurally fit, scaling the potential effect of the concerted minimal custom wardrobe on garment volumes, and user satisfaction and agency. However, this research established that CAD systems and existing research do not truly automate optimal custom structural fit, in part because with multiple gaps, pattern drafting does not produce for each and every body shape, optimal structural fit that does not require alterations. For these reasons, studies on the topic of custom pattern drafting CAD systems were analysed to identify priority topics for subsequent research. They are, automation of custom block patterns that structurally fit, complete body shape data from 3D body scans and expert structural fit evaluation.

Keywords: fashion, garment, wardrobe, fit, custom, automation, environment

Une stratégie en deux étapes pour réduire les volumes de vêtements et avoir pour tous, des vêtements structurellement seyants

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RÉSUMÉ

Cette recherche a élaboré une stratégie en deux étapes pour réduire les volumes de vêtements et avoir pour tous, des vêtements structurellement seyants. La stratégie est basée sur des données issues de discussions semi-structurées et d'une revue exhaustive de la littérature. L’étape 1 consiste en un modèle conceptuel d’une garde-robe sur mesure minimale et concertée qui est composée d'un nombre minimal de vêtements sur mesure qui siéent structurellement à la forme du corps propre à une personne, et qui sont concertés afin de bien s’agencer les uns aux autres et, sur une longue période, aux profiles style, social et climat propres à la personne. L'étape 2 consiste en l'automatisation d’un ajustement structurel sur mesure. C'est-à-dire, la capacité d'un système de conception assistée par ordinateur (CAO) à produire, pour chaque forme de corps et directement à partir de formules et de données de la forme du corps saisies, des patrons qui siéent structurellement sans retouches. Une telle automatisation permet à un plus grand nombre de personnes, de professionnels et d'entreprises de créer, avec moins de compétences et de formation, des vêtements sur mesure qui siéent structurellement, ce qui permet de mettre à l’échelle l'effet potentiel de la garde-robe sur mesure minimale et concertée sur les volumes de vêtements, ainsi que sur la satisfaction et la capacité d’action des utilisateurs. Cependant, cette recherche a établi que les systèmes de CAO et les recherches existantes n'automatisent pas réellement l'ajustement structurel sur mesure optimal, en partie parce qu'avec de multiples écarts, le dessin de patron ne produit pas pour chaque forme du corps, un ajustement structurel optimal qui ne nécessite pas de retouches. Pour ces raisons, des études sur les systèmes de CAO pour le dessin de patrons sur mesure ont été analysées afin d'identifier les sujets prioritaires pour les recherches ultérieures. Ils sont, l'automatisation des patrons de blocs sur mesure qui siéent structurellement, des données complètes sur la forme du corps à partir de scans corporels 3D et une évaluation de l'ajustement structurel selon les experts.

Mots clés : mode, vêtement, garde-robe, ajustement, sur mesure, automatisation, environnement

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LIST OF ABREVIATIONS, ACRONYMS and SYMBOLS

2D	Two-dimensional
3D	Three-dimensional
AMFI	Amsterdam Fashion Institute
ANN	Artificial Neural Network
AUAS	Amsterdam University of Applied Sciences
BMI	Body Mass Index
cm	Centimeter
CAD	Computer-Aided Design
CO_2	Carbon dioxide
DIY	Do It Yourself
GHG	Greenhouse Gas
MLR	Multiple Linear Regression
NN	Neural Network
RISO	Risograph
RTW	Ready-to-Wear
SAT	*Société des arts technologiques*
SVM	Support Vector Machine
UK	United Kingdom
UQAM	*Université du Québec à Montréal*
US	United-States
USD	United-States dollars
UV	Ultraviolet
WTO	World Trade Organization

CHAPTER 1

INTRODUCTION

Garments are a feature of human societies since time immemorial (Nayak & Padhye, 2018). Global garment sales were approximately 500 billion USD[1] in 2018, pre COVID-19. Garments meet the physiological need to maintain blood temperature constant by protecting the human body from the cold and heat (Bye, 2010; H. A. M. Daanen, 2007; Maslow, 1943). While garments are also commonly perceived as a means to represent identity, humans are more than the garments they wear with gestures, facial expressions, remarks, jokes, vocal tones and writing styles (Breuer, 2015). Two current fashion industry challenges include the environmental burden across its value chain and fit of garments.

Volumes of garments in circulation and being discarded are an environmental burden (Fashion Takes Action, 2021; Fletcher & Tham, 2014; Maldini, 2019; WRAP, 2017). Compared to past decades, each person generally purchases more garments and wears a smaller portion of their wardrobe, and each garment is worn less often before disposal (Allwood, Laursen, Rodríguez, & Bocken, 2006; Cipriani, 2019; Cline, 2013; Ellen MacArthur Foundation, 2017; Maldini, 2019; United States Environmental Protection Agency, 2019). To reduce garment volumes and their environmental burden, waste reduction strategies should be prioritised over reuse, reconditioning and recycling (Fletcher & Grose, 2011).

Garments are worn on three-dimensional (3D) and moving bodies. How well a garment conforms to the human body is commonly referred to as fit (Brown & Rice, 2013; Istook, 2002). Garment fit affects a person's visual appearance as well as their comfort and mobility

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[1] https://data.wto.org and https://oec.world. OEC estimate includes clothing and excludes textiles. WTO estimate includes apparel and clothing accessories that are plastic, knitted or crocheted and not knitted or not crocheted; leather, rubber and furskin apparel; articles of apparel of leather or composition leather; and articles of apparel and clothing accessories of furskin

(Brown & Rice, 2013; Liechty & Rasband, 2006; Shen & Huck, 1993; Shin, 2013). Not surprisingly, it also affects what consumers decide to buy from the store, what in their closet they chose to wear and what they discard (Brown & Rice, 2013; Niinimäki, 2010; WRAP, 2017). Nonetheless, it is difficult for some individuals to find, buy and make garments that fit their body shape (Bougourd, 2007; Brown & Rice, 2013; Labat, Salusso, & Rhee, 2007; Li, Lu, Liu, Liu, & Wang, 2013; Liechty & Rasband, 2006; Threads Magazine, 2012). As, from multiple sources, body shape including posture, is unique to each person and affects fit, and ready-to-wear (RTW) standard sizing and manufacturing cannot achieve fit for each and every body shape.

This research first set out to explore the possibility of reducing garment volumes with improved fit from the automation of custom fit garments, also enhancing user satisfaction and agency. As, conceptually, custom garments can increase garment use and lifetime, slow down garment replacement and production cycles, and, in turn, reduce garment volumes and the environmental burden (Maldini, 2019). However, studies by Maldini, Stappers, Gimeno-Martinez, and Daanen (2019) and Maldini (2019) state that custom garments may not be an effective strategy to increase garment use and lifetime and reduce garment volumes. The studies suggest that one reason may be that people, in effect, wear systems of interconnected garments, wardrobes. While suboptimal fit may not be the cause of garment volumes, garment volumes and fit remain industry challenges to be addressed. Therefore, the questions of how to reduce garment volumes and improve garment fit remain relevant. As such, a strategy to reduce garment volumes and improve garment fit for everyone was researched and elaborated. The result is a two-step strategy. The strategy is based on wardrobes, a wider view of fit that relates to various human needs and automation of custom fit.

Step 1 of the strategy is a conceptual concerted minimal custom wardrobe model that is composed of a minimal number of custom garments that structurally fit a person's unique body shape and are concerted to efficiently relate to one another and, over an extended period of time, to the person's unique style, social and climate profiles. For clarity, this research introduced the term structural fit and it relates to how well the shape and size of the garment conforms to the shape and size of the human body while standing, walking, sitting and bending.

Step 2 of the strategy is the automation of custom structural fit. That is, the ability of a CAD system to draft, for each and every body shape and directly from inputted formulas and body shape data, patterns that structurally fit without alterations. The automation of custom structural fit gives more people, professionals, and companies the ability to create, with less skills and training, custom garments that structurally fit for themselves or their clients, scaling the potential effect of the concerted minimal custom wardrobe on garment volumes, and user satisfaction and agency. This democratisation of innovation not only reduces users' reliance on manufacturers, that often act imperfect agents, it also gives them the opportunity to experience the joys of learning, creating and belonging (von Hippel, 2005). To this end, to create, to make, relations and to belong, are human needs (Maslow, 1943). From multiple sources and despite a vast majority of the global population wearing garments every day for hundreds of years, research and technology, current CAD systems do not truly automate custom structural fit as, at least in part, pattern drafting does not, for each and every body shape, produce optimal custom structural fit that does not require alterations. Hence, this research also analysed studies on the topic of custom pattern drafting CAD systems to identify priority topics for subsequent academic research. Figure 1.1 presents a chart of the main research concepts.

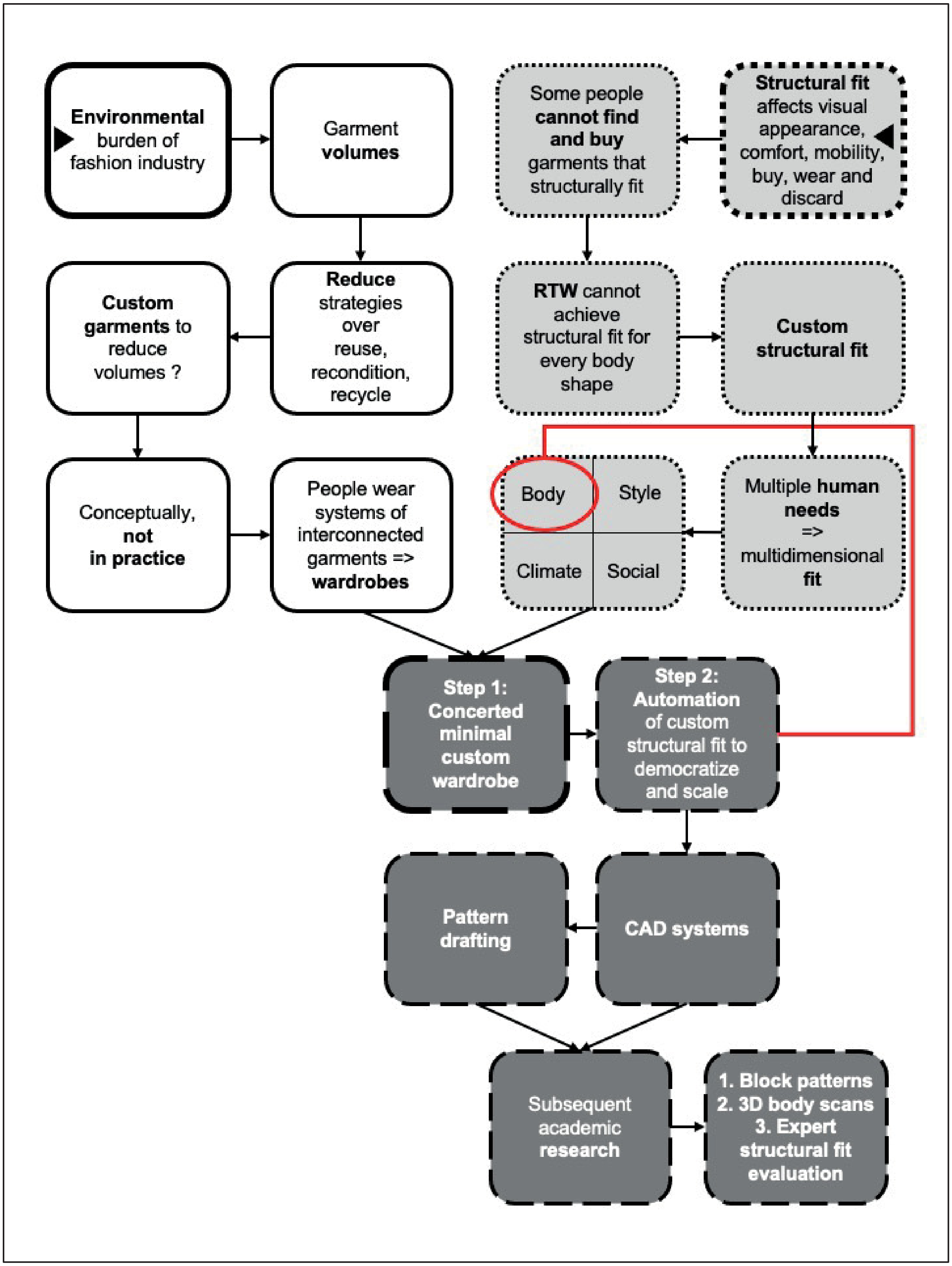

Figure 1.1 Research conceptual chart

1.1 Terminology

Where appropriate:

- Body shape was chosen to encapsulate the widest range of features including bone structure, size, figure, proportion, symmetry, silhouette, morphology and posture;
- Custom was chosen to encapsulate bespoke and made to measure. In this text, custom generally means made for a specific target person. It does not include personalisation or use of categories or averages;
- CAD system was chosen to encapsulate all things related to apps, digital and software;
- Garment was chosen to encapsulate apparel, clothing, fashion;
- "Go with" and "go well with" refer to how well garments relate to one another or interconnect with one another;
- Pattern drafter and drafting was chosen to encapsulate pattern maker, making, cut and cutting; and
- Pattern drafting was chosen to encapsulate pattern drafting practices and instructions.

Where it is said that CAD systems can or cannot automate custom structural fit, it is with the understanding that the performance of the system is dependent on the inputted formulas and data.

The term structural fit is introduced in Section 4.1 and it relates to how well the shape and size of the garment conforms to the shape and size of the human body while standing, walking, sitting and bending. Structural fit is limited to fitting ease and does not include design ease. Ease relates to the dimensional difference between the garment and the body (Brown & Rice, 2013; Chen, 2007; Huck, Maganga, & Kim, 1997; Liechty, Rasband, & Pottberg-Steineckert, 2016). Fitting ease relates to the amount of fabric allowed for breathing and basic body mobility (Chen, 2007; Huang, Mok, Kwok, & Au, 2012). In this research, fitting ease does not relate to a person's perception of comfort or personal preference for loose- or tight-fitting garments. In this research, such perceptions and preferences relate to design ease, a style dimension further presented in Section 4.1. Design ease also relates to flares, tucks and pleats that are added to fitting ease to create different shapes and styles (Brown & Rice, 2013; Chen, 2007; Huang et al., 2012; Liechty et al., 2016).

1.2 Order

CHAPTER 2 GARMENT VOLUMES AND FIT presents information from the literature review and discussions regarding the environmental burden of garment volumes, the importance of reduction strategies over reuse, reconditioning and recycling and the effectiveness of custom garments as a strategy to reduce garment volumes. The Chapter also presents fit, including what it is, its importance and how it is addressed in the current RTW model.

CHAPTER 3 RESEARCH METHOD presents the research method. The research applied a qualitative method that is part exploratory, part content analysis.

CHAPTER 4 CONCERTED MINIMAL CUSTOM WARDROBES elaborates a conceptual custom wardrobe model based on multidimensional fit over an extended period of time as Step 1 of the two-step strategy to reduce garment volumes and improve garment fit for everyone.

CHAPTER 5 CUSTOM FIT CAD SYSTEMS presents information from the literature review and discussions regarding pattern drafting CAD systems and their ability to automate custom structural fit as Step 2 of the two-step strategy to reduce garment volumes and improve garment fit for everyone.

CHAPTER 6 PATTERN DRAFTING presents information from the literature review and discussions regarding pattern drafting and its ability to produce custom structural fit.

CHAPTER 7 EXISTING RESEARCH presents the analysis of 21 studies on custom fit pattern drafting CAD systems.

CHAPTER 8 SUBSEQUENT ACADEMIC RESEARCH presents three priority topics for subsequent academic research to automate custom structural fit.

CHAPTER 9 CONCLUSION presents the conclusion.

CHAPTER 2

GARMENT VOLUMES AND FIT

This Chapter presents a general overview of two fashion industry challenges, the environmental burden of its value chain and fit of garments. While the garment value chain also generates social impacts, they are not addressed in the scope of this research. The Chapter more specifically presents garment volumes, the importance of reduction strategies over reuse, reconditioning and recycling, the effectiveness of custom garments to reduce garment volumes. The Chapter also presents fit, including what it is, its importance and how it is addressed in the current RTW model.

Some statements in this Chapter are intentionally general. Because, as observed by others and in this research, despite popular statements on the garment value chain, reliable, transparent, complete and peer-reviewed data is not necessarily available (Maldini, 2019; Wicker, 2020). One reason may be lack of data. For instance, the Fashion Takes Action (2021) study on textile recycling in Canada stated that, with some exceptions, the majority of municipalities in Canada do not know how much textile waste is in their waste streams. The study also stated that Canadian clothing manufacturers and retailers likely do not know the volume of textile waste they produce (Fashion Takes Action, 2021).

2.1 Environmental Burden

2.1.1 *Garment Value Chain*

The garment value chain includes crop irrigation and agriculture; raw material production, extraction and processing; fiber, yarn and fabric preparation, production, processing, spinning, carding, combing, weaving, bleaching, printing, dyeing and finishing; and garment production, cutting, assembling, sewing, packaging, distribution, retail, use, care, washing, drying, ironing, reuse, recycling, disposal, landfilling and incineration (Allwood et al., 2006; Cline, 2013; Ellen MacArthur Foundation, 2017; Fashion Takes Action, 2021; Fletcher & Grose, 2011; WRAP, 2017). The garment value chain includes use of land, water, pesticides, fertilizers, chemicals, dyes, fossil fuels and energy (Allwood et al., 2006; Ellen MacArthur Foundation, 2017). This usage leads to negative environmental impacts such as ecosystem degradation, pollution and emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) (Ellen MacArthur Foundation, 2017; Maldini, 2019). For instance, fossil fuels are used for machinery, transportation and to generate energy to produce fibers and to heat water and air for laundering (Allwood et al., 2006). Toxic chemicals are used for agriculture and to dye and print fibers (Allwood et al., 2006). Finally, solid waste is generated from manufacturing and disposal (Allwood et al., 2006). The garment value chain is global, where, cotton can be grown in Africa, spun into fabric in India, dyed in China, assembled as a garment in Vietnam, retailed and sold in Canada and be exported to Africa for disposal (Cipriani, 2019).

The garment value chain is generally linear, where non-renewable resources are extracted to produce garments that are discarded with their materials often being sent to landfill or incinerated (Ellen MacArthur Foundation, 2017; Fashion Takes Action, 2021). Garments discarded by people are either sent to charities, recycled, landfilled or incinerated (Allwood et al., 2006; Cline, 2013; Fashion Takes Action, 2021; United States Environmental Protection Agency, 2019). Garments that are sent to charities and recycled can be resold, upscaled, balled, exported, ragged, incinerated, landfilled or have their fibers recycled (Allwood et al., 2006; Cline, 2013; Fashion Takes Action, 2021; United States Environmental Protection Agency, 2019).

The cycle of garment consumption and disposal generates more second-hand garments than what can be retailed locally (Ericsson & Brooks, 2014). The best quality garments are sent for local resale, but most are compressed and wrapped into large bales and shipped for resale in Eastern Europe, the Middle East or Africa (Allwood et al., 2006; Ericsson & Brooks, 2014; Hawley, 2008). There is a concern that developing countries are dumping their unwanted garments in developing countries and leaving them with the environmental pollution and a diminished local textile industry (Fashion Takes Action, 2021). These export markets face multiple challenges and some countries have banned or restricted import of used garments (WRAP, 2017). Furthermore, the import of used garments is one of the factors in the decline of garment manufacturing in Africa (Ericsson & Brooks, 2014). Some argue that rather than exporting the problem, societies should each address their over-consumption of fashion (Ericsson & Brooks, 2014). How much of the exported garments are reused is unknow (Maldini, 2019).

Unsold garments can be resold at a discount, revalorized, exported, transformed into rags, insulation or padding, incinerated or landfilled (Allwood et al., 2006; Cipriani, 2019; Cline, 2013; Fashion Takes Action, 2021; United States Environmental Protection Agency, 2019). The quantity and detailed routing of unsold garments is largely unknow (Cipriani, 2019; Cline, 2013; Fashion Takes Action, 2021). Despite popular statements that an important percentage of garments produced remain unsold, most produced goods are in fact sold, although many of them at discounted prices (Maldini, 2019).

2.1.2 *Garment Volumes*

While sources differ on details and percentages, many agree on an overall trend in comparison to 20 to 60 years ago: each person purchases more garments and wears a smaller portion of their wardrobe and each garment is worn less often before disposal (Allwood et al., 2006; Cipriani, 2019; Cline, 2013; Ellen MacArthur Foundation, 2017; Maldini, 2019; United States Environmental Protection Agency, 2019).

Some proposed solutions include moving toward regenerative farming practices, processes that require less resources and favor renewable inputs, and low laundering and ironing fabrics (Ellen MacArthur Foundation, 2017; Fletcher & Grose, 2011). However, trade-offs between such alternatives can be difficult to compare and the net positive result difficult to determine. First, each fiber, whether natural and manufactured, has its own complex ecological footprint (Cline, 2013; Fletcher & Grose, 2011). Second, there’s disagreement on what phase of the value chain generates most impacts, whether production or use and care. For example, one reference states that the generation of impacts during use and care is important, another states that it is minimal, and another states that production is the most impactful (Maldini et al., 2019; Quantis, 2018; WRAP, 2017).

Other proposed solutions include reselling and further reusing garments and their materials (Ellen MacArthur Foundation, 2017; Fashion Takes Action, 2021). Although reuse, reconditioning and recycling are positive, they do not do not address the root cause of the problem of garment waste and do not prevent waste from being produced in the first place (Fletcher & Grose, 2011). Furthermore, recycling options result in a lower grade material such as insulation or rags (Ellen MacArthur Foundation, 2017; WRAP, 2017). The beneficial effect of recycling is minimal as these lower grade materials do not replace the use of new materials to make and sell new garments (WRAP, 2017). Finally, the recycled form is also eventually incinerated or landfilled (Ellen MacArthur Foundation, 2017). To this end, some fibers such as synthetic ones, can take hundreds of years, if not a thousand, to biodegrade and will indefinitely occupy landfill space (Fashion Takes Action, 2021; Wicker, 2016).

In effect, the sheer volumes of garments in circulation and being discarded is an environmental burden (Fashion Takes Action, 2021; Fletcher & Tham, 2014; Maldini, 2019; WRAP, 2017). The risk of designing and producing garments that have less impacts per item, is that the effort will be undermined by a rise in the volume of garments being bought (WRAP, 2017). If the result is an increased number of garments in circulation, efforts to reduce the impact per garment may not lead to a net positive impact over the industry as a whole (Fletcher, 2014). While the impact per garment may be reduced, a larger volume of garments in circulation will overshadow the reduction (Fletcher, 2014).

2.1.3 *Reducing Volumes*

For some, custom garments can increase garment utilisation and lifetime, reducing consumption and waste (Chapman, 2014; Ellen MacArthur Foundation, 2017; Niinimäki, 2010). Conceptually, one imagines that with custom garments, people will wear more of their garments more often, and over longer periods of time, delaying garment disposal and production of new garments, in turn reducing garment volumes and the environmental burden (Maldini, 2019). Conceptually, this has the benefit of reducing environmental impacts at all phases of the value chain from production to disposal. One exception may be the use and care phase, if garments are washed, dried and ironed in the same manner. However, a study with 40 participants and 20 companies in the Netherlands cautions that, in practice, custom garments do not, as anticipated, increase garment use and lifetime and reduce garment volumes (Maldini et al., 2019). One explanation is that wardrobes are complex systems of interconnected garments influenced by internal and external factors and serving a variety of, at times, overlapping purposes (Maldini, 2019).

The in practice effects of other strategies have not been studied and they, thereby, remain hypothetical solutions (Maldini, 2019; Maldini et al., 2019). Consequently, rather than discard custom garments as a strategy to reduce volumes and the environmental burden, this research scaled the custom strategy to wardrobes as presented in CHAPTER 4.

Furthermore, other strategies such as service-based systems, may not address fit. Garment fit affects a person's visual appearance as well as their comfort and mobility (Brown & Rice, 2013; Liechty & Rasband, 2006; Shen & Huck, 1993; Shin, 2013). Not surprisingly, it is one of the main reasons people purchase, wear and discard garments. Garments that do not fit are not bought and are left hanging on retailers' markdown racks, if they are bought, they are seldomly worn and left hanging in consumers' closets (Brown & Rice, 2013). 246 participants in an online survey in Finland listed fit as one of the main reasons for garment purchase (Niinimäki, 2010). 2 058 surveyed shoppers in the UK stated that the main reason they discarded garments was because they did not fit (WRAP, 2017)[2]. A cross-national study of 30 participants found that fit was the most significant evaluation cue (Rahman, Fung, Chen, &

[2] https://www.wrap.org.uk/sustainable-textiles/scap/report/consumer-clothing-survey

Gao, 2017). Fit and comfort were separate cues in the study, and the study found a strong correlation between fabric, fit and comfort (Rahman et al., 2017).

To illustrate how service-based systems may not address fit, Figure 2.1 shows a screen capture from a Dragon's Den episode. Dragon's Den is a Canadian television show where aspiring entrepreneurs pitch their business concepts and products to a panel of business moguls for their investment. In the screen capture, a pitching entrepreneur is wearing a dress from their garment rental business. While possibly a pretty dress, the wrinkles around the hips indicate the fit of the dress is not optimal for the entrepreneur. The dress likely hikes up the hips because the dress is too tight around the hips so the fabric cannot fall back into place after walking, sitting or bending. Fit is further presented in the following Section 2.2.

Figure 2.1 Screen captures of an online clothing rental business pitch[3]

[3] https://www.cbc.ca/dragonsden/m_pitches/chic-marie

2.2 Garment Fit

Fit commonly relates to how well the garment conforms to the human body (Brown & Rice, 2013; Istook, 2002). It is a function between the shape and size of the garment and the body (Chen, 2007; Huck et al., 1997; Liechty et al., 2016). Well-fitted garments hang smoothly from the shoulders, waist and hips and the fabric does not cling, bind, pull, twist or hike up (Liechty & Rasband, 2006). Well-fitted garments adjust naturally to body movements and return to their natural position, free of wrinkles, when not in movement (Liechty & Rasband, 2006). In addition to having a neat and smooth appearance, well-fitted garments provide maximum comfort and mobility (Brown & Rice, 2013; Shen & Huck, 1993; Shin, 2013). Garments that fit generate less strain on the fabric and last longer (Liechty & Rasband, 2006). They look better longer yielding a better dollar-value (Liechty et al., 2016). Criteria to evaluate fit include garment balance, grain, line and set (Brown & Rice, 2013; Shin, 2013). Fit evaluation is further presented in Section 6.6.

A person's body shape including bone structure, size, figure, proportion, symmetry and posture, affects garment fit (Beazley, 1999; Beazley & Bond, 2003; Brown & Rice, 2013; Kwong, 2004). Posture variations such as erect, rounded, sway back, sway front and slumped affect fit (Liechty et al., 2016). Figure 2.2 and Figure 2.3 taken from Aldrich (2008) and Liechty et al. (2016) illustrate how posture, large backside and large abdomen affect the fit of skirts. Fit and body shape variability are further presented in subsection 6.2.1.

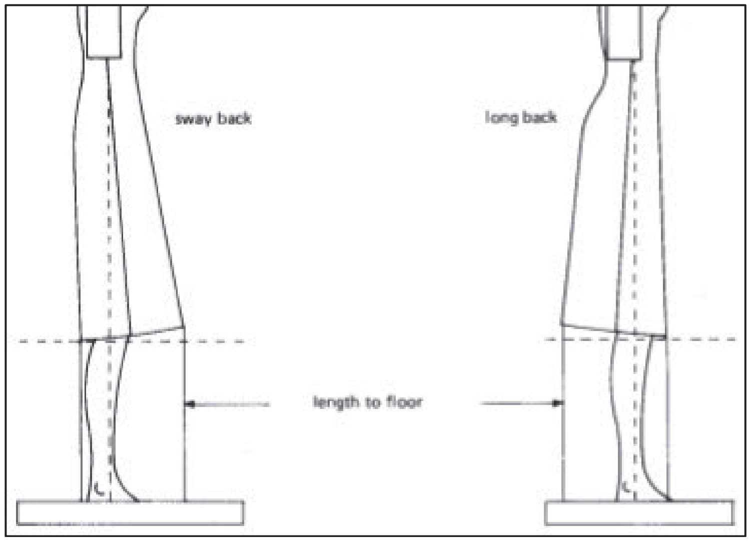

Figure 2.2 Posture and fit
Taken from Aldrich (2008, p. 190)

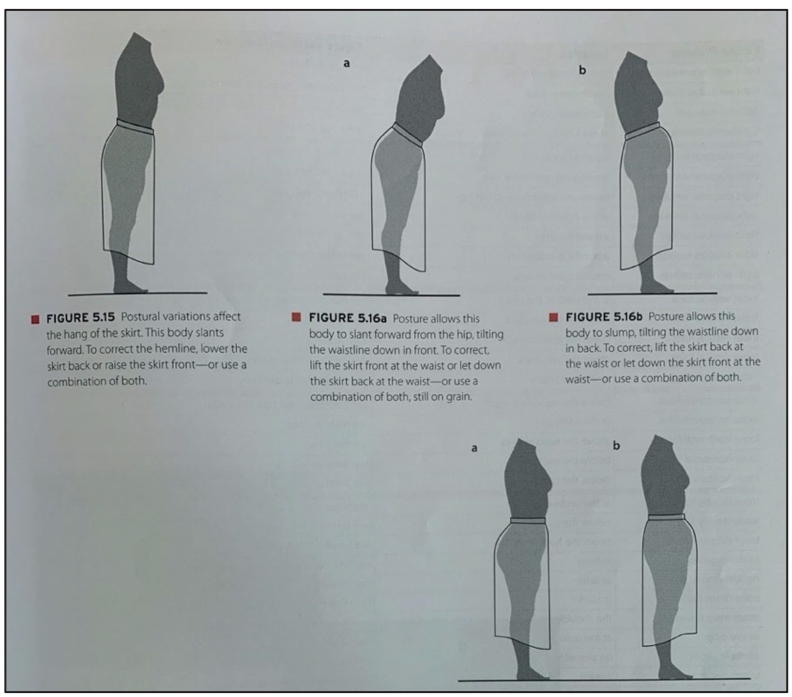

Figure 2.3 Posture, backside, abdomen and fit
Taken from Liechty et al. (2016, p. 121)

2.2.1 *Ready-to-Wear*

RTW garments became available during the 19th century with the industrial revolution and its machinery, factories and new sources of power (Aldrich, 2007; Kidwell & Christman, 1974). RTW garments are designed to fit a chosen standard body type (McKinney, Gill, Dorie, & Roth, 2017; Mullet, 2015). Where custom tailored garments were designed to fit a target person, RTW garments are mass produced and designed to fit a standard body type (Bye, 2010; Mullet, 2015). Standard bodies are based on statistical averages gathered from a brand's own research and data, anthropomorphic surveys or a culturally defined ideal body (Liechty et al., 2016; Mullet, 2015; Yu, 2004a). Countries such as the US and the UK have conducted large-scale anthropometric surveys of over 10 000 participants to establish and revise national sizing standards (Yu, 2004a). However, as body shapes vary significantly within a country and from country to country, it may not be feasible to establish a single sizing system to be universally applied (Yu, 2004a).

RTW garments are produced in several sizes by grading patterns to increase or decrease sizes (J. Zhang, Innami, Kim, & Takatera, 2015). Proportional grading increases or decreases the standard pattern proportionally in circumference and length one size to the next according to a size chart (Han, Kim, & Park, 2015; Liechty et al., 2016). With uniform grading, bust, waist and hips are increased or decreased by the same amount from size to size (Mullet, 2015). With mixed grading, bust, waist and hips are increased or decreased by different amounts from size to size (Mullet, 2015). Each grading system determines for itself the amounts to be decreased or increased from size to size (Mullet, 2015).

When sizing and grading methods emerged in the 19th century, they were varied and each publication had different recommendations (Kidwell & Christman, 1974). Some manufacturers developed their own sizing systems based on trial and error (Kidwell & Christman, 1974). Still today, many manufacturers establish and adopt their own sizing systems (Griffin & Dunne, 2016; Yu, 2004a). Different manufacturers, designers and brands establish their own rules to grade patterns from one size to another (Griffin & Dunne, 2016; Liechty & Rasband, 2006).

Retailers often guard this information as commercially sensitive making it difficult to understand how the systems work or how they were developed (Gill, 2015).

Patterns made from proportional grading change proportionally in circumference and length when in reality, people with larger circumferences are not necessarily taller and vice versa (Han et al., 2015). With standard sizing and proportional grading, garments only fit bodies of similar proportions to the standard pattern that is based on average symmetrical shapes and postures (Han et al., 2015; Kwong, 2004; Shin, 2013; J. Zhang et al., 2015). As no person is exactly average and people have a much larger variety of shapes and sizes than standard and graded patterns, desired fit is not achieved (Istook, 2002; Li et al., 2013). One participant recalled an anthropometrics, sizing and fit expert stating at a conference in Minnesota, US, that size charts cannot accommodate the large variety of sizes and shapes (10). Furthermore, mapping sizing data shows that some people fall outside of established size ranges, leading to question how they experience fit (Gill, 2015).

The RTW system is unable to provide well-fitted garments for all body shapes as they vary significantly (McKinney et al., 2017; Mullet, 2015). To effectively fit the variety of body shapes of a given population, manufacturers would need to produce and distribute a large and impractical number of sizes (Griffin & Dunne, 2016). Therefore, no manufacturer, or no single sizing system, can fit an entire population (Griffin & Dunne, 2016). While mass production benefits the manufacturer with simplified supply chains and reduced costs, people experience garment fit on an individual basis which RTW does not accommodate (Gill, 2015).

Another consideration is people who do not follow the industry set norm for their age or gender. For instance, some people over 50 with mature body shapes, have a hard time finding garments with the desired aesthetic that fit (5, 16). Common body shape changes with age include posture, rounding shoulders, narrowing chest, broadening back, lowering bustline, protruding abdomen, thickening waist increasing high hips and lowering and flattening of the seat (Liechty et al., 2016; Threads Magazine, 2012). Gender non-conforming people also have difficulty finding desired garments that fit. For instance, a person born male with typical height and shoulder width will not find a dress that fits as dresses are produced for the typical female body shape that is shorter and narrower (3).

People with body shapes that do not fit into standard sizes available in stores rely on alterations (Hong, Bruniaux, Zeng, Curteza, & Liu, 2018). The process of altering a garment to fit a target person was an important part of the historic processes of garment development and these have since been omitted (Gill, 2015). When department stores first offered RTW garments, they were altered in workrooms at no extra charge (Aldrich, 2003). These alteration workrooms were essential to providing an acceptable fit (Aldrich, 2003). While some stores still offer alterations services, they are limited to basic alterations such as hemming and not all stores advertise the services (Baldwin, 2017). Seams, finishes and production methods used by most mass production do not accommodate garment alterations (Gill, 2015).

There is great opportunity to improve RTW sizing systems (Ashdown, Lyman-Clarke, Smith, & Loker, 2007). Each body is unique and the expectation that everyone can wear standardized garments needs to change toward developing garments that fit each person (Bye, 2010). How a person looks and feels in a garment is important, regardless of their size, shape, age and gender (3, 5, 6, 16). Nevertheless, standard sizing is taught in many, if not most or all fashion schools (5, 8).

Additionally, the size of a garment can be unintentionally altered during production steps such as marking, cutting, sewing, processing and labelling (Ashdown et al., 2007). Up to 20% of garments produced do not meet production standards, a very high percentage in comparison to other manufactured products (Ashdown et al., 2007). Garment manufacturers acknowledge having major production repeatability problems (Bellemare, 2014). In one instance, pant waists were up to 5 cm larger than indicated (Bellemare, 2014). Such a variation is the equivalent of over one female body size (Beazley & Bond, 2003; Pellen, 2014). Many consumers are aware of the lack of reliable sizing even between garments of the same size and style (Ashdown et al., 2007). Experienced shoppers often try different samples of the same garment in the same style and size as they know that there may be differences that can affect fit between these supposedly identical garments (Ashdown et al., 2007). Such sizing problems affect the quality of the product and decrease the consumer's confidence in the brand and reduce sales (Ashdown et al., 2007). Achieving uniformity is costly so it is important for a brand to know its target market and their expectations to provide an appropriate trade-off between reliable fit and retail price point (Ashdown et al., 2007). Fit can also change over time from shrinking after washing and drying or stretching after wear (Shin, 2013). Fabric should wear and wash well over time in addition to feeling good next to the skin (Cline, 2013).

2.2.2 *Home Sewing*

Commercial patterns used by home sewers to make garments apply the same methods of standardised sizing and proportional grading as RTW (Labat et al., 2007; Threads Magazine, 2012). Most women's commercial patterns are drafted for women between 163 cm and 168 cm tall, with a B cup bra size (Threads Magazine, 2012). Given the variety of body types, proportions and postures, commercial patterns do not solve fitting problems for the home sewer (Loker, 2007). Consequently, home sewers experience the same dissatisfaction with garment fit as RTW consumers and alterations are normally required to achieve proper fit (Threads Magazine, 2012). Attempting to make a garment that fits can be a frustrating experience and people quit sewing garments because they are unable to make garments that fit properly (Liechty & Rasband, 2006).

A survey of 235 of home sewers that were females aged from 17 to 81 years and from and Washington and Minnesota, listed better fit is the first reason to sew one's own garments (Labat et al., 2007). 92% of the home sewers surveyed indicated that they altered patterns at least sometimes to achieve better fit (Labat et al., 2007). Even when patterns were altered, the surveyed home sewers remained unsatisfied with fit (Labat et al., 2007). While altering patterns leads to improved fit, the process requires advanced skills (Labat et al., 2007). As pattern adjustments skills are not routinely taught in schools and the knowledge is no longer passed from one generation to the next, most home sewers likely have limited opportunity to gain these skills (Labat et al., 2007). Hence, typical home sewers may not have the necessary skills to sew well-fitting home-sewn garments (Labat et al., 2007).

Home sewers invest considerable time and money to make a garment and are then unsatisfied with the fit (Labat et al., 2007). The amount of time spent on patterns is significantly correlated with sewing enjoyment (Labat et al., 2007). Less experienced sewers who spend more time adjusting patterns find that pattern adjustment significantly decreased their sewing enjoyment (Labat et al., 2007). While experienced sewers are able to get better fitting patterns more quickly, they are still generally dissatisfied with the outcome and with the process (Labat et al., 2007). When experienced home sewers cannot succeed in adjusting patterns, it is likely that the fit was largely beyond fixing (Labat et al., 2007). Many home sewers may not consider sewing garments to be a worthwhile endeavor and certainly not a pleasurable one (Labat et al., 2007). Hence, new home sewers may be discouraged to continue due to the struggle to obtain a good fit (Labat et al., 2007).

Home sewers may not be willing to invest precious time in adjusting sewing patterns if the results are not satisfactory (Labat et al., 2007). This experience may lead to loss of industry's future sales (Labat et al., 2007). Pattern companies are well advised to find methods to consistently develop patterns that fit without complicated adjustments or extensive time commitment (Labat et al., 2007). Methods such as using computer technologies to provide custom patterns and offering less body-defining patterns to simplify pattern adjustments (Labat et al., 2007).

2.3 Chapter Conclusion

According to multiple sources, the large volume of garments in circulation from production, distribution, use and care to end of life, is an environmental burden. Waste reduction strategies should be prioritised over reuse, reconditioning and recycling (Fletcher & Grose, 2011). Conceptually, custom garments can increase garment use and lifetime, slow down garment replacement and production cycles, and, in turn, reduce garment volumes and the environmental burden (Maldini, 2019). In practice, custom garments may not be an effective strategy to reduce volumes as people, in effect, wear systems of interconnected garments, wardrobes (Maldini, 2019; Maldini et al., 2019). Garment fit affects a person's visual appearance as well as their comfort and mobility (Brown & Rice, 2013; Liechty & Rasband, 2006; Shen & Huck, 1993; Shin, 2013). Not surprisingly, it is a main reason people buy, wear and discard garments (Brown & Rice, 2013; Niinimäki, 2010; WRAP, 2017). Therefore, strategies to reduce garment volumes should, in the least, consider wardrobes and fit. More precisely, custom fit as, according to multiple sources, body shape, including posture, affects fit and RTW and commercial patterns use, for practical manufacturing, standard body sizing systems that cannot achieve fit for each and every body shape.

CHAPTER 3

RESEARCH METHOD

This Chapter presents the qualitative research method that was part exploratory, part content analysis, to elaborate a strategy to reduce garment volumes and improve garment fit for everyone. The Chapter presents details on the assumptions and limitations, literature review, semi-structured discussions and analysis of 21 studies. Qualitative research is useful to determine what is important and what should be studied when problems are multifaceted and information, variables or theory is missing (Leedy & Ormrod, 2016). Furthermore, exploratory research is useful to analyse and clarify a problem and establish priorities and an approach for subsequent more detailed research (Creswell & Clark, 2017; Sreejesh, Mohapatra, & Anusree, 2014). The qualitative data that is collected and analysed during the exploratory research can serve to develop and conduct subsequent quantitative research that generates more conclusive results (Creswell & Clark, 2017; Leedy & Ormrod, 2016; Sreejesh et al., 2014).

3.1 Assumptions and Limitations

This research elaborated a strategy to reduce garment volumes and improve garment fit for everyone based on two essential steps. Nonetheless, the strategy can be completed with other steps not considered in this research. Step 1 of the strategy is a conceptual wardrobe model based on the notions that the function of a wardrobe is to provide physical and psychological comfort over an extended period of time and that a person's body, style, social and climate profiles are stable over that time. Where the conceptual wardrobe model changes current garment design, production and consumption, and the professional field of garment design and pattern drafting, this research does not consider in depth the operational implementation or the economic viability of the model. Step 2 of the strategy is the automation of custom structural fit based on the notion that every person, regardless of shape, age or gender, is entitled to garments that structurally fit; that known body to garment relationship formulas to achieve that fit for each and every body shape is a worthy scientific endeavour; and that with current knowledge and technology, it is achievable.

3.2 Literature Review

The literature review was in part based on searches in Compendex, Scopus et Web of Science, that included the keywords listed below by general theme from top to bottom :

Fashion	3D body scan	Theory
Apparel	Parametri*	Fit
Garment	Parameteri*	Fit evaluation
Cloth*	Bespoke	Fit assessment
Environment*	Made to measure	Artificial neural network
Impact	Custom*	Support vector machine
CAD	Pattern	Wardrobe
Comput*	Patternmaking/pattern making	Minimal wardrobe
Technolog*	Block	Capsule wardrobe

Referenced sources span 78 years with recent sources, as well as multiple sources from past decades. This is not unique to this research. For instance, the 21 studies selected for the analysis presented in CHAPTER 7 referenced sources that spanned between 14 and 73 years with an average of 31 years. Older sources are referenced in this research, in part, because when more recent sources referenced older sources, in good practice, the older sources were reviewed and are referenced. Said differently, the research generally began with newer sources, and went back in time as appropriate. That newer sources still reference older sources may indicate that some long standing practices, gaps and challenges remain relevant today.

3.3 Discussions

Over the span of 26 months, discussions of approximately 60 minutes were held with 16 participants.

3.3.1 *Participants*

Eighteen people were contacted by email, three did not respond to the initial request by email or follow-ups by phone and/or email and one participant invited a second participant to join the discussion.

Seven participants were referred by a professor; three participants were referred by another participant; three participants were not referred directly but their place of employment was referred by another participant; two participants were contacted following their participation at a relevant conference or panel discussion; and one participant was a personal acquaintance with a relevant field of expertise.

The participants were active academics, professionals or entrepreneurs in the fields of fashion, pattern drafting, wearables, engineering, technology, computational and parametric design, digital arts or virtual reality. Participant details are presented in APPENDIX I. Participant input is presented as (1) to (18) in the research.

3.3.2 *Semi-Structured*

Discussions with participants were semi-structured. Somewhat unstructured and free-flowing interviews with a conversational tone allow some flexibility and departure from the prepared questions and topics (Leedy & Ormrod, 2016). Topics can be explored by collecting qualitative open-ended data in semi-structured interviews with a limited number of participants before engaging a larger sample in a quantitative research (Creswell & Clark, 2017; Given, 2008). One-on-one in depth interviews with major open-ended questions allow researcher and participant to explore an issue through conversation without restricting participants in their responses (Creswell & Clark, 2017; Sreejesh et al., 2014). Such interviews also give the researcher the opportunity to ask further questions and clarify any uncertainties (Sreejesh et al., 2014). The data collection is influenced by the dynamic developed between the researcher and the participants (Naber, 2015).

Face-to-face discussions were held with 10 participants in or near Montréal, Québec, Canada; face-to-face discussions were held with three participants in Amsterdam, Netherlands; two discussions were held over video conference with one participant in New York, New York, United-States (US) and one in Manchester, United Kingdom (UK); one discussion was held over the phone with the participant in Amsterdam. Eleven of the 13 face-to-face discussions were held at the participant's place of work or practice. Two face-to-face discussions were held in a coffee shop. Early on, written notes were taken during discussions. Later, notes were typed in a Word document on a laptop during the discussions.

Participants were first researched on the web to gain general knowledge of their experience and expertise to define how they can best contribute to the research. Where participants published studies, they were read. Participants were then contacted by email requesting a meeting to discuss. The email introduced the topic of the research. Generally, current understandings and research objectives as well as discussion objectives were detailed. Prior to the discussions, further questions and topics of discussion were prepared but not shared with participants ahead of the discussion. The discussion process ended when topics had been discussed with multiple participants and statements were generally coherent from participant to participant.

3.3.3 *Bias*

The lack of structure of semi-structured interviews introduces the possibility of bias where the presence of the researcher influences participant responses (Sreejesh et al., 2014). Participants can respond with a bias to support what they believe is desired by the researcher (Leedy & Ormrod, 2016). Although the following reduce potential bias, they do not remove potential bias completely. Participants were mainly referred by a third party, and except for one, were strangers and were not part of a shared network. Participants were experts in their field with more experience, knowledge and influence in their respective fields than the researcher. Participants were provided research understandings and objectives ahead of time giving them the opportunity to reflect, offer corrections or specifications, or ask for further clarification or questions if required. No incentive was offered, and as the research was exploratory without a predefined end, there was no tangible incentive for the participants. Lastly, topics were typically discussed with multiple participants to ensure a certain level of coherence and agreement.

3.3.4 *Compilation*

Discussion data was compiled in an Excel table. The table first included research understandings and objectives at the time participants were contacted. These were included in the emails sent to participants requesting a meeting to discuss. Second, questions and topics of discussion prepared ahead of the meeting. Third, participant statements compiled during the discussion. Fourth, references shared by participants. Having the references in their own column rather than within the statements, facilitated their review. Fifth, major new research developments.

For coherence and to avoid redundancy, with the assistance of an Excel module, synonyms were searched and replaced where appropriate, with unique words. Examples include replacing where appropriate, CAD with digital; tool with system; tailor, pattern cutter, pattern maker and designer with pattern drafter; fashion, clothing and apparel with garment; customer and consumer with wearer; formulas and instructions with theory. In some instances, participant statements were not modified to remain true to the statement.

Research understandings and objectives were then copied to a new tab in Excel with one item per line. When an understanding or objective was repeated, only the first one was retained. Participant statements were also copied to a new tab with one statement per line. Keywords were then assigned to each participant statement. Individual research understandings and objectives, and participant statements, were then printed, cut and laid out on large 25”x30” easel Post-it sticky sheets in three different patterns. First, research understandings and objectives were laid out by chronology. Second, participant statements were laid out by chronology. Third, participant statements were laid out by keyword. The last pattern, participant statements laid out by keyword, was retained.

Given the exploratory method, the literature review and discussions evolved hand in hand, in an iterative process. Understanding from the literature guided the direction of the research and subsequent participant selection. Alternatively, discussions with participants guided the direction of the research and subsequent literature review. To reflect this evolution, data from the literature review and discussions with participants is presented by topic, alongside one another.

3.4 Analysis of 21 Studies

The literature review and discussions established, as presented in CHAPTER 5 and CHAPTER 6, that CAD systems do not automate custom structural fit as pattern drafting does not produce it. For these reasons, 21 studies on the topic custom fit pattern drafting CAD systems were analysed. As, by analysing the content of a body of material, patterns, themes, and biases can be identified (Leedy & Ormrod, 2016). The studies' technical, sampling and evaluation methods, and conclusions, were compiled in an Excel table for comparison and analysis. The table is discussed in CHAPTER 7 and presented in APPENDIX II.

CHAPTER 4

CONCERTED MINIMAL CUSTOM WARDROBES

Where CHAPTER 2 established that strategies that aim to reduce garment volumes should, in the least, consider wardrobes and fit, more precisely, custom fit. This Chapter presents Step 1 of the strategy to reduce garment volumes and improve garment fit for everyone. Step 1 is a conceptual concerted minimal custom wardrobe model that is composed of a minimal number of custom garments that structurally fit a person's unique body shape and are concerted to efficiently relate to one another and, over an extended period of time, to the person's unique style, social and climate profiles. Figure 4.1 illustrates the main concepts of the concerted minimal custom wardrobe. The model and its concepts are further presented in this Chapter.

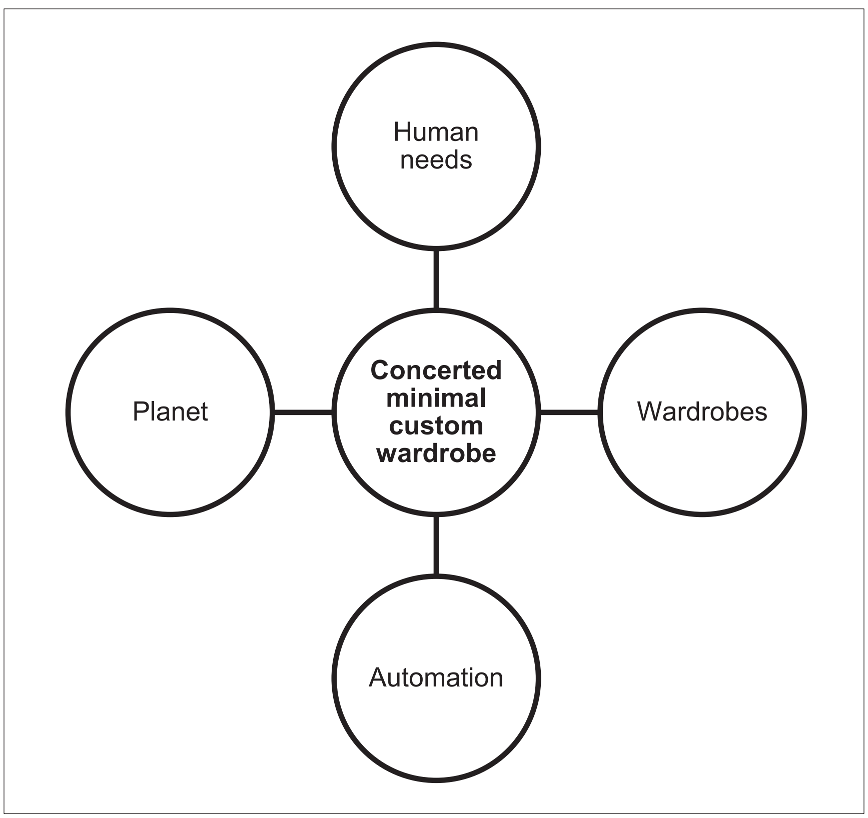

Figure 4.1 Concerted minimal custom wardrobe conceptual chart

4.1 Multidimensional Fit

Thus far in this research, fit has referred, as it generally does, to the relation between body and garment shapes. But people are more than mere bodies. They are humans with needs such as self-confidence, relations and sense of belonging (Maslow, 1943). In this respect, fit relates to other dimensions such as visual appearance, whether a garment portrays the right image for the person and whether it is appropriate for the type of social event such as a job interview versus a sporting occasion (Shin, 2013). In sum, fit relates to physical and psychological comfort, and confidence (Shin, 2013). Going forward, this research considers that confidence is a matter of psychological comfort and that the function of a garment is to provide physical and psychological comfort. Garments also protect the body from the elements (Maslow, 1943). For these reasons, Figure 4.2 illustrates garment fit with body, style, social and climate dimensions that are further presented below.

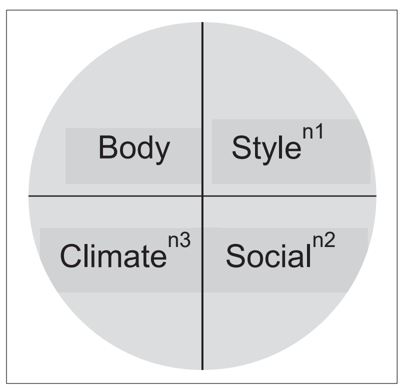

Figure 4.2 Fit Dimensions

The body dimension refers to the relation between body and garment shapes. Hereafter, the term structural fit will be used to refer to this body to garment relation. As defined in Section 1.1, structural fit relates to how well the shape and size of the garment conforms to the shape and size of the human body while standing, walking, sitting and bending. It relates to fitting ease to allow breathing and basic body mobility. It does not relate to design ease for personal perceptions of comfort. Design ease, comfort, visual appearance, fabric elasticity, weight, bulk and texture, and other garment specifications that relate to personal perceptions and preferences relate to the style dimension. Separating structural fit and personal perceptions and preferences in two distinct dimensions, body and style, reduces the subjectiveness of structural fit evaluation as further presented in Section 8.3. The social dimension refers to different types of social events, and the climate dimension to different climates and weather. One study found that the greatest challenge with a capsule wardrobe was to dress appropriately for special events and during change of seasons (Bang, 2019).

The multiple fit dimensions must be met simultaneously. For instance, feeling cold in a garment that otherwise fits, leads to discomfort and a garment that fits the body, but is not the right style for the target person or a specific social event, also causes discomfort. Furthermore, all garment areas must simultaneously structurally fit the body as a garment that fits at the shoulders, but is too tight around the upper arms, causes discomfort. Therefore, garments must simultaneously adequately relate to, or fit, a person’s unique body and their unique style, social and climate profiles.

In effect and as illustrated in Figure 4.3, individual garment pieces do not meet all fit dimensions. For instance, while a top or a bottom garment piece may fit a body shape, on its own, a garment will not meet style, social or climate dimensions. Hence, fit must be considered in the least, at the scale of outfits. While an outfit can meet style, social and climate dimensions for a moment, such as a day or a specific social event, it does not meet style, social and climate dimensions over an extended period of time. As, over time, a person’s style, social and climate profiles vary. Therefore, over an extended period of time, fit dimensions are met by a wardrobe of outfits. At the wardrobe scale, style, social and climate dimensions are annotated with n1, n2 and n3 respectively, to indicate that the extent to which each of these dimensions varies, depends on the person. For instance, a person may wear multiple styles, attend limited types of social events and live in a tropical climate. Another, may stay true to one style, attend multiple types of social events and live in a temperate climate. And so on. Nonetheless, it is assumed that n1, n2 and n3 are stable for each person over an extended period of time. The front, side and back views in Figure 4.3 reflect that structural fit is 3D.

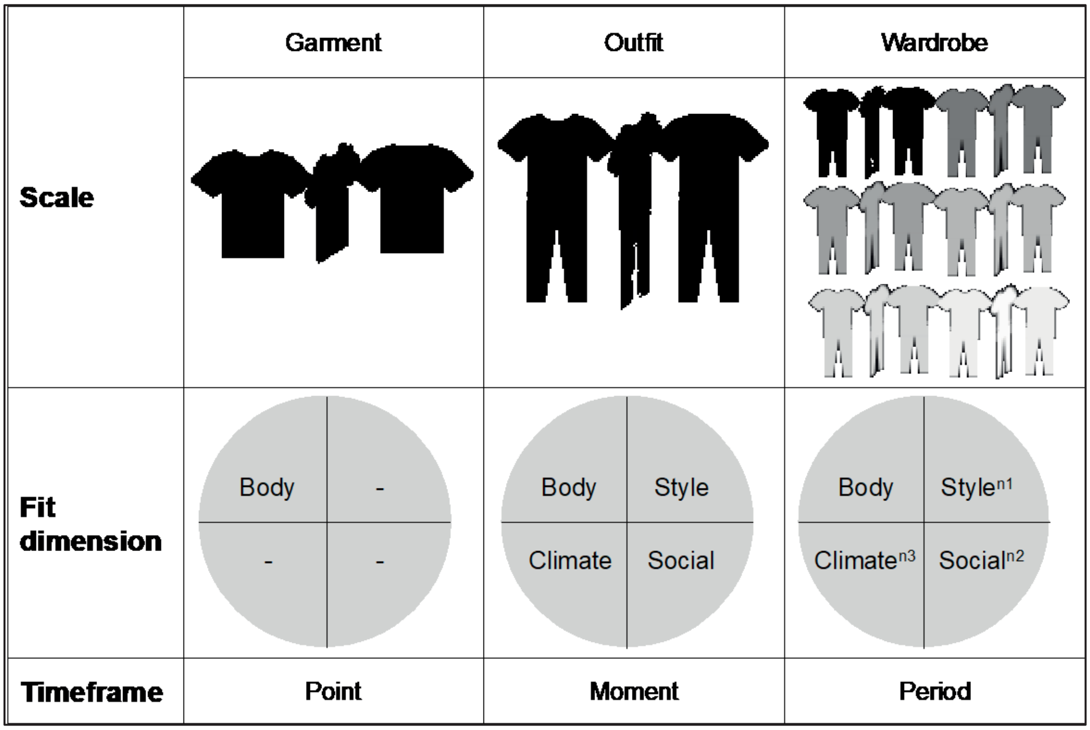

Figure 4.3 Custom garments to custom wardrobes

4.2 Minimal Number of Garments

While all people, regardless of shape, age or gender, are entitled to garments, outfits and wardrobes that meet their needs, they also live in a closed system with limited space and resources, planet Earth, which cannot meet all of their unrestrained wants. Currently, one may have in their wardrobe, a pair of pants for which they like the fit at the waist, another for which they like the length, another for which the like the color and another for which the fabric is right for the season or a specific occasion. Despite the four pairs, none checks all the boxes. Nevertheless, four pairs of pants were shopped for, bought, and have gone through the extraction, production and distribution phases of the supply chain. Furthermore, how well each pair of pants goes with a top is highly uncertain, especially given that current fast fashion production cycles sell garments as individual pieces rather than as part of an outfit with concerted styles, colors and fabric. As garments are not bought as concerted pieces of an outfit that go well with one another, wardrobes are filled with individual pieces that may or may not go well with one another, and purchasing another garment piece to go with an existing or newly purchased piece is sometimes required.

One may be reminded that their wardrobe is composed of interconnected garments and that fit is multidimensional when travelling. For instance, when choosing garments to pack, one may realise that one garment only goes well with one specific other garment or a limited number of specific garments. One also needs to consider the climate of where they are travelling to as well the type of social events they will be attend. One’s suitcase is quickly filled with garments to wear in case the weather the changes, or in case one gets invited to an unexpected outdoor hike or formal dinner. The “in case” garments only go well with certain garments that are also added to the suitcase. In sum, if someone else were to pack one’s suitcase, one could not simply have the other randomly pick a certain number of tops, bottoms, jackets, shoes, etc., because the individual garments do not necessarily go well with all other garments, and may not be suitable for all types of social events or climates.

To minimise the number of garments within a wardrobe, garments and outfits in the conceptual concerted minimal custom wardrobe model are concerted to efficiently relate to one another, and over an extended period of time, to the person’s unique style, social and climate profiles. Thereby, the model primarily reduces volumes of garments by reducing the number of garments that a person buys or has in their wardrobe that do not relate with other garments or to the person’s style, social and climate profiles. While there is a minimal number of garments and the choice is reduced, the selection is concerted, potentially providing the person with more ease of mind than a feeling of limited choice. 87.5% of 128 participants in study based on a capsule wardrobe of 10 garments stated being “interested in possessing a package of essential clothes” (Jalil & Shukhaila, 2019). Barack Obama, when president of the US, only wore gray or blue suits[4]. Not having to decide what to wear allowed him to focus on other decisions[4]. Mathilda Kahl, an art director at an advertising agency in New York, US, wears a work uniform that allows her to feel great about she is wearing without spending time thinking

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[4] https://www.vanityfair.com/news/2012/10/michael-lewis-profile-barack-obama

about she is going to wear [5]. Another study found that males living in rural areas with no particular interest in clothing had the smallest wardrobes (Maldini, 2019). This may not be accurate, but in addition to their lack of interest in clothing, one can also image rural farmers who, on a daily basis, wear a sort of work uniform with a limited variety of garment types contributing to their smaller wardrobes.

The success of personal uniforms, essentials and the concerted minimal custom wardrobe is partly founded on a person knowing and understanding in what garments they feel they most comfortable, physically and psychologically, the most confident, the most themselves, less conscious about what they are wearing. Some people know exactly what they want and do not want in a garment. Mature people in age may have a better sense of what they want to wear and what they feel good in (5). Either from more experience wearing different types of garments and testing what feels right and what does not. Or from having a greater sense of who one is. Nevertheless, some people do not know what they want in a garment (18). Such people may need assistance with questions about garments they currently own or have owned in the past, questions pertaining to ease, style, feel of fabric on the skin, thickness of fabric, tightness or looseness of fabric in certain areas, areas where the person normally feels warm or cold, etc. A complete registry of such questions may need to be further researched.

As a conceptual model, the concerted minimal custom wardrobe requires other subsequent research to, for instance, establish efficient numbers of garments, outfits, interconnections and layering options, with potential different levels of minimalism according to climate profiles as a sort of target. The model also requires subsequent research to validate its in practice effect on garment purchase, use, lifetime and volumes. Research to date on minimal and capsule wardrobes is limited. Studies to date mainly focused on observing the effect of selecting and wearing a limited number of garments from a current wardrobe (Bang, 2019; Bardey, Booth, Heger, & Larsson, 2021; Rhee & Johnson, 2019). The studies generally observed that minimal wardrobes make people aware of garment numbers, sustainability and needs versus wants, as

[5] https://www.harpersbazaar.com/culture/features/a10441/why-i-wear-the-same-thing-to-work-everday/

well as lower stress and decision fatigue, lower pressure to follow trends and enhanced creativity (Bang, 2019; Bardey et al., 2021; Rhee & Johnson, 2019). Nonetheless, further awareness-raising efforts may be required to optimise the in practice effect of the concerted minimal custom wardrobe on garment purchase, use, lifetime and volumes.

4.3 Levels of Use

This Section presents the model's two levels of use, wearers and makers.

4.3.1 *Wearers*

At the first level, a person gradually ideates with a professional a concerted minimal custom wardrobe according to the person's unique body shape and their unique style, social and climate profiles. A CAD system automates custom structural fit, and it stores patterns and specifications of past garments such as, ease values, styles and fabrics. The wearer shares information about themselves, their lifestyle, their personal preferences and feedback on their past and current garments, outfits and wardrobe. The professional shares their knowledge on garments, outfits and wardrobes. The professional receives feedback from the wearer and sees, in the flesh, the fruit of their labor. The professional sees how the wearer looks and behaves in the garments and outfits. For instance, do they give off a sense of comfort or discomfort, of being confident and unconscious of the garments they are wearing or are they self-conscious and always pulling and readjusting the garments. The professional also sees the strain and wear of fabric over time. All these forms of feedback are valuable for continued improvement. This echoes the functional design process for protective clothing from occupational hazards presented in Easter (1994). In this process the end user and the designer establish requirements and garment specifications to meet the requirements. The end user provides insight outside of the designer's knowledge and experience and vice versa. The end user provides information on their human needs and the designer looks beyond the user's obvious request for a more comprehensive portrait of the user and their environment. To assess the protective garments, the designer makes direct visual observations of the user in the protective garment in their work environment and the user is interviewed (Easter, 1994). This also changes the role and potentially the training of professional designers and pattern drafters.

4.3.2 *Makers*

At the second level, people sew their own garments. Making relates to the human self-actualisation needs to make and to create (Maslow, 1943). Again, a CAD system automates patterns to structurally fit the maker's unique body shape, reducing the challenges that home sewers encounter with structural fit as presented in subsection 2.2.2. While making garments may seem daunting, in effect, most current garment styles are rather simple to sew with few pleats, shoulder pads, lining and other design features.

Real maker spaces are equipped with the CAD system that automates custom structural fit, computers, lookbooks, sewing machines, embroiderers, laser cutters, printers, projectors and 3D body scanners. Makers use real and virtual spaces to learn, make and collaborate through classes, workshops, webinars and independent use. Makers learn how to sew garments as well as how to build a concerted minimal custom wardrobe. The making and learning happen at the spaces, in the home or a combination of both. Technologically up to date garment maker spaces that offer classes, workshops and tutorials to learn, and exchange is of interest to fashion students, home sewers and designers (3, 8). Maker spaces could also help young professionals prepare for the digital fashion workforce (12). Although not dedicated to garment making, the Makers Lab at the Amsterdam University of Applied Sciences is an example of digital fabrication workshop and open design space (Amsterdam University of Applied Sciences, n.d.). It is free of charge for students and employees to make and create in a do it yourself (DIY) spirit using the Lab's risograph (RISO), ultraviolet (UV) and 3D printers, laser, foam and sticker cutters and other tools[6]. The Makers Lab is also part of the school's curriculum and students learn to collaborate, make, think critically and question the designs, benefits, needs,

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[6] https://www.amsterdamuas.com/create-it/research/facilities/facilities.html

technologies and branding strategies of existing products (Amsterdam University of Applied Sciences, n.d.).

4.4 Cost and Revenue

The purchase of a reduced number of garments helps offset the difference in cost per garment between RTW and custom. While custom garments may be more expensive per unit, people are purchasing a reduced number of garments with the benefit of having wardrobes that are concerted to meet their unique needs and fit dimensions. The principle becomes the cost of a wardrobe rather than the cost of a garment. Furthermore, 70% of the cost of a product is generally attributed to marketing and the other 30% to materials and labor (10). The need to allocate up to 70% of a garment's price to marketing can be challenged with new model objectives and varied sources of revenue such as user fees, classes, workshops, webinars, consulting services and sale of patterns.

4.5 Production

Customisation requires a change in current mass production and distribution with methods, technologies and unit production systems that efficiently produce small quantities (Loker, 2007). This consideration is not explored in depth in this research, but custom garments could be produced by hubs of small-scale custom garment manufacturers that service multiple local designers (6). While such a change may be difficult, manufacturers can profitably participate in emerging and user centered models by offering custom manufacturing to specific users (von Hippel, 2005). Technology and proximity to target markets can produce locally manufactured goods with an advantage over foreign produced goods (Yang, Zhang, & Shan, 2007).

The ability to produce on demand may also have an effect on consumer behavior. Knowledge that one can have a garment produced when needed may reduce the consumer urge to buy as a result of perceived scarcity. When consumers perceive scarcity, that is strategically created by retailers, they develop an urge to buy a product now in case it will not be available tomorrow (Gupta & Gentry, 2016).

4.6 Technological Readiness

The conceptual concerted minimal custom wardrobe goes beyond custom structural fit. Nevertheless, custom structural fit is essential as is a CAD system that automates custom structural fit. While, some envision a future garment experience that starts with a person's 3D body scan and ends with home delivered custom garments (Hein A. M. Daanen & Psikuta, 2018). Others caution that custom fit and look requires high-performance software (18). The ability of pattern drafting CAD systems to automate custom structural fit is presented in CHAPTER 5.

4.7 Chapter Conclusion

Based notions in Shin (2013) and Maslow (1943), the function of a garment is to provide physical and psychological comfort and fit includes body, style, social and climate dimensions. Consequently, the elaborated conceptual concerted minimal custom wardrobe model to reduce garment volumes and improve garment fit for everyone, is composed of a minimal number of custom garments that structurally fit a person's unique body, and are concerted to efficiently relate to one another and, over an extended period of time, to the person's unique style, social and climate profiles. Separating structural fit and personal perceptions and preferences in two distinct dimensions, body and style, reduces the subjectiveness of structural fit evaluation. The model is user centered, it enhances user satisfaction and agency, and it engages users as wearers and makers. The model is in part founded on the ability of a CAD system to automate custom structural fit and automation of custom structural fit is Step 2 of the two-step strategy.

CHAPTER 5

CUSTOM FIT CAD SYSTEMS

This Chapter presents Step 2 of the strategy to reduce garment volumes and improve garment structural fit for everyone. Step 2 is the automation of custom structural fit, that is, the ability of CAD systems to draft, for each and every body shape and directly from inputted formulas and body shape data, patterns that structurally fit without alterations. A CAD system that automates custom structural fit democratises innovation by giving more people, professionals, and companies the ability to make, with less skills and training, for themselves or their clients, custom garments that structurally fit. Greater access can scale the potential effect of the concerted minimal custom wardrobe on garment volumes, and user satisfaction and agency. Automation of other fit dimensions, such as style, and garment specification are desirable but are not included in the scope of this research. The information in this Chapter is solely based on the literature review and discussions. It does not consider claims by commercially available CAD systems as their true methods and performance beyond marketing strategies are not easily verifiable.

While pattern drafting is further presented in CHAPTER 6, the current paragraph provides the novice reader some basic concepts. Garments are 3D shapes made from two-dimensional (2D) patterns to cover the complex geometry of the body (Hong, Zeng, Bruniaux, & Liu, 2017). The 2D pattern is the foundation of the garment (Beazley & Bond, 2003). A (structurally) well-fitted garment relies on accurate pattern drafting (Huang et al., 2012). The complexity lies, in part, in the nonlinear deformation of the 3D garment surface to the corresponding 2D pattern (Yang et al., 2007). The complexity is often underestimated (Beazley & Bond, 2003; Gill, 2015). Darts, seen as wedges in the 2D pattern, remove unwanted fullness to accommodate the hollow areas of the 3D body (Armstrong, 2010). Figure 5.1 taken from Armstrong (2010) illustrates pattern darts.

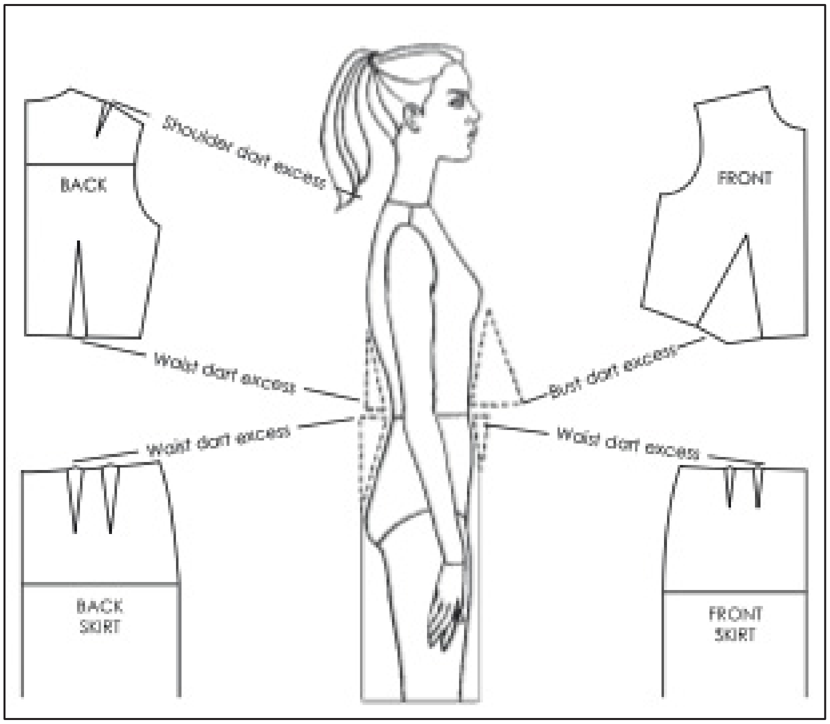


Figure 5.1 Pattern darts
Taken from Armstrong (2010, p. 39)

5.1 System Methods

Based on their technical method to generate custom patterns, CAD systems generally fall into three main categories. They are, pattern drafting, 3D to 2D flattening and virtual simulation. Each is presented in the following subsections.

5.1.1 *Pattern Drafting*

With CAD systems founded on pattern drafting, the user, or system, first determines the best size match between the target person and the system's standard sizes, that is what size would (structurally) fit the target person best without alterations (Istook, 2002; Song & Ashdown, 2012). The system then compares the person's measurements with the standard body and alters the standard pattern to the person's body measurements (Istook, 2002; Song & Ashdown, 2012). Grading rules within the system determine by how much each pattern location needs to be increased or decreased (Istook, 2002). Such systems store a large database of size charts and graded patterns, or they apply predetermined mathematical formulas to selected areas to grade patterns to the target person's measurements (Beazley & Bond, 2003; Istook, 2002; Song & Ashdown, 2012; Xiu, Wan, & Cao, 2011).

These CAD systems require a significant amount of behind-the-scenes effort (Istook, 2002; Yang et al., 2007). To make alterations rapidly, the CAD systems rely on rules defined by experienced pattern drafters as the systems do not carry the knowledge and are not able to learn it by experience (Istook, 2002; Kwong, 2004). The systems provide a shorter product development cycle, without the ability to produce better (structural) fit (Beazley & Bond, 2003; Song & Ashdown, 2012; Tao, Chen, Zeng, & Koehl, 2018; Xiu et al., 2011).

5.1.2 *3D to 2D Flattening*

CAD systems founded 3D to 2D flattening, first convert a 3D body scan to a virtual 3D body, garment or pattern model that is then flattened to a 2D pattern with an algorithm (Huang et al., 2012; D. Zhang, Wang, & Yang, 2014). The surface of a 3D garment is complex and cannot be flattened to a 2D pattern without distortion and error (Yang et al., 2007). 3D to 2D flattening methods always present some distortions especially for garments with complex styles (Yang et al., 2007). Boundaries of neighboring pieces that do not maintain the same length when flattened due to distortion, result in wrinkling when pieces are sewn together (Y. Zhang & Wang, 2011).

While different 3D to 2D flattening methods have been researched and some success is achieved, improvements such as practicality and accuracy are required (Su, Liu, & Xu, 2015; Yang et al., 2007). Further research is required before a commercial system that produces custom 2D patterns from 3D body scans is suitable for practical application and is widely available (Bye, 2010; Hyo Kim, Hwan Sul, Park, & Kim, 2010).

5.1.3 *Virtual Simulation*

Some simulation systems are intended to support practitioners in garment development processes and improve prototyping (Gill, 2015). For instance, designers can evaluate design, fabric suitability and patterns in a virtual environment and simultaneously change the 2D pattern and virtual 3D garment model before producing a physical garment and testing and altering it for (structural) fit (Huang et al., 2012; Hunter & Fan, 2004; Tao & Bruniaux, 2013). Other simulation systems are intended for customers to preview the (structural) fit of a garment based on their body measurements and/or body shape to reduce returns (Gill, 2015). Some systems require the consumer to classify their own body shape (Gill, 2015). For this to be effective, the consumer must have the ability to classify their body shape despite general and subjective categories (Gill, 2015). While most systems claim to present realistic effects, their performance needs to be evaluated by the end user and further development is required to produce life-like avatars, postures and fabric properties (Gill, 2015; Hunter & Fan, 2004). One limitation is that virtual body models do not have compressible flesh, as a result they do not displace flesh and bulge at waist (D.-E. Kim & LaBat, 2013).

Simulation technology can be useful to visually evaluate virtual garments, but its application to garment production is uncertain and it does not produce precise (structural) fit (Dong-Eun & LaBat, 2013; Hong et al., 2017; Huang et al., 2012). In other words, the technology enhances virtual product development but does not provide theory that relates to practice (Gill, 2015).

5.2 3D Body Scanning

All categories of CAD systems can use 3D body scanning. 3D Body scanners are increasingly within the spectrum of mass adoption with costs ranging from 1 000$ to 20 000$ and short capture times (Gill, 2015). 3D body scanners make a digital copy of the outside shape of the human body capturing approximately 300 000 x, y and z data points in approximately 12 seconds (Hein A. M. Daanen & Psikuta, 2018; Loker, 2007). Measurements obtained from 3D body scans can be entered and stored in a pattern drafting CAD system (Chen, 2007; Hein A.

M. Daanen & Psikuta, 2018). Given the high number of available measurements from scans, a careful selection of measurements is required (11). Scanners need to be calibrated and scan data can be influenced by the posture of the person during the scan capture as well as the time of day the scan is captured (Bellemare, 2014). For instance, measurements can differ up to 2.5 cm whether a subject is holding their stomach in, is in an erect posture or a relaxed posture (Bellemare, 2014). Generally, subjects are scanned in a fixed position with arms and legs away from the body (Gill, 2015). Undergarments, particularly bras, worn during the scan can also affect body shape (Threads Magazine, 2012). Scanning subjects with their own undergarments reflects the size and shape of the body to be clothed and not their "natural" body shape (Gill, 2015). Hence, scans should be taken with the undergarments that will be worn with the garment to ensure accurate fit (Threads Magazine, 2012).

Some believe that measurements from 3D scans have fewer errors than when taken manually with a tape and may lead to (structurally) better-fitting garments (Brown & Rice, 2013). Measurements such as hip circumference, if defined as the largest circumference at the hip, may be easier to identify with a 3D scan (Hein A. M. Daanen & Psikuta, 2018). However, body landmarks identified by palpitating for skeletal protrusions cannot be identified from scans (Ashdown, Mee Sung, & Milke, 2008). One example is the shoulder point, an important landmark in pattern drafting (Ashdown et al., 2008). Moreover, measurements and their definitions may differ between manual and 3D scanning methods and can result in differences exceeding 10 cm (Bellemare, 2014; Hein A. M. Daanen & Psikuta, 2018; Dabolina, Vilumsone, Dabolins, & Belakova, 2015). Depending on the location, such a variation can be the equivalent of over two female body sizes (Beazley & Bond, 2003; Pellen, 2014). Finally, scans also do not define body density and extensibility variations such as around the abdomen (Bellemare, 2014).

Others believe that the advantage of 3D scans in pattern drafting lies in the available body shape information such as circumferences, arcs, widths and depths (Bellemare, 2014; Hein A. M. Daanen & Psikuta, 2018; Gill, 2015; Loker, 2007). Whether 3D body scans can provide more precise and accurate measurements is irrelevant, their main benefit is that they better reflect the shape of the 3D body than manual measurements (12).

Despite the availability and possibilities of body scans, with a few exceptions, they are not widely adopted in commercial systems (Gill, 2015). Patterns remain predominantly based on traditional methods and instructions from published sources and no commercial system is producing accurate pattern shapes directly from body scans (Gill, 2015). In the end, the systems often compare the proportions a person against a large database and do not typically use individual body scans (Gill, 2015). In order to translate the wealth of body scan data to improved (structural) fit, the direct scan to pattern relations need to be established (Gill, 2015). There's hope that pattern drafting theory can evolve with the greater number of measurements offered by 3D body scans (6).

5.3 Performance

Current pattern drafting CAD systems present opportunities for improvement such as adaptability to a person's body shape, accuracy and user-friendliness (3, 6, 16, 18). Unpredictable (structural) fit limits automation and the application of technology (Gill, 2015; Yang et al., 2007). With current pattern drafting CAD systems, drafted patterns have to be corrected to (structurally) fit individuals (McKinney et al., 2017). Where pattern drafting CAD systems generally facilitate the development of garments, the knowledge and skill of the operator remain very important (Dabolina et al., 2015). The systems can be complicated to operate, and some require a highly experienced pattern drafters with extended knowledge and experience in garment design, pattern drafting and (structural) fit evaluation (Gu, Gu, & Liu 2017; Istook, 2002; Yang et al., 2007). In effect, current pattern drafting CAD systems are intended for pattern drafters (18). And for some pattern drafters, CAD systems meet their needs (9, 12). Other pattern drafting CAD systems can be difficult for pattern drafters to use. On the one hand, data and engineering driven CAD systems can be difficult for pattern drafters to adopt because their link to traditional practices is not clear (Gill, 2015). On the other hand, with little documented pattern drafting theory, the developers of these systems do not grasp pattern drafting complexities (Gill, 2015). Furthermore, pattern drafting CAD systems are generally heavily dependent on a specific style of a garment (Han et al., 2015; Li et al., 2013). New garments generally require new formulas, patterns or other system setups by an experienced practitioner (Han et al., 2015; Li et al., 2013).

Many improvements need to be made to 3D CAD systems such as Gerber, Lectra and PAD to produce custom garments (Yang, Zou, Li, Ji, & Chen, 2011). CAD systems such as Assyst, Gerber, Investronica, Lectra, Optitex and PAD have different interfaces but share the same basic underlying theory that allows “automatic” pattern alterations according to a target person’s measurements (Istook, 2002). While such systems are considered automatic, they require a lot of laborious preparation by a practitioner with strong garment design, grading and production knowledge as well as computer software understanding (Istook, 2002). CAD systems such as Gerber, Lectra and Assyst, require considerable pattern drafting knowledge to use them appropriately (Guo & Istook, 2021).

CAD systems such as Lectra, Telmat and ScanVec use body scans to simulate garments in a virtual environment, manage orders and make (structural) fit and size adjustments (D. Zhang et al., 2014). However, the process of modifying patterns according to scanned body measurements is manual (D. Zhang et al., 2014). Hence, these systems require a professional designer to alter patterns to produce a custom garment according to the person’s measurements (D. Zhang et al., 2014).

Systems such as Dress Shop, LEKO, Patternmaker, Personal Patterns and Wild Ginger, were developed for the home sewing industry (Loker, 2007). The home sewer choses a style and the system produces a pattern to their measurements (Loker, 2007). In effect, these systems also require development to make the process of making (structurally) well-fitted garments by the home sewer easier and more successful (Loker, 2007).

Older sources in this Section are still referenced in recent sources, some as recent as 2021, and the statements remain relevant today. In effect, the automation of custom structural fit remains a challenge. To this end, two participants involved in the research and development of pattern drafting CAD systems, stated that each of their systems would not produce optimal custom structural fit and would require alterations (3, 6).

5.4 Chapter Conclusion

According to multiple sources, CAD systems, regardless of technical method, do not truly automate custom structural fit. For instance, pattern drafting based systems require extensive set up by a knowledgeable pattern drafter, 3D to 2D flattening systems produce distortions and virtual simulation systems are limited to preview fit before purchase or garment development.

CHAPTER 6

PATTERN DRAFTING

Given that CHAPTER 5 established that CAD systems based on pattern drafting do not automate custom structural fit, this Chapter presents pattern drafting and its ability to produce custom structural fit.

6.1 Block Patterns

In the late 18th century, most garments were custom made by tailors (Yu, 2004a). Each tailor had a personal system and methods to measure bodies and fit garments (Kidwell & Christman, 1974; Yu, 2004a). Tailors had a very detailed understanding of the anatomy, physiology and geometry of the body (Gill, 2015). With this understanding each tailor developed their own methods to measure the body and record required information to produce block patterns for individual customers (Gill, 2015). Sometime during the 20th century, tailors' practice of creating custom block patterns for individual customers was replaced by RTW's practice of creating block patterns for standard sizes that could then be altered to fit the customer (Gill, 2015). RTW's practice of standard sizing was further presented in Section 2.2.1.

Block patterns are the foundation of the final shape of the pattern and garment (Beazley & Bond, 2003). Blocks are limited to fitting ease that is further presented in subsection 6.3.1. Without any style features, blocks are meant to replicate the body shape as much as possible reflecting its size, figure and posture (Beazley & Bond, 2003; Threads Magazine, 2012). Figure 6.1 taken from Huang et al. (2012) illustrates a block in muslin fabric that combines bodice and skirt. Blocks permanently record the correct (structural) fit for the bodies for which they were developed (Beazley & Bond, 2003). Primary blocks include bodice, sleeve, skirt and pants (Beazley & Bond, 2003). Complicated stylized garments are created by adding design features such as design ease to blocks (Beazley & Bond, 2003; Chen, 2007; Huang et al., 2012; Liechty et al., 2016; Threads Magazine, 2012).

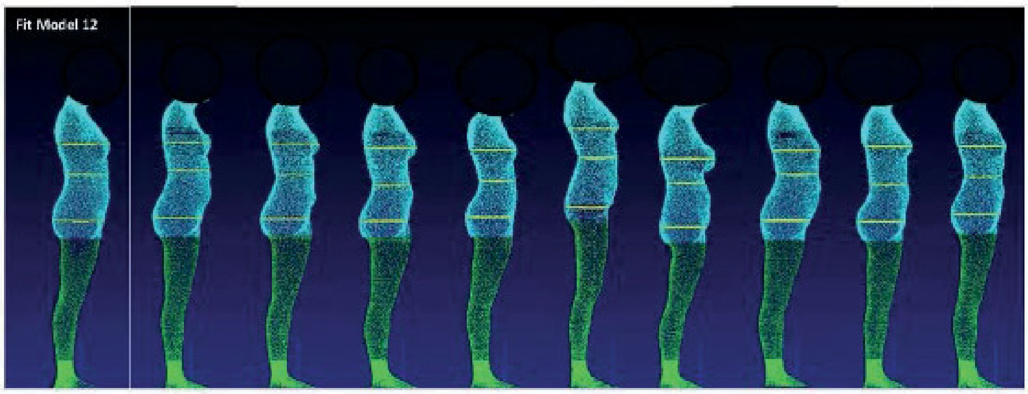
Figure 6.1 Bodice and skirt block in muslin fabric
Taken from Huang et al. (2012, p.689)

6.2 Measurements

The selection and number of measurements collected to establish size charts and sizing systems vary greatly amongst practitioners and researchers, anywhere from four to 140 (Gill, 2015). From a selection of nine authors, the number of measurements required to develop a bodice varied from three to 15 (Gill, 2015).

The manual method of taking measurements with a measuring tape is time consuming and accuracy and reliability depend on the skill of the person taking the measurements (Shen & Huck, 1993). 2D measurements can also be generated from 3D body scans. Measurements errors can happen from both body scans and the manual method (Guo & Istook, 2021).

Pattern drafting mostly relies on 2D measurements such as width, circumference and height with little information on the 3D curved body shape (Soyoung Kim, Yeonhee, Yejin, & Kyunghi, 2010; Kwong, 2004). Such 2D measurements fail to consider more complex and detailed information related to individual shape (Gill, 2015). Pattern drafters can complete 2D measurements with qualitative descriptions of body variations but these have their own limitations (Kwong, 2004). For instance, classifications based on ideal, triangular, inverted triangular, rectangular, hourglass, diamond, tubular or oval body types focus on front views and fail to consider posture and its effect on (structural) fit (Gill, 2015; Liechty & Rasband, 2006; Liechty et al., 2016). Posture makes it so patterns can (structurally) fit people with the same measurements differently (Kwong, 2004). Figure 6.2 taken from Gill (2015) illustrates that bodies with identical measurements can have different shapes. The following subsection 6.2.1 presents how different shapes can affect structural fit. Nevertheless, body shape is rarely considered in sizing systems (Gill, 2015).



Scans are filtered by first identifying those who meet the hip criteria, then those who meet this and the waist criteria, finally those who fit all three Hip, waist and bust. This reduced 50 potential candidates to about 30, then to 9.

Figure 23. Example of using a fit model as a size determiner compared to a population sharing similar key dimensions.
Source: Image developed during the Size Nottingham Project 2013 by S. Gill.

Figure 6.2 Identical body measurements with different body shapes
Taken from Gill (2015, p. 40)

6.2.1 *Body Shape Variability*

Bodies vary in height, bone structure, proportion, weight, weight distribution and posture (Liechty & Rasband, 2006). No two bodies are alike, and some are not symmetrical left to right (Beazley & Bond, 2003; Brown & Rice, 2013; Liechty et al., 2016). Hips may be anywhere from 5 cm to more than 30 cm below the waist (Threads Magazine, 2012). Even within a specific population of size 36 US military males, there are significant horizontal and vertical variances (Griffin & Dunne, 2016). Beazley and Bond (2003) identified 29 body and posture variations and Liechty et al. (2016) identified 88. These variations are listed in APPENDIX III. Naturally, a person can have a combination of these variations, increasing the number of possible variations even higher. Many (structural) fit problems are related to such body variations and other body characteristics (Brown & Rice, 2013). Figure 2.2 and Figure 2.3 illustrated how erect, rounded, sway back, sway front and slumped posture, large backside and large abdomen affect (structural) fit of skirts.

Pattern drafting does not produce (structural) fit for diverse body shapes (Gu et al., 2017). The outdated methods behind current sizing systems do not adequately address the complexities of body variations (Gill, 2015). Garments need to be more closely linked to unique body shapes (Gill, 2015). To accommodate varied body shapes it is necessary to add measurements (Gill, 2015). Additional or different measurements than those used by traditional pattern drafting may be required (McKinney et al., 2017).

6.3 Body to Pattern Relations

Body to pattern relations are non nonlinear (1). That is, change in body does not equal the same change in the pattern. While body to pattern relations are correlated, some are correlated to, not one, but multiple body measurements (Chan, Fan, & Yu, 2005). By in large, the relations between body shapes and patterns and how to formalise them are still unknown (Gill, 2015). Body to pattern relations, including ease, are unpredictable and have undergone limited study (McKinney et al., 2017). As a result, pattern drafting instructions vary according to author (Gill, 2015). For pattern drafting to evolve, it requires sound body to pattern theory that responds to individual bodies (6). That is, the theory needs to understand that this body shape needs this pattern (6). Given the lack of theory, to develop a pattern drafting algorithm that could automate custom structural fit, one participant attempted to establish body to pattern relations with engineering principles (3).

6.3.1 *Fitting Ease*

Ease values are generally added to body measurements in a standing position. One study used a mean of body dimensions in various body positions such as with raised hands and bending (Choi & Ashdown, 2002). Garments with inappropriate amounts of ease will wrinkle and not hang smoothly on the body (Liechty et al., 2016). Questions remain as to what constitutes a suitable amount of ease for different body shapes, body locations and garment styles and whether ease should be an absolute or proportional value (Gill, 2015; Li et al., 2013; McKinney et al., 2017). Amongst reviewed literature, suggested absolute ease values varied from 4 cm to

7 cm for the waist and from 4 cm to 10 cm for the bust (Beazley & Bond, 2003; Chen, 2007; Dabolina et al., 2015; Gu et al., 2017; Huang et al., 2012). Such variations are the equivalent of one to over two female body sizes (Beazley & Bond, 2003; Pellen, 2014). Others claim that absolute ease is not an appropriate practice (Chan et al., 2005). Participants also had different views on absolute and proportional ease values. One stated that ease is and will remain an absolute value (6). The participant stated that if ease were a function of a measurement, the result would be very large ease values for larger bodies and very small ease values for children (6). Another participant was perplexed by the use of absolute values for ease (3). The participant also questioned the use of other absolute values without adequate explanation or reasoning in pattern drafting books (3). To determine the correct amount of ease, garments are tried-on and their fit is evaluated (Beazley & Bond, 2003). Ease research is important because it is a critical component of fit (Gill, 2015).

6.3.2 *Side Seams and Darts*

Side seams divide the body and the garment on the perpendicular axis into front and back components (Ashdown et al., 2008). Side seams should be at the center of the body, straight and perpendicular to the floor (Brown & Rice, 2013; Chen, 2007). While the appropriate placement of a side seam is important to create well balanced garments, there is no obvious body landmark to properly locate the side seam for differently shaped people (Ashdown et al., 2008). Rules on side seam location is limited and where rules are available, they are unreliable given the variation in body shapes (Ashdown et al., 2008). Some rules work well for certain body shapes but do not transfer well to others (Ashdown et al., 2008). While some methods are based on a perpendicular side seam, a non-perpendicular side seam may be more appropriate for some shapes (Ashdown et al., 2008). Thereby, pattern drafting experts use different landmarks to locate the side seam (Ashdown et al., 2008). In the end, appropriate placement of a side seam is a skilled task and a challenge to automation (Ashdown et al., 2008). Another challenge is the complex placement and depth of darts (6).

6.4 Empirical Knowledge

Processes to achieve (structural) fit remain largely undocumented (Ashdown & Delong, 1995; Gill, 2015). The elements that influence (structural) fit are usually learned in practice (Gill, 2015). The ability to draft patterns that achieve good (structural) fit requires knowledge and experience, some of which is based on trial and error (Liechty & Rasband, 2006). Knowledge to make (structurally) well-fitted garments is limited to highly skilled pattern drafters and graders (Ashdown & Delong, 1995). This knowledge is a function of experience rather than the development of rules and procedures (Ashdown & Delong, 1995). When three tailors were asked what measurements were required to create a (structurally) well-fitted pair of pants, their responses varied but all agreed that there is no indispensable measurement, rather an understanding the appropriate pattern for the body shape (Bellemare, 2014). One of the three tailors added that the understanding is an automatic reflex that comes with experience (Bellemare, 2014). Similarly, some tailors do not measure exact shoulder angles, they rather rely on their experience and observation of the person's shoulder slope (Chan et al., 2005). A pattern drafter who joined a discussion with a participant stated that with a person's measurements, they can visualise the shape of the body and based on their experience and knowledge, make necessary adjustments to the software used to produce custom products (10K). This type of knowledge is inefficiently transferred from experts to novices and a shortage of skilled labor is expected (Simard-Lessard, 2017).

During the transition from custom tailored garments to RTW, the ability to recognize good (structural) fit and the expertise to make custom-fitted garments was lost (Bye, 2010). Many pattern drafters that develop garments for a brand and its standard body, do not understand the relations between measurements and (structural) fit and do not know how to alter patterns to fit a target person (Istook, 2002). As already mentioned in Section 2.2.1, custom pattern drafting is typically not included in school curriculums.

6.5 Alterations

Differences between the body and the pattern are addressed at the fitting stage (McKinney et al., 2017). To produce a (structurally) well-fitting garment it is essential to alter its pattern and several fittings and pattern alterations are often required (Armstrong, 2010; Ashdown et al., 2007; Istook, 2002). The most accurate method to alter patterns to (structurally) fit is to make the garment in an inexpensive fabric such as muslin, fit it during a try-on, and transfer the changes to the pattern before cutting the final fabric (Loker, 2007). This method is time consuming and costly (Loker, 2007). Alternatively, pattern drafters first determine where (structural) fit problems may occur on a pattern (Istook, 2002). Then, they determine the amount of change that is required on the pattern by comparing the target person's measurements against the standard body used to make the standard pattern (Istook, 2002).

Even skilled pattern drafters with a great amount of expertise and years of experience make several alterations to obtain (structurally) well-fitted garments (Li et al., 2013)(8). They often use heuristics to make pattern alterations rapidly (Kwong, 2004). For as long as pattern theory does not explain the achievement of (structural) fit, it will remain a product of trial and error (Gill, 2015). Without sound body to garment relations and theory, patterns will always require alterations (6).

6.6 Structural Fit Evaluation

Criteria to evaluate (structural) fit include garment balance, grain, line and set (Brown & Rice, 2013; Shin, 2013). Balance refers to how a garment hangs on the body from front to back and side to side (Beazley & Bond, 2003; Chen, 2007; D.-E. Kim & LaBat, 2013). Fit at the neck, shoulders and upper bust affects upper body balance, and fit at the waist and hips affects fit lower body balance (Beazley & Bond, 2003). Grain refers to the cut of the fabric in relation to its grainline (Brown & Rice, 2013). Line refers garment structural lines, and they should be in alignment with the natural lines of the body (Brown & Rice, 2013; D.-E. Kim & LaBat, 2013). One example are side seams that divide the body and the garment on the perpendicular axis into front and back components (Ashdown et al., 2008). Side seams should be at the center of the body, straight and perpendicular to the floor (Brown & Rice, 2013). Set refers to the way the garment hangs on the body. A well-set garment follows the body contour without undesirable wrinkles (D.-E. Kim & LaBat, 2013). It follows the shape of the shoulders, waist and hips smoothly, with no stress folds or torqued areas (Ashdown, Loker, Schoenfelder, & Lyman-Clarke, 2004). Set winkles are often the result of garments that are too large or too small and sag or pull in areas where the garment does not fit (Brown & Rice, 2013). Garments that wrinkle generally indicate incorrect (structural) fit (Liechty et al., 2016). Most (structural) fitting problems can be identified by unwanted wrinkles or uneven hemlines (Beazley & Bond, 2003; Liechty et al., 2016).

Fitting guides, checklists and scales are used to evaluate (structural) fit at defined garment locations (D.-E. Kim, 2009). The evaluation methods are not standardised, and fit definitions can vary according to styles, norms and people, and may be misunderstood (Gill, 2015; Yu, 2004c). For instance, one study indicated that seven experts used different criteria to judge the ideal side seam location (Ashdown et al., 2008). Communications and conclusions derived from research are limited by the lack of agreement within the industry of what constitutes good or optimal (structural) fit as well and the commonly qualitative and subjective nature of fit evaluation (Ashdown & Delong, 1995; Gill, 2015; D.-E. Kim, 2009; Yu, 2004b, 2004c). Although a quantitative (structural) fit evaluation method is desirable, it is difficult to achieve and not commonly used (Yu, 2004b).

Older sources in this Chapter are still referenced in more recent sources and the statements remain relevant today. In effect, pattern drafting gaps and challenges remain to this day.

6.7 Chapter Conclusion

That pattern drafters learn through experience and rely on try-ons and alterations to correct structural fit, indicate that pattern drafting does not, for each and every body shape, produce optimal custom structural fit. Try-ons and alterations are needed to correct structural fit as, despite garments being made for a vast majority of the global population for hundreds of years, pattern drafting has gaps. The following gaps and challenges are synthesised from multiple sources referenced in the Chapter. Gaps include body to pattern relations for fitting ease, placement of side seams, and depth and placement of darts, for each and every body shape. Challenges to solve these gaps include that body to pattern relations are body shape specific, correlated but nonlinear and some are related to multiple body measurements. Furthermore, while the relations are body shape specific, the necessary measurements to reflect a person's complete and unique body shape are unknown. Lastly, there is no standardised structural fit evaluation criteria. The gaps explain that pattern drafting does not produce, for each and every body, optimal custom structural fit that does not require alterations. They also, at least partly, explain the inability of CAD systems to automate custom structural fit as established in CHAPTER 5. As, except for neural networks (NNs), technology generally automates established formulas or relations rather than develop theory or fill theory gaps.

CHAPTER 7

EXISTING RESEARCH

Given first, that CHAPTER 5 established that CAD systems do not truly automate custom structural fit. Second, that CHAPTER 6 established that pattern drafting does not produce, for each and every body, optimal custom structural fit that does not require alterations. This Chapter presents the analysis of 21 studies from 2006 to 2021 on the topic custom fit pattern drafting CAD systems. Information on the studies' technical, sampling and evaluation methods, and conclusions, is presented as it was in the studies. Thereby, different levels of detail can be presented. A summary table is presented in APPENDIX II. The term structural fit is used sparingly in this Chapter as the notion of fit in some of the selected studies related to personal comfort, perceptions and preferences, that in this research relate to the style dimension.

7.1 Technical Methods

Based on the technical method to generate custom patterns, the studies generally fall into five main categories. They are, traditional pattern drafting, improved grading, relations, 3D to 2D flattening and virtual simulation. Five studies applied traditional pattern drafting based, where mentioned, on the books Patternmaking for fashion design by Helen Joseph Armstrong (1987 and 2010 editions), Metric Pattern Cutting for Women's Wear by Winifred Aldrich (2008) and Men's wear pattern technique by T. Kwak and W. Seo (2008), the study A study on the pattern grading for men's formal wear by KJ Park, KJ Yoo and JR Lee (2002) as well the APDS-3D, Gerber and Telestia systems. Two studies established new pattern grading methods. One study established measurement relations from different body landmarks to make size predictions to produce real custom garments. 11 studies used 3D body scanners and then flattened a virtual reference 3D body, garment or pattern model to a custom 2D pattern. One study tested the accuracy of virtual 3D garment models compared to real garments and one study illustrated virtual garment simulation.

7.2 Garments, Measurements and Ease

Fifteen studies produced real garments or blocks, four generated virtual garments and two generated virtual patterns. All studies that produced real garments were limited to one style of garment. The latter is in accordance with statements by Han et al. (2015) and Li et al. (2013) in Section 5.3 that pattern drafting CAD systems are generally heavily dependent on a specific style of a garment.

Measurement methods, numbers and locations varied across the studies. This is in accordance with the statement by Gill (2015) in Section 6.2, that number of measurements vary amongst practitioners and researchers. Some measurements were obtained using a measuring tape, a contact-type digitizing system or a 3D body scanner. Some measurements from scans required human interventions. Measurements were typical of traditional pattern drafting and mainly related to neck, shoulder, armhole, bust, waist, hip, thigh, knee, back and front lengths, crotch and inner and outer seams.

Ease was applied as absolute or proportional values. From the three studies that clearly indicated the amount of ease that was applied: absolute ease values for bust varied from 4 cm to 10 cm; absolute ease values for waist varied from 4 cm to 6 cm; and absolute ease value for hips was 4 cm for both studies that included hip measurement. Such bust and waist variations are the equivalent of one to over two female body sizes (Beazley & Bond, 2003; Pellen, 2014). Many studies did not clearly specify the type or amount of ease that was applied. One study suggested that future research is required to define whether ease should be an absolute or proportional value. Four studies either clearly specified that ease was not needed or suggested that for tight-fitting garments, the body contour without added ease could be flattened to a 2D pattern. These statements are in accordance with those by Gill (2015), Li et al. (2013) and

McKinney et al. (2017) in subsection 6.3.1, that questions remain as to what constitutes a suitable amount of ease and whether ease should be an absolute or proportional value.

7.3 Participants

The numbers of participants stated below are based on the numbers of participants for which a garment or pattern was produced. Numbers of participants to establish body relations or categories are not considered here. Nine studies were conducted with one to 37 real female participants and one study with three real male participants. One study was conducted with 12 real male participants. Four studies were conducted with one to six female mannequins. One study was conducted with six mannequins without specifying if they were female or male. One study was conducted with data from a 3D female body scan from an unknown source and another study with a virtual female body model from an unknow source. One study was conducted with an unclear number of male and female virtual body models from unknown sources. One study was conducted with one real physical model from a real scaled-down male.

The maximum age range of participants for studies conducted with real females or males was one study with 27 females aged 18 to 35 years. Two studies stated the ethnicity of participants. One study stated that the participants were from a midwestern university, another from a university in Raleigh, U.S, and another study stated that participants were from New York.

Eight studies provided sufficient information to determine the largest absolute measurement difference between participants of each study. Withstanding height, in five studies, the largest absolute difference was at the waist with an absolute difference ranging from 3 cm to 41 cm. In two studies, the largest absolute difference was at the hips with an absolute difference ranging from 6 cm to 8 cm. In one study, the largest absolute difference was at the bust with an absolute difference of 10 cm. For reference, one female size difference is approximately 4 cm (Beazley & Bond, 2003; Pellen, 2014).

7.4 Evaluation Methods

Evaluation methods were qualitative, at times subjective, and varied across the studies. This is in accordance with statements by multiple sources in Section 6.6, that methods to evaluate fit are qualitative, at times subjective, and are not standardised. The methods are further presented below.

7.4.1 *Judges, Criteria and Scales*

Evaluations were conducted by one to 10 judges with some level of expertise, participants or not specified. Where information was provided, evaluations were conducted on one criterion, such as general fit, to 25 criteria. Where evaluations had multiple criteria, they all applied 5- to 9-point scales such as much worse to much better, very dissatisfied to very satisfied, strongly dissatisfied to strongly satisfied, very tight to very loose and very uncomfortable to very comfortable. Two studies included the notion of perfect fit in their evaluation. One study had a point scale from extremely poor to excellent or perfect fit, the other, very tight to perfect to very loose.

7.4.2 *Body Position*

Four studies evaluated fit in multiple body positions including with participants or models standing, walking, sitting, flexed at the hips and with arms down, apart at 45° and 90° and bending at waist, bust and shoulder level. Ten studies showed photos with front, back and side views, six studies showed one view, either a side or semi-side view.

7.4.3 *Control Measures*

Some studies specified control measures used to increase the likelihood that garment fit observations could legitimately be linked to study's system or method and no other factor such as craftsmanship or bias. Multiple studies did not clearly mention the application of control measures. One control measure was comparing fit of garments produced using different methods, the study's method and another method. Another control measure was ensuring that garments were made with the same level of craftsmanship. For example, having the pieces cut and sewn by the same people or by people with the same level of expertise, and/or assessing and controlling the quality of the produced garments. Another control measure was having the fit of garments blindly evaluated by the participants and/or one judge or multiple judges. The blind evaluation indicates that the participant or the judge did not know if the garment they were evaluating was produced from the study's method or another method. One study had different judges for different fittings.

7.5 Conclusions by Technical Method

7.5.1 *Traditional Pattern Drafting*

From the five studies that applied traditional pattern drafting, two stated that the methods used needed improvements, three stated that the methods produced garments that appeared to fit properly or achieved good or satisfactory fit. The McKinney et al. (2017) study stated that the methods used to produce pant block patterns were unsuitable for custom pattern drafting, that measurements may need to be added or substituted, and that whether ease should be an absolute or proportional value needs to be defined. The Chen (2007) study stated that the method used to produce real custom block bodices needs to be revised, more measurements are required and participants with multiple shape variations were harder to fit. The Guo and Istook (2021) study stated that real dresses similar to blocks were judged by experts to achieve good fit and that participants were satisfied with final fit. The study had a sample of five real females aged 18 to 25 years and final fit was the result of multiple fittings and alterations. The Sohn, Lee, and Kim (2020) study stated that according to participants, fit was satisfactory and that it was better than RTW. The study had a sample of 12 males aged 20 to 32 years. The Lu, Wang, Chen, and Wu (2010) study stated that its method produced a real scaled-down custom shirt and pants that "appeared" to fit one scaled-down model properly. The study had a sample of one real male scaled down to a real model 1/6th its size.

7.5.2 *Improved Grading*

From the two studies that applied an improved grading method, the Song and Ashdown (2012) study stated that its method produced real custom pants with best fit. The study stated that its method required a user to correctly develop elements such as size charts, block patterns and grading and that these steps could be avoided if a method were able to produce a pattern directly from a person's measurements. The study suggests that its datasets of body measurements and fitted custom patterns could be used to explore a method that can develop block patterns directly from a person's body measurements. Authors were contacted to enquire about datasets, but they did not respond. The study stated that while it is important to get the participants' fit perceptions, they are not fit experts, and their responses focus on whether pants felt very tight or very loose. The study also stated that ability to accommodate a person's fit preferences is desirable as ultimately, their perception of fit determines their satisfaction and the method's success. The study stated that different criteria may be required to meet participants' level of knowledge and to better capture their experience. The Han et al. (2015) study stated that its method produced real custom pants with better fit. The study had a sample of three real males.

7.5.3 *Relations*

The Gu et al. (2017) study applied a method that established relations between body landmarks. The study stated that its method produced real custom blazers with satisfactory fit. The study had a sample of five real females aged 18 to 24 years.

7.5.4 *3D to 2D Flattening*

11 studies used 3D body scanning and a 3D to 2D flattening method with either direct flattening, relations or deformation. They generally stated positive conclusions.

7.5.4.1 Direct

Four studies potentially directly flattened the target virtual 3D garment or pattern model to a target 2D pattern. Generally, the methods consisted of selecting control points on the virtual target 3D body model to a create virtual 3D garment model in the form of a wireframe that was flattened to a 2D pattern. The advantage of this type of method is that the complete body shape obtained from the 3D body scan is potentially being used to produce the pattern, providing, the selected control points are adequate and complete. The Huang et al. (2012) study stated that its method produced real custom dress blocks with satisfactory fit. The study had a sample of 18 real women aged 18 to 25 years of various shapes and Body Mass Index (BMI). Shape information was not provided, and BMI categories were under, normal or over weight. The evaluation was performed by the participants and the study does not specify if the fit comparison to other methods was blind. The Cho et al. (2006) study stated that approximately 80% of "individuals" preferred the fit of real skirts produced with the study's method. The study had a sample of two mannequins and the credentials of the "individuals" that performed the evaluation were not specified, mentioned or clear. The Hlaing, Krzywinski, and Roedel (2013) study made positive claims although it mainly demonstrated a process without a clear evaluation. The process was shown on one virtual model. The Hong et al. (2018) study included a 3D to 2D flattening method in a design, display, evaluate and adjust process that included an alteration step to improve the fit of real bodice blocks for complex body shapes. The study had a sample of 20 real females physically disabled of scoliosis. The study stated that the method effectively simulated real garments with high accuracy and that different judges had a common perception of fit.

7.5.4.2 Applied Relations

Three studies applied relations between the reference virtual 3D body and garment models to create a target virtual 3D garment model that was then flattened. Generally, the methods consisted of establishing relations at selected locations between the reference virtual 3D body and garment models and applying them to a target virtual 3D body or garment model. The J.

Zhang, Kim, and Takatera (2017) study stated that its method produced real custom sleeveless and collarless jackets that looked better. The study had a sample of three female mannequins within two dress sizes. The D. Zhang et al. (2014) study stated that its method produced a real dress that fit well. The study had a sample of one real female. The Li et al. (2013) study illustrated its method that was limited to the virtual space and did not specify an evaluation method or results.

7.5.4.3 Body Model Deformation

Two studies deformed the reference virtual 3D body model to the target virtual 3D body model on which a target garment model was created and then flattened. Generally, the methods consisted of selecting locations on the reference virtual 3D body model to deform it to the target virtual 3D body model. The Hyo Kim et al. (2010) study stated that its method produced real bodice blocks that fit well and that two of the three participants felt comfortable in the bodice blocks and one did not. The evaluations were conducted by the participants with an unspecified level of understanding of fit criteria. Measures to control bias from participants evaluating only garments produced by the study's method, were not specified. The Sungmin Kim and Kyu Park (2007) study stated that its method can produce various styles in various sizes. The study was limited to the virtual space and had a sample of one real female.

7.5.4.4 Comparison

Two studies compared their flattening methods to another method. The Y. Zhang and Wang (2011) study stated its flattening method produced better fitting jeans with a sample of one real female. The Yang and Weiyuan (2007) study stated its flattening method was relatively accurate at keeping shape of pattern with a sample of one virtual pattern.

7.5.5 *Virtual Simulation*

Two studies tested virtual 3D garment simulation. The D.-E. Kim and LaBat (2013) study stated that its simulation method was “moderately good” but not enough to perform online fit evaluation. The Tao et al. (2018) study stated that its method can adjust body model measurements, t-shirt size and shape of t-shirt and pattern. The study was limited to the virtual space and had a sample size of one female mannequin model.

7.6 Transferability

Given a combination of factors such as small and/or homogeneous samples, limitation to the virtual space, evaluation of a single garment style, varied qualitative and at times, subjective, evaluation scales, obtained results and conclusions, the transferability of the studies’ technical methods and results to larger population samples or other garments styles is uncertain. Furthermore, studies had multiple parameters including technical method, measurements, type of garment, population sample and evaluation method. In addition to having multiple parameters within a study, they varied between the studies. Lastly, many studies, as presented, do not allow for replication. This may be a consequence of limited publication space.

7.7 Chronological Trends

No chronological trend was observed from the 21 studies. Technical, measurement and evaluation methods varied across the studies and over time. For instance, traditional and more technologically advanced technical methods spanned the entire timeframe of the studies. One the one hand, traditional methods were the subject of studies ranging from 2007 to 2021. On the other hand, the more technologically advanced method of flattening a 3D body or garment model to a 2D pattern was the subject of studies ranging from 2006 to 2017. Results and conclusions also did not show a trend, such as improvement over time.

7.8 Chapter Conclusion

Generally, the selected studies did not automate optimal custom fit. First, the technical methods of multiple studies included at least some form of set up. For instance, some methods, including 3D to 2D flattening methods, applied reference body/garment/pattern relations at selected locations to a target body/garment/pattern. Such methods do not use the target person's unique body shape to generate patterns. Rather, they, like other CAD systems, use standard bodies as further presented in subsection 5.1.1. This is accordance with the statement by Gill (2015) in Section 5.2, that even CAD systems that use 3D body scans do not generate patterns directly from the scans. Second, multiple studies included try-ons and alterations. This is in accordance with statements from multiple sources in Section 6.5, that fittings and alterations are often required to achieve fit, even when working with skilled pattern drafters. Third, even studies with positive conclusions such as appearing to fit properly, best fit, better fit, satisfactory fit, fit well, better look and comfortable do not indicate optimal structural fit that does not require alterations. Such conclusions also demonstrate, as suggested by multiple sources in Sections 6.6, that qualitative and subjective evaluation methods limit what can be derived from studies. In the absence of standardised evaluation methods, the studies use qualitative and subjective methods despite their documented limitations. Another similar example is measurements. The studies use measurement methods despite their documented inability to capture complete body shape as further presented in Section 6.2. Furthermore, it is difficult to determine causality of success or failure with multiple parameters, such as technical, measurement and evaluation methods, within a study. Lastly, it is difficult to compare the studies as these methods vary between the studies.

CHAPTER 8

SUBSEQUENT ACADEMIC RESEARCH

Based on learnings from previous Chapters, to truly automate, for each and every body shape, optimal custom structural fit that does not require alterations, three priority topics for subsequent academic research were identified. They are automation of custom block patterns that structurally fit, complete body shape data from 3D body scans and expert structural fit evaluation. While the topics are interrelated and require coordination, the complexity of each topic merits its own knowledge building effort.

8.1 Automation of Custom Block Patterns that Structurally Fit

The previous Chapters established that while current CAD systems are heavily dependent on a specific type of garment, garments are made from blocks patterns that record body to pattern relations to structurally fit the target body shape (See Sections 5.3, 6.1 and 7.2). Bodice, sleeve, pant and skirt block patterns developed for a target person are the foundation of all garments made for that person. The block patterns record the body to pattern relations to structurally fit the target person so the garments developed from the blocks, will also structurally fit. The desired outcome is a method that can automate custom block patterns that structurally fit the target person according to their body shape data from a 3D body scan as presented in Section 8.2. The structural fit of the blocks will be evaluated according to a consensus of experts as presented in Section 8.3. Automation, from 3D body scans, of custom blocks that structurally fit to then produce garments is an original idea worthy of further research (18). It would be beneficial to sewing students and garment producers (10J). It is recommended to first focus on less body-defining garments as they simplify pattern adjustments (see subsection 2.2.2). Once achieved, focus can shift to more body-defining garments. Nevertheless, the automation of custom blocks that structurally fit requires subsequent research to establish body to block relations including ease, side seams and darts for each and every body shape. The following subsections present two possible approaches.

8.1.1 *JBlockCreator*

One approach is to collaborate with current research efforts. For instance, research is being conducted in the UK to develop an open-source system that automates custom block patterns from 3D body scans (Harwood, Gill, & Gill, 2020). While the system, JBlockCreator, currently uses traditional pattern drafting to develop the blocks, the research team sees an opportunity and the value to use the system and the research data for academics to evolve pattern drafting theory with more robust body to pattern relations (Harwood et al., 2020).

8.1.2 *Neural Network*

Another approach is to establish scan to block relations from a NN or a support vector machine (SVM). While pattern drafting is a complex process, from a mathematical perspective, garment patterns consist of points, lines and curves (Xiu et al., 2011). NNs can be used to solve pattern drafting problems and create garment developing systems (Xiu et al., 2011; Yang et al., 2007). With large datasets of body scans and fitted custom blocks, a NN can learn, as does the pattern drafter, body to pattern relations for each body and every shape and extrapolate them. The ability of a NN to simultaneously solve multiple gaps is a great advantage. For instance, while natural language processing was initially based on rules, what worked in the end was letting NNs process a large volume of data (1). A NN could also be used to process images to evaluate structural fit based on presence or absence of wrinkles and other criteria (1). That is, the NN could learn what structurally fits and what does not.

The literature review did not find the application of NNs to produce patterns or garments that fit. The closest application was two studies by the same authors that studied the ability of a Multiple Linear Regression (MLR) and an Artificial Neural Network (ANN) to predict shirt pattern parameters from measurements (Chan, Fan, & Yu, 2003; Chan et al., 2005). The shirt pattern parameters that were to be predicted were based on traditional pattern drafting methods, undisclosed in Chan et al. (2003), and based on the book Metric Pattern Cutting for Menswear by Winifred Aldrich (1997) in Chan et al. (2005). The predictions did not consider fit or its evaluation.

One limitation of a NN approach is that it requires large datasets of body scans and fitted patterns with a large sample of participants that range in size, shape, posture, age, ethnicity and gender. A large and varied sample could be obtained by collaborating with a company or organisation with a large pool of uniformed employees. For instance, airline or delivery companies, postal service, armed forces, etc.

8.2 Complete Body Shape Data from 3D Body Scans

The previous Chapters established that body shape is unique to each person and affects fit, that body to pattern relations are body shape specific, that 3D body scans can capture the complete body shape, and that the necessary measurements to reflect a person's complete and unique body shape are unknown (See subsection 2.2.1 and Sections 5.2, 6.2, 6.3 and 7.2). The desired outcome is a method that captures from 3D body scans, complete body shape data including curves and posture with the assurance that identical data could not result in different body shapes as illustrated in Figure 6.2. The method does not need to relate to traditional measurements. Furthermore, to favor automation, the selected method should limit or preferably, not require human intervention. The smallest quantity of data possible is desired, without compromising the complete shape for each and every body shape. One challenge is that scans generate such a high volume of data that a selection is required (11). One recommended experiment option is to fix selected data on a 3D body model generated from a 3D body scan; manipulate the model; observe if the body shape varies; if body shape varies; fix further data; repeat until the body model remains stable; apply to different body models and repeat.

8.3 Expert Structural Fit Evaluation

The previous Chapters established that methods to evaluate fit are qualitative, at times subjective, and are not standardised which limits what can be derived from research (See Sections 6.6 and 7.4). Initially focusing on expert structural fit evaluation avoids the noise and discrepancies of personal perceptions and preferences. The following statements demonstrate the benefit of separating, as further presented in Section 4.1, structural fit and personal perceptions and preferences in two distinct dimensions, body and style, to reduce the subjectiveness of structural fit evaluation. Everyone has their perception of what looks good, feels good, and is right for them (Liechty et al., 2016). Some may prefer the look and feel of tight pants while others prefer loose pants, or short or long skirts (Brown & Rice, 2013). Some people may value comfort in fit, others may not, and what may be tight for one may not be for another (Shin, 2013). Furthermore, people perceive measurement changes at various body locations, such as waist, hip, crotch, differently (Ashdown & Delong, 1995). Some can perceive hip and crotch variations of 1.5 cm and waist variations as small as 0.5 cm (Ashdown & Delong, 1995). Personal fit preferences may not align with expert opinion (Shin, 2013). People and experts may also have different fit criteria (Song & Ashdown, 2012). Lastly, fit criteria such as lines and ease can be difficult for a non-expert to understand and evaluate (Ashdown et al., 2004). For these reasons, the first desired outcome is a consensus by experts of how to evaluate the structural fit of blocks. Once achieved, focus can shift to evaluate other fit dimensions such as style, that includes personal perception and preferences from the perspective of the wearer. To this end, to better communicate personal preferences, people could learn to use quantitative ease values rather that qualitative and subjective descriptions such as tight, loose and comfortable. With time and experience, people could learn what different ease values feel and look like and their preferences.

8.4 Funding

Despite the various complexities, technically, a CAD system that automates, for each and every body shape, custom block patterns that structurally fit without alterations, is possible (11).

While the task may be complex, further technical complexities have been resolved with appropriate resources (11). However, the fashion and the software industries are not interested in funding academic research to further improve pattern drafting CAD systems (6). The challenge may be that that a CAD system that automates custom structural fir is not viable in the current production and consumption model and requires a new model (11). To this end, major fashion retail brands that filed for bankruptcy in 2019 or before, pre COVID-19, include Forever 21, Barneys New York, Diesel and Sears[7]. Major fashion retail brands that announced store closures in 2019 or before, pre COVID-19, include Topshop, JCPenney, Abercrombie & Fitch, Gap, H&M, J.Crew[8]. This new landscape may open opportunities for new technology and business models, if not make them necessary. The film, hotel, music, taxi and personal computer industries have demonstrated that business models can evolve with technology. In effect, although some brands are seeing a shift, including towards customisation, and feel they are lagging behind, they do not know how to adopt it (Sander Schellens, personal communication, April 18, 2019).

8.5 Further Developments

The automation of custom structural fit is a next step and not the end goal. For instance, new materials that respond to climate with heating or cooling properties, are comfortable on the skin, can maintain shape over time or be reshaped if and as desired, and require less energy intensive care, could also be developed. As could a production line that produces 3D garments directly from a CAD system and 3D scans. Lastly, tactile simulation with sensors on the body that simulate the feel of garments on the skin before production. With the simulated feel of the garment, the wearer can give feedback without having to first produce and wear it. The idea of simulating tactility, how a garment feels, before it is produced is not such a futuristic idea (18).

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[7] https://www.cbinsights.com/research/retail-apocalypse-timeline-infographic/

[8] https://fashionunited.uk/news/business/these-are-the-companies-downsizing-or-filing-for-bankruptcy-in-2019/2019052443381

https://www.styledemocracy.com/brands-retailers-closed-stores-bankruptcy-2019/

Nevertheless, before embarking on these other developments, fundamentals such as automation of custom block patterns that structurally fit, complete body shape data from 3D body scans and expert structural fit evaluation should first be established, documented and shared.

CHAPTER 9

CONCLUSION

This research elaborated a two-step strategy to reduce garment volumes and improve structural fit for everyone. The research first established that strategies to reduce garment volumes should, in the least, consider wardrobes and structural fit, more specifically, custom structural fit as RTW standard sizing and manufacturing cannot achieve structural fit for each and every body shape. This research then introduced multidimensional fit with body, style, social and climate dimensions with the notion that the function of a garment is to provide physical and psychological comfort. To this end, this research introduced the term structural fit which relates to the body dimension and refers to how well the shape and size of the garment conforms to the shape and size of the human body while standing, walking, sitting and bending. In this research, personal perceptions and preferences relate to the style dimension. Separating personal perceptions and preferences from structural fit in two distinct dimensions, body and style, reduces the subjectiveness of structural fit evaluation.

Then, this research elaborated Step 1 of the two-step strategy to reduce garment volumes and improve structural fit for everyone. Step 1 is a conceptual concerted minimal custom wardrobe model that is composed of a minimal number of custom garments that structurally fit a person's unique body shape including posture, and are concerted to efficiently relate to one another, and over an extended period of time, to the person's unique style, social and climate profiles. The concerted minimal custom wardrobe is user centered, it enhances user satisfaction and agency, and it engages people as wearers and makers.

Step 2 of the strategy is automation of custom structural fit. That is, the ability of a CAD system to draft, for each and every body shape and directly from inputted formulas and body shape data, patterns that structurally fit without alterations. Such automation democratises innovation by giving more people, professionals, and companies the ability to create, with less skills and training, custom garments that structurally fit for themselves or their clients, and scales the potential effect of the concerted minimal custom wardrobe on garment volumes, and user satisfaction and agency. Heightened awareness combined with enhanced user satisfaction with wardrobes that meet, over time, multiple needs such as to keep warm or cool, self-confidence, sense of belonging, to make and to create, and that provide physical and psychological comfort, may better predispose people to reduce their consumption and disposal of garment volumes.

To this end, this research established that CAD systems and existing research do not truly automate optimal custom structural fit. One reason is that with its gaps and challenges, pattern drafting does not produce for each and every shape, optimal structural fit that does not require alterations. Gaps include for each and every body shape, body to pattern relations for fitting ease, placement of side seams, and depth and placement of darts. Challenges to solve these gaps include that body to pattern relations are body shape specific, correlated but nonlinear and some are related to multiple body measurements. Furthermore, while the relations are body shape specific, the necessary measurements to capture a person's complete and unique body shape are unknown. Lastly, there is no standardised structural fit evaluation criteria. This research also established that while some pattern drafting CAD systems are heavily dependent on a specific type of garment, garments are made from block patterns that record body to pattern relations to structurally fit the target body shape. For these reasons, this research identified automation of custom block patterns that structurally fit, complete body shape data from 3D body scans and expert structural fit evaluation as priority topics for subsequent academic research to automate optimal custom structural fit. A CAD system developed through academic research to automate custom block patterns that structurally fit can be shared with makers, professionals and companies, so each can efficiently create garments that structurally fit a target person, whether its themselves or a client. Thus, reducing their reliance on manufacturers to act as their often imperfect agents, while experiencing the joys and human needs of creating, making, building relations and belonging. Automation through academic research is desired to democratise innovation and provide more people access to a concerted minimal custom wardrobe, scaling the potential effect on global garment volumes, and user satisfaction and agency.

In addition to further academic research to establish automation of custom block patterns that structurally fit, complete body shape data from 3D body scans and expert structural fit evaluation, other topics worthy of further research include:

- Further garment value chain data such as volumes and environmental impacts;
- Numbers of garments and outfits that go with one another in current wardrobes and the effect of purchasing outfits with concerted styles, colors and fabric vs individual garment pieces on consumer satisfaction and behavior and garment volumes;
- Efficient numbers of garments, outfits, interconnections and layering options within a wardrobe and potential levels of minimalism for different climate profiles;
- Questions to develop a person's unique style, social and climate profiles to better understand their personal perceptions and preferences relating to garments and outfits;
- Training of professionals on the concepts of the concerted minimal custom wardrobe, including those in the two previous bullets;
- In practice effect of the concerted minimal custom wardrobe of garment use, lifetime and volumes;
- Automation of other fit dimensions such as style and garment specifications;
- Identification and combination of other strategies such as low impact laundering and fabric innovation;
- Relation between low-cost fabrics and labor and industry profits on motivation to allocate resources to further develop the automation of custom structural fit; and
- Unit production.

APPENDIX I

PARTICIPANTS

Table-A I-1 List of participants

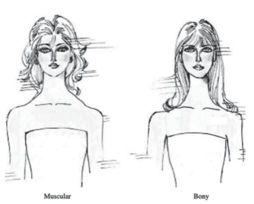
Name	Place of work/study	Occupation
Atzmon Shaked, Tal	Amsterdam Fashion Institute (AMFI), Amsterdam University of Applied Sciences (AUAS)	Master of Arts student
Babin, Marc	*Cirque du soleil*	Designer
Breuer, Rebecca	AUAS	Researcher and Senior Lecturer
Chicoine, Céline	*Université du Québec à Montréal* (UQAM)	Lecturer and Designer
Desbiens, Nicolas	Kohn Pedersen Fox Associates	Head of Digital Practice
Desrochers, Pierre	Olotech, PAD System	Founder and CEO
Gill, Simeon	University of Manchester	Senior Lecturer
Lamontagne, Valérie	FashionTech Festival, Fashion Research and Technology, AMFI, AUAS	Director, Professor
Lessard, Isabelle	Vestechpro	Project Manager
Maranzana, Roland	*École de technologie supérieure* (ETS)	Professor
Rottschafer, Maarten	Faculty of Digital Media and Creative Industries, AUAS	Head of Research
Roy, Marco	*Cégep Marie-Victorin*	Coordinator and Public Affairs
Savoie, Monique	*Société des arts technologiques* (SAT)	Founding President and Artistic Director
Schwaab, Quentin	Litige	Cofounder and Designer
Tanguay, Stéphane	CDRM	President
Vonk, Lisette	Fashion Technology Lab and Virtual/Augmented Reality Atelier, AUAS	Researcher and Coordinator

APPENDIX II

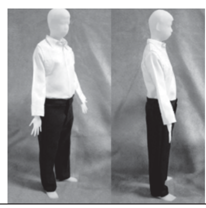
SUMMARY TABLE OF 21 STUDIES

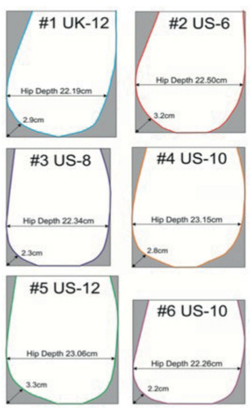
Studies in the table are ordered by category, then by authors.

Table-A II-1 Summary of 21 studies

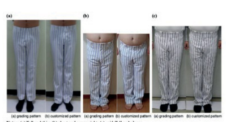
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Chen (2007)	CAD using traditional pattern drafting	Traditional pattern drafting; 10 real females were scanned. Measurements with added ease were manually entered into an industry standard CAD system (APDS-3D) for size 9 bodice blocks to generate patterns. Real bodice blocks were created and fit was evaluated on participants and analyzed according to shape categories. 	10 Real Taiwanese female students aged 20-25 yrs with various shapes. The shapes of 10 participants were categorized according to "Pattern..." (Armstrong 1987) by a panel of 3 professional judges who were faculty teaching garment design and fit. Categories Body: hourglass (ideal), straight, broad shoulders/small hips, narrow shoulders, large hips Shoulder: ideal, sloped, square, muscular, bony Chest: ideal, hollow, pigeon Back: ideal, flat, round Posture: ideal, forward, upright 1 part ideal in 5 cat; 1 part ideal in 3 cat; 2 part ideal in 2 cat, 4 part ideal in 1 cat; 2 part 0 ideal cat.	For bodice blocks, from body scans: bust circumference, waist circumference, center back length, shoulder, bust span, neck, back across shoulder. Largest difference between participants is 16.8 cm at waist (see table). This represents 4 sizes according to (Beazley and Bond, 2003) and (Pellen, 2014).	Absolute Bust 8 cm Waist 4 cm	Real bodice blocks	Panel of judges were 3 professionals who were faculty teaching garment design and fit. 25 criteria (not specified, mentioned or clear, referenced Shen 1991, an unpublished master's memoire) on a 9-point scale (not specified, mentioned or clear). No photos of the bodice blocks.	Negative; Study stated that system needs to be revised and more measurements are required. Participants with multiple shape variations were harder to fit so figure variation needs to be further analyzed. System limited to value ranges (± 25%) and were at times too restrictive for participants' measurements and at times too generous to adequality identify inaccurate inputs. Armholes didn't align with body curves. Other problem areas were bust, shoulders, shoulder seams as well as shoulder and waist darts.	Evaluation by panel of 3 professionals	System needs to be revised and more measurements are required. Participants with multiple shape variations were harder to fit. The 25 evaluation criteria are not explicitly provided, the study references Shen 1991, unpublished master's memoire. Study presented drawings from Armstrong body categories but not of bodice blocks. Not always easy to identify differences in categories, e.g., bony vs muscular shoulders. Results from statistical analysis is presented in the article, but no table with results is presented.	51

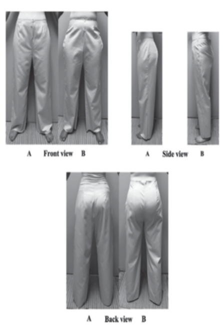
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Guo and Istook (2021)	CAD using traditional pattern drafting	Traditional pattern drafting. 5 real females were scanned. **Gerber**: Developed a basic block pattern (dress) for A in Gerber. Made bloc in muslin and fitted on A. Required 3 fittings. 1 and 2 in muslin, 3 in knit. Final made in woven fabric. Developed a stylised dress pattern for A from block. Developed a MTM system with a size table, grade rules and alteration rules at bust, waist, high hips, hip length, back waist, knee length and bust length. From stylised dress for A and MTM system, generated stylised dress patterns for other 4 participants. Dresses were made and fitted on participants. 3 fittings were required. **Telestia**: From scan data, Telestia generated a body croquis (2D body shape?) and bloc pattern. Blocs were made and fitted on participants. 2 fittings were required. Stylised dress patterns were generated from blocs. Dresses were made and fitted on participants. At least 1 fitting was required. 	5 real females aged 18-25 yrs. Shapes: 2 bottom hourglass, 1 hourglass, 1 spoon, 1 rectangle Sizes (based on bust): 8, petite 8 (x3), petite 16	Gerber: Bust, **back-waist,** bust length, waist, hips, hip length, high hip, knee height Telestia: Chest, chest bust difference, total bodice length, bust length, bust distance, waist, hips, hip length, dress length	Not specified, mentioned or clear.	1 real block and 1 real dress for each participant, dress similar to bloc	Authors who are experienced pattern drafters, evaluated fit based on their judgement of good fit, on live participants, including walking and sitting.	Positive; Judgement of good fit by 2 experts and overall, participants were satisfied with final fit.	-	Small sample size. Participant shape categories are front facing, no posture consideration. Changes between bloc and stylised dress are minor. Required multiple fittings and alterations. Gerber requires set up and pattern drafter. Good fit and satisfied with fit are not predicted/optimal fit.	28

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Lu et al. (2010)	CAD using traditional pattern drafting	Traditional pattern drafting; 1 real male was scanned. Measurements can also be obtained from photos. The measurements were entered in AutoCAD to create a 2D pattern with methods from existing but unspecified books and references. Shirt and pant were created and fit was evaluated on real scaled-down model. 	1 real male scaled down to real model 1/6 in size.	For shirt: chest circumference, back length, sleeve length and shoulder width. For pants: no mention which measurements are used. For body shape: If photos, 23 dimensions used to generate 1 of 6 stand body models (6 males, 6 females). The best fit standard model is chosen and adjusted to the individual's measurements. If scan, up to 31 measurements.	Not specified, mentioned or clear.	Real scaled down (1/6) men's shirt and pants.	Not specified, mentioned or clear. Photos of side and semi side views.	Positive; Study stated that shirt and pant appear to fit properly.	-	Small sample size with a scaled-down model. Appear to fit properly is not predicted/optimal fit. Evaluation method not specified, mentioned or clear.	16

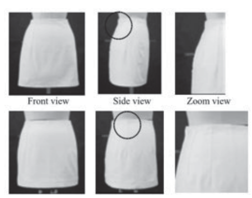
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
McKinney et al. (2017)	CAD using traditional pattern drafting	Traditional pattern drafting; Compared methods of two books (Armstrong, 2010 and Aldrich, 2008) commonly used in schools and by industry professionals. Pant block patterns were drafted and trued along curves and lines to get correct angles. Patterns were digitized and mannequins were scanned to analyze and compare patterns relationships. 	6 mannequins from different manufacturers (2), time periods (1992-2007) and countries (2) of same size. Mannequins rather than actual people were used to obtain symmetric and consistent body measurements from scans.	For pant block patterns: waist, hip, thigh, knee, and ankle circumferences and crotch length from scans. Largest difference between participants 5.6 cm for waist, expected as supposed to be near same size (see table).	Not specified, mentioned or clear. Study states that need to define whether ease should be an absolute or proportional value.	2 digitized pant block patterns for 6 body shapes = 12. Patterns were drafted by a pattern technician with 20 yrs of experience in block creation, teaching and researching.	Relationships between body and pattern at waist, hip, crotch, knee and ankle were statistically analyzed within and between two methods.	Negative; Study stated that pattern alterations would be required. Mannequin to pattern shape relationships were inconsistent within and between methods making unsuitable for custom patternmaking. Notably, each method had patterns with similar crotch shapes despite differences in actual mannequin crotch shapes. Some challenges are use of proportions or standard rather than actual body measurements, ease, and trueing/blending/connecting and methods. These pattern drafting issues need to be resolved before considering mass-customization. A new method that uses a greater number of measurements and that reflect shape from body scans needs to be developed. Current measurements may need to be added or substituted. Need to define if ease should be an absolute or proportional value.	Compared two methods.Patterns drafted by professionals.	Unsuitable for custom patternmaking.Measurements may need to be added or substituted.Need to define whether ease should be an absolute or proportional value.Patterns were trued.	35

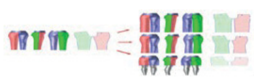
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Sohn et al. (2020)	CAD using traditional pattern drafting. Also has visualisation step	Traditional pattern drafting. 12 real males were scanned. Body models were generated. Males were grouped in S, M and L based on chest. A M virtual jacket model for a M chest of 96 cm and height of 173 cm was generated using Kwak and Seo's 2008 "Men's wear pattern technique" and graded using Park, Yoo and Lee's 2002 "A study on the pattern grading for men's formal wear". S, M and L virtual jacket models were simulated on the S, M and L virtual body models using CLO 3D. Front, side and back images of were sent to participants for evaluation and alteration requests. Real jackets were made. Participants evaluated fit of real jacket compared to final virtual garment model and to their past RTW experience.   	12 real Korean males aged 20-32 yrs. S, M, L.	Maybe chest, waist, hip (and maybe height)	Not specified, mentioned or clear.	1 real jacket for each participant	By participants at 16 locations using a 5-point scale. Overall, length, shoulder width and angle, neck, chest, waist, back, sleeve width and length, upper arm, collar length and width, armhole front and back. Strongly dissatisfied to strongly satisfied, and different to similar.	Positive; study stated according to participants, fit was satisfactory and that it was better than RTW.	-	At some locations, fit of real jackets was not as good as what participants had expected from their final virtual jacket model. Satisfactory and better fit are not predicted/optimal fit.	19

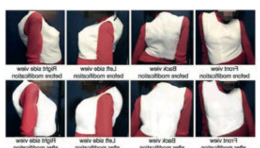
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Han et al. (2015)	Grading according to width and height	Traditional pattern drafting with improved independent width and height grading; An experienced patternmaker created a CAD male pant pattern for a size 80 cm waist by analyzing industry patterns (unspecified). Size 80 reference pattern was graded to size 85 using industry standard system (Yuka) and statistics for adult Korean men aged 18 to 59 for height and width independently. Target body measurements and graded size 80 and 85 patterns were used to generate custom target pattern. Real pants were created and fit was evaluated on participants and compared to another traditional grading method. 	3 real males of non proportional body shape (tall and thin, short and overweight, mid-tall plump).	For pants: height, waist girth, hip girth, inseam or out seam and waist height. To grade pattern: waist girth, hip girth, thigh girth, hem girth, crotch length, inseam, outseam. Biggest difference between participants is 31 cm for height and 8 cm for hip (see table). This hip value represents 2 women's sizes according to (Beazley and Bond, 2003) and (Pellen, 2014).	Not specified, mentioned or clear.	2 real baseball pants made using 2 methods, study's and traditional grading.	Not specified, mentioned or clear. Photo of front views.	Positive; Study stated that for 2 of the 3 males the pants made with the study's method fit better and the traditional method was either too short or too long. For 1/3 males, the pants made with traditional grading fit better because of the participant's small leg length to height ratio (short legs).	Compared real pants between 2 methods.	Small sample size. Better fit is not predicted/optimal fit. Evaluation method not specified, mentioned or clear. Inseam or out seam may be better measurement than height for garment.	73

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Song and Ashdown (2012)	Grading according to 3 different body shapes	Custom; Traditional pattern drafting with improved grading based on 3 shapes; To develop shape grading US size 10 pants were made and fitted for 3 real women of three different shapes. Patterns were graded and size charts were developed using traditional method. 27 real female participants were categorized in 1/3 shapes and corresponding pattern was graded to their size. Real pants were created and fit was evaluated on participants and compared to another method with traditional grading. 	27 real NY females aged 18-35 yrs, sizes 4-20, of different shapes (curvy, hip tilt, straight)	To compare to size chart and develop pants, from scans: waist grith, hip girth, waist to crotch length, thigh girth and inseam length. Used measurements from body scans to categories females in one of the shape categories (curvy, hip tilt, straight).	Not specified, mentioned or clear.	2 pairs of real pants for women made with 2 methods, study's and another with traditional grading.	3 expert judges working in as designers in apparel industry for 8 yrs or more and participants. 13-14 criteria on waist, abdomen, hip, crotch, thigh, knee, side seam and inseam in four postures (standing, sitting, walking and stepping) on 5-point scale (very dissatisfied to very satisfied). Photos of front, back and side views.	Positive and negative; Negative not so much in results but in process; Study stated that 70.4% of the judges, and 59.3% of the participants ranked the pants made from shape driven patterns best fit (not neck. as expected or optimal). Study stated that system requires a user to correctly develop elements such as size charts, block patterns and grading and that these steps could be avoided if a system was able to create a pattern directly from an individual's measurements. The study suggested that the study's data sets of body measurements and fitted custom patterns could be used to explore such a system. Study also stated that while it is important to get the participants' fit perceptions, participants are not fit professionals and their responses focus on whether pants felt very tight or very loose. It goes on to state that a desired improvement of the body-shape-driven system would be the ability to accommodate individuals' fit preferences. It may also be beneficial to adapt participants' fit criteria to their level of knowledge and better capture their experience as ultimately it is the consumers' perception of fit that will determine their satisfaction and the system's success.	Compared real pants between 2 methods. Evaluation includes 3 expert judges.	Best fit is not predicted/optimal fit. System requires a user to correctly develop elements such as size charts, block patterns and grading. Required at least three fittings and alterations. Steps could be avoided if a new system were able to create automated MTM patterns directly from an individual's body measurements. Making steps like creating charts and graded patterns, unnecessary. The sets of detailed body measurements and the respective well-fitted MTM patterns from study could be used as the basis for new system that changes block patterns directly according to an individual's body measurements. While it is important to get the participants' fit perceptions, participants are not fit professionals and their responses focus on whether pants felt very tight or very loose. Ability to accommodate individuals' fit preferences is desirable but may require different criteria to their level of knowledge and to better capture their experience as ultimately it is the wearers' perception of fit determines their satisfaction and the system's success.	32

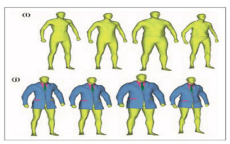
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Gu et al. (2017)	Relations between body landmarks	Relations; Developed size relations from 17 body scan landmarks to generate predictions and blazer pattern rules. Real blazers were created for 5 real females and fit was evaluated on participants. The fit of 1 of the 5 blazers was also compared to a blazer created with traditional grading. 	5 real female students aged 18-24 yrs with different body sizes at bust, waist and hip. 216 real female students aged between 18 and 24 yrs were 3D scanned and 17 measurements were obtained from the scans to establish landmark relations.	For blazer: bust, waist and hip. 17 landmarks from scans for relations: Shoulder width, side neck point height, shoulder point height, chest height, waist height, hip height, bust width, waist width, bust depth, front bust depth, waist depth, front waist depth, bust girth, front bust girth, waist girth, front waist girth, back neck girth. Biggest average difference between bodies scanned was 5.67 cm for bust with a standard deviation of 6.62 for a sample size 169. This represents approximately 1 or 2 sizes, whether smaller or larger sizes, according to (Beazley and Bond, 2003) and (Pellen, 2014). Biggest difference between participants is 10 cm for bust (see table). This represents 2 or 3 sizes, whether smaller or larger sizes, according to (Beazley and Bond, 2003) and (Pellen, 2014).	Absolute Bust 4cm Waist 6 cm Hip 4 cm	Real blazers 1 real blazer using traditional grading	By designer and participants at bust, shoulder and armhole in five postures (arms down, 45d, 90d, on shoulder and bending) using a 5 point scale (very uncomfortable to very comfortable). Photos of front views.	Positive; Study stated satisfactory fit for 5 blazers and that one blazer compared to traditional grading, study's method was better fitting.	Compared 2 methods for 1/5 real blazers.	Small sample size. Satisfactory fit and comfortable not predicted/optimal fit.	21

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Cho et al. (2006)	Flatten (direct) virtual 3D garment model to 2D pattern.	Flatten; 2 female mannequins were scanned. Skirts pattern lattices were drafted on the virtual 3D mannequin models according to a method developed for the study and the fit was adjusted using grainlines. Virtual 3D skirt pattern lattices were flattened to 2D patterns using grainlines. Real skirts were created and fit on mannequins was compared between the study's method and a traditional pattern.  	2 female mannequins of Japanese Industrial standard.	Measurements used by study's method to generate skirt pattern lattices unclear. May be body features or shapes from scans. Biggest difference between participants is 18 cm at waist (see table). This represents 4 sizes according to (Beazley and Bond, 2003) and (Pellen, 2014).	Not specified, mentioned or clear.	2 real skirts per mannequin. Study + 1 traditional pattern (unspecified)	10 individuals blindly compared the fit of 2 skirts. Evaluation based on "perception of fit" on a 5-point scale (much worse to much better). Photos of front and side views.	Positive; Study stated approximately 80% of individuals preferred fit of skirt with study method.	Blindly compared real skirts between 2 methods.	Small sample size with mannequins. Preferred fit is not predicted/optimal fit. Study stated that for tight fitting garments, the curved shape of the garment is the same as the body contour. Thus, not sure if study's method includes ease. Measurements used to generate skirt pattern lattices unclear. May be body features or shapes from scans. Traditional patterns used unclear. Evaluators' credentials unclear. Results in table seem to suggest different conclusion than authors: 75% much or slightly better, or 80% much or slightly better or no different. Results were 70% much better and 10% slightly better for one mannequin, and 10% much better and 60% slightly better. This may indicate that the study's method performance is different according to shape.	48

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Hlaing et al. (2013)	Flatten (maybe direct) 3D garment M to 2D pattern	Flatten; Some elements of the study are unclear. Intent seems to be to show that can draft a virtual 3D pant model on a virtual 3D body model by connecting predetermined vectors with predetermined ease and adding side seams and front and back crease lines. **Unclear if an individual would be scanned and virtual 3D pant model would be drafted and flattened,** or if individual measurements would be used to modify patterns developed for standard body sizes and categories based on waist. As real people are asymmetrical, the optimal side was duplicated 	One virtual female model. Unspecified number of virtual female models were categorized in sizes 38-48, and four different waist types (narrow, stand, wide and extra wide). 6 sizes * 4 waist types = 24 groups. Not clear of intent.	Vectors from scans to generate virtual pant model: waist girth, hip girth, upper thigh girth, knee girth, calf girth, ankle girth.	Absolute.	Virtual female pants	Not specified, mentioned or clear. Photos of front, back and side views	Positive; Study made positive claims although it mainly showed a process without a clear evaluation	-	Limited to virtual space. Evaluation method not specified, mentioned or clear. Body right or left side was mirrored to achieve a symmetrical virtual 3D body model. Study stated that pants are loose fitting and that close fitting pants are the body contour that is flattened, no ease. Loose fitting were simply flares in non fit critical areas.	20

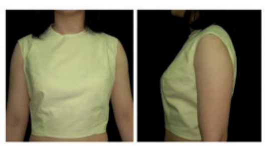
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Hong et al. (2018)	Flatten (direct) virtual 3D garment model to 2D pattern.	Flatten; 20 real females physically dis- abled of scoliosis were scanned. Bodice block frameworks were drafted on the virtual 3D body model by connecting control points and adding ease values. Virtual 3D bodice block models were flattened to virtual 2D bodice block patterns using selected control points. Virtual 2D patterns were modified to smooth curves and correct lengths and darts. Fit of virtual 3D bodice blocks on virtual body models was evaluated and altered if need be. Real bodice blocks were created and fit on participants was evaluated. 	20 real females physically disabled of scoliosis.	24 control points to generate bodice blocks from scans include waist, side, neck, armhole and shoulder	Ease but details not specified, mentioned or clear.	Real bodice blocks in greige cloth.	5 experienced fashion designers evaluated virtual fit based on length, waist, bust, shoulder, neck and armhole on 5-point scale (very tight to perfect to very loose). 2D patterns were edited according to their evaluation. The edits were simulated in virtual 3D space and fit was re-evaluated by different designers. Photos of front, back, right and left side views	Positive; Study stated judges can have a common perception of fit and software can simulate real garments with high accuracy and that design, display, evaluate and adjust process is effective	Use of different sets of judges	Process includes alterations for the complex figures to fit. Judges can have common perception of fit	35

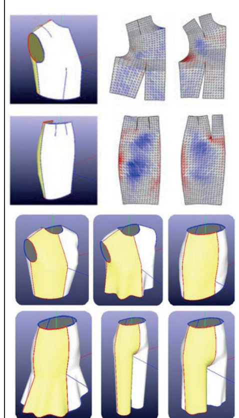
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Huang et al. (2012)	Flatten (direct) virtual 3D garment model to 2D pattern.	Flatten; 18 real females were scanned. Dress block wireframes were drafted on the virtual 3D body models according to body features and added ease. Virtual 3D dress blocks were flattened to 2D patterns using wireframes. Real dress blocks were created and fit on participants was compared between study's method and two other traditional methods. 	18 real female participants aged 18-25 yrs of different body shapes and BMIs (under-, normal and over-weight).	Body features from scans to create dress block wireframe, some automatically others are manually defined: waist line, bust point, bust line, hip line, high hip line, center front line, center back line, front neck point, side neck point, back neck point, neck line, shoulder point, chest line, front arm point, back arm point, lowest armhole point, armhole, side seam, front princess line, back princess line, front side seam, back side seam.	Absolute Bust 10 cm Waist 5 cm Hip 4 cm	3 real muslin dress (bodice+skirt) blocks per participant. Study + 2 traditional methods (Britain and Japan).	Participants compared fit of 3 dress bodices based on 10 criteria (neckline, bust, side seam, hip, armhole, shoulder seam, waistline, overall, best bodice shape) on a 5-point scale (poor to perfect fit). Photos of front, back and side views.	Positive; Study stated method produces satisfactory fit. Study's method equaled or outperformed the 2 traditional methods for all criteria. 47% of participants said they liked the shape of dress black generated by study's method the most vs 40% for the Japanese and 13% for British methods. 67% of participants preferred the fit of the dress block generated by the study's method vs 20% for British and 13% for Japanese methods.	Compared real garments between 3 methods	Satisfactory fit is not predicted/optimal fit. Blind evaluation not specified, mentioned or clear. Participants' level of understand of fit criteria not specified. Span of measurements of participants not provided. Interesting to see difference between participant evaluation of overall shape and fit.	21

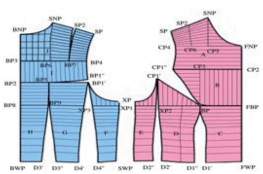
Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Li et al. (2013)	Flatten (relation) virtual 3D garment model to 2D pattern.	Relations at a selection of control points between reference virtual 3D body and garment models are applied to virtual target body model to get virtual 3D target garment model. The virtual target garment model is flattened to a virtual 2D pattern. 	Virtual male and female body models (source not specified, mentioned or clear). From photos may be 4 men 2 women.	Control points and number of control points were not specified, mentioned or clear.	Not specified, mentioned or clear.	Virtual 3D men's jacket, women's dress, models.	Not specified, mentioned or clear. Photos of angled front and back views.	Not specified, mentioned or clear.	-	Limited to virtual space. Evaluation method and results are not specified, mentioned or clear.	34

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
D. Zhang et al. (2014)	Flatten (relation) virtual 3D garment model to 2D pattern.	Flatten; 1 real female was scanned, segmented and sliced to create a symmetric virtual 3D body model based on a selection of feature points. A reference virtual dress and seamlines were drafted on reference virtual 3D body model and flattened with study's flattening algorithm to a reference 2D pattern. The dress and seamlines can be adjusted to a target scanned body and flattened to a target 2D pattern. A real dress was made to for a real female and fit was evaluated. 	RF 1 R female, additional information not specified, mentioned or clear.	To create dress: Contour lines (not specified) that include silhouette lines and cross sections. Feature points from scan to segment body: neck, shoulder, bust, waist, hip, crotch, knee, ankle, elbow, wrist.	Not specified, mentioned or clear.	Real dress.	Not specified, mentioned or clear. Photo of front view.	Positive; Study stated that dress fitted well.	-	Small sample size. Fit well is not predicted/optimal fit. No comparison. Evaluation method not specified, mentioned or clear. Symmetrized body. Statement that can flatten body contour for tight garments, suggesting no ease.	15

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
J. Zhang et al. (2017)	Flatten (relation) virtual 3D pattern model to 2D pattern.	Flatten; A female mannequin wearing a real sleeveless and collarless jacket was scanned. With 3D cross-sections of scan of reference mannequin wearing the refence jacket at selected locations, horizontal and vertical relations between reference mannequin and reference jacket were calculated for selected locations. 3 target mannequins were scanned. Vertical and horizontal relations between the reference mannequin and reference jacket were applied to target mannequin line models to draft virtual target jackets. Virtual target jackets were flattened to target 2D patterns. Real jackets were created using 2 methods and fit was evaluated on mannequins and compared. 	3 female mannequins.	For jackets: bust girth, waist girth, hip girth + vert: back neck to waist, front neck to bust, front bust to waist, waist to hip. Biggest difference between mannequins is 6 cm for hip (see table). This represents 1 to 2 sizes, whether smaller or larger sizes, according to (Beazley and Bond, 2003) and (Pellen, 2014).	Not specified, mentioned or clear.	2 real sleeveless and collarless jackets made with wool fabric for each mannequin (with and without vertical grading, 3x2=6).	Not specified, mentioned or clear. Compared real jackets made with and without the vertical relations. Mention wrinkles in upper-bust, armpit, back, alignment of garment and mannequin bust line. Photos of front, back and side views.	Positive; Study stated that all 3 jackets with vertical relations looked better.	Compared real jackets between 2 methods.	Small sample size with mannequins. Look better is not predicted/optimal fit. Evaluation method not specified, mentioned or clear, though wrinkling is mentioned.	26

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Hyo Kim et al. (2010)	Flatten (deformation) virtual 3D garment model to 2D pattern	Flatten; 1 female mannequin measurements were obtained from a contact-type digitizing system to generate a virtual 3D mannequin model. A free form deformation lattice was generated on the reference virtual 3D mannequin model. The lattice was then deformed at selected control points to get target virtual 3D body models of 3 real females. Virtual bodice block models were drafted and then flattened to a 2D pattern. Real bodices were created and fit was evaluated on participants. 	3 real females, additional information not specified, mentioned or clear.	For reference bodice: front neck to waist, back neck to waist, bust point to bust point, neck circumference, chest circumference, bust circumference, waist circumference, shoulder angle Control points to deform reference virtual body model may include neck, chest, bust, waist, front and back length. Participants: neck girth, waist girth, bust girth, upper bust girth, back length, front length. Biggest difference between participants is 3 cm at waist and upper bust. (See table)	Absolute but details not specified, mentioned or clear.	Real bodice blocks.	Participants evaluated fit based on 12 criteria on neck, bust, waist, shoulder, armholes, length and overall appearance using a 5-point scale. Photos from front and side views.	Positive; Study stated that bodice blocks fit well; 2 participants felt comfortable and 1 did not.	-	Small sample size. Fit well and comfortable are not predicted/optimal fit. Participant's level of understand of fit criteria not specified. Participant evaluation may have been biased as no comparison so participants may have known that tested bodice block was from study with desired positive outcome.	21

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Sungmin Kim and Kyu Park (2007)	Flatten (deformation) virtual 3D garment model to 2D pattern.	Flatten; 1 female mannequin measurements were obtained from a contact-type digitizing system to generate a virtual 3D mannequin model. The reference virtual 3D mannequin model was deformed to target virtual 3D body model of an unspecified real female user based on selected measurements. Virtual 3D bodice, skirt and pant blocks were drafted onto target virtual 3D body model and flattened to virtual 2D patterns. 	1 unspecified real female user	For virtual bodice, skirt and pant blocks, may be virtual 3D body shell of unspecified user, may be from contact-type digitizing system. To deform reference virtual body model to target body model: Bodice: bust girth, front leg girth, neck girth, side length, armhole depth, shoulder angle Skirt/pant: waist girth, abdomen girth, hip girth, thigh or thigh level girth, side length	Not specified, mentioned or clear.	Virtual female bodice, skirt and pants.	Not specified, mentioned or clear. Photos of semi-front-side views of virtual blocks.	Positive; Study stated that method can generate various styles for various sizes.	,-	Small sample size. Limited to virtual space. Evaluation method not specified, mentioned or clear. The blocks may be body shell. The stylized garment are blocks with added flares that don't modify key fit areas such as shoulders or hips.	14

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Yang and Weiyuan (2007)	Flatten (comparison) virtual 3D garment model to 2D pattern.	Flatten; 1 female body scan data was symmetrized to create a virtual 3D model. Drafted a virtual bodice block model without ease on virtual body model according to a standard industry method (Bunka) and manually defined features. A wireframe of the virtual bodice model was developed and then flattened to a 2D pattern. Compared 2D patterns generated from 3D to 2D flattening to non flattening, AutoCAD, methods. 	1 female body scan data from unknown source	Manually defined features on 3D body model from scan data: bust point to center front, shoulder to side neck, side to front neck, side neck to back neck, front center to side waist, side to back center waist, front armhole arc, back armhole arc, front mid armhole to front center, back mid armhole to back center, high armhole to back, center, neck to bust line, bust line to center front, bust point to waist, armhole front to waist, armhole center to waist, back armhole to waist, protruding back to waist, center back neck to high back, center high back to back center waist.	No ease was added to virtual body model that was flattened	2 virtual patterns. No real pattern or garment.	Statistical analysis of differences between patterns from 3D to 2D flattening non flattening. Photo view n/a	Positive; Study stated 7/10 segments error less than 1cm2, others are within 3cm2. So method relatively accurate at keeping shape of non flattening pattern method.	Compared virtual patterns between 2 methods	Small sample size. Ease not added. Limited to virtual space. Study compares pattern generation not fit of patterns. Method uses manually defined features.	15

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Y. Zhang and Wang (2011)	Flatten (comparison) virtual 3D pattern model to 2D pattern.	Flatten; 1 virtual 3D garment model from traditional method (not specified) was drafted (not on a body model) and flattened to a 2D pattern using study's flattening algorithm that controls distortions and surface length variations. Real jeans made for what appears to be 1 real female. Compared the study's flattening method to another method. 	1 real female (from photo appearance).	Not specified, mentioned or clear.	Not specified, mentioned or clear.	2 real pair of jeans for one participant. Study flattening algorithm and another (from one of study's authors).	By one "fashion specialist". Criteria and scale not specified, mentioned or clear. Photos of front, back and side views.	Positive; Study stated that flattening algorithm created better fitting jean with better back waist band and yoke.	Compared real jeans between 2 methods.	Small sample size. Indication of better not necessarily predicted or optimal fit Evaluation by one person. Blind evaluation, criteria and scale not specified, mentioned or clear.	37

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
D.-E. Kim and LaBat (2013)	Visualisation	37 female participants were scanned and virtual 3D body models were generated. Real pants were created from patterns developed and graded in 10 sizes from size 2 to 20 using a pattern making book (Rosen, 2005). Virtual pants models were generated in each size and participants chose the best size by viewing a fit simulation of the virtual pants models on their virtual 3D body model. Participants tried on the real pants in the selected size and evaluated accuracy between the virtual and real pants.  	37 real females from a US midwestern university, aged 19-35 yrs, majority were aged 19-22, size 2-20.	-	Not specified, mentioned or clear.	1 pair for real and virtual pants per participants.	Participants evaluated fit of virtual and real pants at 13 areas (related to waist, abdomen, hip, thigh, crotch, side, inseams, hem) with a 7-point scale (extremely poor fit to excellent fit). They were also asked to what extent they believed the virtual pants fit like the real pants on a 7-point scale (strongly disagree to strongly agree). They were not given fit instructions, rather to use their own fit criteria that they would normally use when shopping for a garment. Photos of front, back, and side views.	Negative; Study stated that accuracy was moderately good but not enough to perform online fit evaluation, for example garment and body shape relationship and wrinkles were not accurately represented. Participants generally rated the virtual pants as better fitting. One challenge is that the 3D virtual body model does not have compressible flesh so the virtual pant model does not displace flesh that results in bulging. Additional challenges are fabric representation.	-	-	48

Study	Category	Technical	Participants	Measurements to dev. pattern or garment	Ease values to dev. pattern or garment	Garment	Evaluation	Conclusions	Controls	Transferability and observations	Ref. year span
Tao et al. (2018)	Visualisation (collaborative design)	A virtual t-shirt model in different sizes was simulated on a 3D standard female mannequin model. 6 participants that were students or researchers with textile or apparel knowledge attended a fit training session and evaluated the fit. Their evaluations were used to establish the relationship between the virtual t-shirt model in different sizes and fit on the virtual mannequin model to estimate fit perception without trying on. 	1 standard female mannequin model.	Circumference: neck, shoulder, chest, waist, hip bicep Length: torso, arm Depth: armhole	Not specified, mentioned or clear.	Virtual long sleeve t-shirt. The pattern was developed in a pattern making software and then imported in a simulation software where the virtual t-shirt was simulated onto the 3D virtual mannequin.	by 6 participants based on 8 criteria (neckline, shoulder, chest, waist, garment length, sleeve length, arm restriction in movement, torso restriction in movement) on a 9-point scale (extremely tight to extremely loose) in a standing and a dynamic position. Photos of front, back and side views.	Positive; The study stated that 3D virtual body model measurements, t-shirt size and if desired, shape of t-shirt and pattern can be adjusted.	-	Limited to virtual space.	34

APPENDIX III

BODY AND POSTURE VARIATIONS

Taken from Beazley and Bond (2003, p. 159-185):

Height

1) Short
2) Tall

Shoulder angle

3) Square
4) Slanting

Crotch height (depends on torso to leg length proportion)

5) Low
6) High

Stance

7) Closed
8) Open

Posture

9) Erect
10) Stooping

Pelvis tilt

11) Backward
12) Forward
13) Front

14) Back

Neck width

15) Narrow

16) Wide

Arm angle

17) Backward

18) Forward

Bust

19) Small

20) Large

Hips

21) Small

22) Large

Shoulders

23) Flat

24) Prominent

Seat

25) Flat

26) Prominent

Thighs

27) Small

28) Large

Stomach

29) Prominent

Taken from from Liechty et al. (2016, p. 177-476):

Bodice

1) Long lower rib cage/low waist
2) Long upper rib cage/low waist
3) Long shoulder joint
4) Short lower rib cage/high waist
5) Short upper rib cage/high waist
6) Short shoulder joint
7) Square shoulders
8) Sloped shoulders
9) Forward shoulder joint
10) Posterior shoulder joint
11) Large shoulder joint
12) Small shoulder joint
13) High neck base
14) Low neck base
15) Forward head
16) Rounded chest
17) Shallow chest
18) High bust position
19) Low bust position
20) Dowager curve
21) Rounded upper back
22) Erect back
23) Prominent shoulder blades
24) Flat shoulder blades
25) Large neck

26) Small neck
27) Prominent collar bone
28) Wide/broad shoulders
29) Narrower shoulders
30) Wide/chest upper back
31) Narrow chest/upper back
32) Large bust
33) Prominent bust
34) Small bust
35) Wide bust span
36) Cylindrical upper torso
37) Flat oval-shaped upper torso
38) Wide rib cage
39) Narrow rib cage
40) Flared lower ribs
41) Large waist
42) Small waist

Sleeve

43) Long arms
44) Short arms
45) Large upper arms
46) Large arms
47) Small arms
48) Inward rotation of elbows
49) Outward rotation of elbows
50) Large elbows
51) Large forearms
52) Large wrists
53) Small wrists

Skirt and pants

54) Long legs
55) Short legs
56) Long lower torso
57) Short lower torso
58) Inward rotation of knees
59) Outward rotation of knees
60) Hyperextended knees/prominent calves
61) High buttocks contour
62) Low buttocks contour
63) Sway front
64) Sway back
65) Large waist for lower torso
66) Small waist for lower torso
67) Prominent hip bones
68) High hip curve
69) Low hip curve
70) Large/wide hips
71) Small/narrow hips
72) Cylindrical lower torso
73) Flat oval-shaped lower torso
74) Small/flat abdomen
75) Large/prominent abdomen
76) High abdominal contour
77) Low abdominal curve
78) Large/prominent buttocks
79) Small flat buttocks
80) Prominent pubic area
81) Reduced pubic area
82) Large thighs at side

83) Large thighs at front
84) Large thighs at inside
85) Shallow thighs on inside
86) Large calves
87) Large legs
88) Thin legs

LIST OF REFERENCES

Aldrich, W. (2003). The Impact of Fashion on the Cutting Practices for the Woman's Tailored Jacket 1800-1927. *Textile History, 34*(2), 134-170.

Aldrich, W. (2007). History of sizing systems and ready-to-wear. In *Sizing in Clothing: Developing effective sizing systems for ready-to-wear clothing* (pp. 1-48): Elsevier Ltd.

Aldrich, W. (2008). *Metric Pattern Cutting for Women's Wear*: Wiley.

Allwood, J., Laursen, S., Rodríguez, C., & Bocken, N. (2006). *Well Dressed? The Present and Future Sustainability of Clothing and Textiles in the United Kingdom*.

Amsterdam University of Applied Sciences. (n.d.). Minor Maker Lab: Making as Research. In Amsterdam University of Applied Sciences (Ed.).

Armstrong, H. J. (2010). *Patternmaking for Fashion Design*: Pearson Education.

Ashdown, S. P., & Delong, M. (1995). Perception testing of apparel ease variation. *Applied Ergonomics, 26*(1), 47-54.

Ashdown, S. P., Loker, S., Schoenfelder, K., & Lyman-Clarke, L. (2004). Using 3D scans for fit analysis. *Journal of Textile and Apparel, Technology and Management, 4*(1).

Ashdown, S. P., Lyman-Clarke, L., Smith, J., & Loker, S. (2007). Production systems, garment specification and sizing. In S. P. Ashdown (Ed.), *Sizing in Clothing: Developing effective sizing systems for ready-to-wear clothing* (pp. 348-374): Woodhead Publishing Limited.

Ashdown, S. P., Mee Sung, C., & Milke, E. (2008). Automated side-seam placement from 3D body scan data. *International Journal of Clothing Science and Technology, 20*(4), 199-213.

Baldwin, C. (2017). All the Stores You Probably Didn't Realize Do Free Tailoring. Retrieved from https://www.racked.com/2017/10/30/16562054/store-alteration-service-free-hemming-tailoring

Bang, H. (2019). *Personal Experiences of a Capsule Wardrobe.* (Ph.D.). University of Minnesota, Ann Arbor. ProQuest Dissertations & Theses Global database. (13902447)

Bardey, A., Booth, M., Heger, G., & Larsson, J. (2021). Finding yourself in your wardrobe: An exploratory study of lived experiences with a capsule wardrobe. *International Journal of Market Research*.

Beazley, A. (1999). Size and fit: The development of size charts for clothing - Part 3. *Journal of Fashion Marketing and Management, 3*(1), 66-84.

Beazley, A., & Bond, T. (2003). *Computer-Aided Pattern Design and Product Development*: Wiley.

Bellemare, J. (2014). *Variables stratégiques fondamentales et cardinalité nécessaires au vêtement sur-mesure de masse pour hommes.* (Thèse de doctorat). École Polytechnique de Montréal

Bougourd, J. (2007). Sizing systems, fit models and target markets. In S. P. Ashdown (Ed.), *Sizing in Clothing: Developing effective sizing systems for ready-to-wear clothing* (pp. 108-151): Woodhead Publishing Limited.

Breuer, R. L. (2015). *Fashion beyond identity: The three ecologies of dress.* (PhD). University of Amsterdam

Brown, P., & Rice, J. (2013). *Ready-to-Wear Apparel Analysis*: Pearson Education.

Bye, E. (2010). *Fashion design* (English ed. ed.). Oxford: Berg.

Chan, A. P., Fan, J. T., & Yu, W. (2003). Men's Shirt Pattern Design: Part II: Prediction of Pattern Parameters from 3D Body Measurements. *Sen-i Gakkaishi, 59*, 328-333.

Chan, A. P., Fan, J. T., & Yu, W. (2005). *Prediction of men's shirt pattern based on 3D body measurements* (Vol. 17).

Chapman, J. (2014). Prospect, seed and activate. In K. Fletcher & M. Tham (Eds.), *Routledge Handbook of Sustainability and Fashion* (pp. 74-81). New York, NY: Routledge.

Chen, C.-M. (2007). Fit evaluation within the made-to-measure process. *International Journal of Clothing Science and Technology, 19*(2), 131-144.

Cho, Y., Komatsu, T., Inui, S., Takatera, M., Shimizu, Y., & Park, H. (2006). Individual Pattern Making Using Computerized Draping Method for Clothing. *Textile Research Journal, 76*(8), 646-654.

Choi, M.-S., & Ashdown, S. P. (2002). The Design and Testing of Work Clothing for Female Pear Farmers. *Clothing and Textiles Research Journal, 20*(4), 253-263.

Cipriani, J.-P. (2019). Qu’est-ce qui cloche dans nos vêtements? *L’actualité, 44(04)*.

Cline, E. L. (2013). *Overdressed: The Shockingly High Cost of Cheap Fashion*. USA: Penguin Group.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and Conducting Mixed Methods Research*: SAGE Publications.

Daanen, H. A. M. (2007). Function, fit and sizing. In S. P. Ashdown (Ed.), *Sizing in Clothing: Developing effective sizing systems for ready-to-wear clothing* (pp. 202-219): Woodhead Publishing Limited.

Daanen, H. A. M., & Psikuta, A. (2018). 10 - 3D body scanning. In R. Nayak & R. Padhye (Eds.), *Automation in Garment Manufacturing* (pp. 237-252): Woodhead Publishing.

Dabolina, I., Vilumsone, A., Dabolins, J., & Belakova, D. (2015). Usage of 3D Anthropometric Data in CAD/CAM Individual Measurement List. *Advanced Materials Research, 1117*, 283-286.

Dong-Eun, K., & LaBat, K. (2013). Consumer experience in using 3D virtual garment simulation technology. *Journal of the Textile Institute, 104*(8), 819-829.

Easter, E. P. (1994). Design of Protective Cloting. In M. Raheel (Ed.), *Protective Clothing Systems and Materials*: CRC Press.

Ellen MacArthur Foundation. (2017). *A new textiles economy: Redesigning fashion's future*.

Ericsson, A., & Brooks, A. (2014). African seconhd-hand clothes. In K. Fletcher & M. Tham (Eds.), *Routledge Handbook of Sustainability and Fashion* (pp. 91-99). New York, NY: Routledge.

Fashion Takes Action. (2021). *A Feasibility Study of Textile Recycling in Canada, by Kelly Drennan, Sabine Weber, Colin Jacob-Vaillancourt, Anika Kozlowski, and Laurence Fiset-Sauvageau*.

Fletcher, K. (2014). Other fashion systems. In K. Fletcher & M. Tham (Eds.), *Routledge Handbook of Sustainability and Fashion* (pp. 13-24). New York, NY: Routledge.

Fletcher, K., & Grose, L. (2011). *Fashion & Sustainability. Design for Changr*. London: Laurence King Publishing Ltd.

Fletcher, K., & Tham, M. (2014). Conclusions. In K. Fletcher & M. Tham (Eds.), *Routledge Handbook of Sustainability and Fashion* (pp. 293-298). New York, NY: Routledge.

Gill, S. (2015). A review of research and innovation in garment sizing, prototyping and fitting. *Textile Progress, 47*(1), 1-85.

Given, L. M. (2008). *The Sage Encyclopedia of Qualitative Research Methods: A-L ; Vol. 2, M-Z Index*: SAGE Publications.

Griffin, L. A., & Dunne, L. E. (2016). Effects of ready-to-wear sizing conventions on sensor placement for medical wearable sensing. *Journal of Medical Devices, Transactions of the ASME, 10*(2).

Gu, B., Gu, P., & Liu , G. (2017). Pattern generation rules for basic women's suits. *International Journal of Clothing Science and Technology, 29*(3), 330-348.

Guo, S., & Istook, C. L. (2021). Evaluation of 2D CAD Technology for Garments Customized for Body Shape. *Fashion Practice*, 1-27.

Gupta, S., & Gentry, J. W. (2016). The behavioral responses to perceived scarcity – the case of fast fashion. *The International Review of Retail, Distribution and Consumer Research, 26*(3), 260-271.

Han, H.-S., Kim, S., & Park, C. K. (2015). Automatic custom pattern generation using width-height independent grading. *International Journal of Clothing Science and Technology, 27*(6), 908-921.

Harwood, A., Gill, J., & Gill, S. (2020). JBlockCreator: An open source, pattern drafting framework to facilitate the automated manufacture of made-to-measure clothing. *11*.

Hawley, J. (2008). Economic impact of textile and clothing recycling. *Sustainable Fashion: Why Now? A Conversation about Issues, Practices, and Possibilities*, 207-232.

Hlaing, E. C., Krzywinski, S., & Roedel, H. (2013). Garment prototyping based on scalable virtual female bodies. *International Journal of Clothing Science and Technology, 25*(3), 184-197.

Hong, Y., Bruniaux, P., Zeng, X., Curteza, A., & Liu, K. (2018). Design and evaluation of personalized garment block for atypical morphology using the knowledge-supported virtual simulation method. *Textile Research Journal, 88*(15), 1721-1734.

Hong, Y., Zeng, X., Bruniaux, P., & Liu, K. (2017). Interactive virtual try-on based three-dimensional garment block design for disabled people of scoliosis type. *Textile Research Journal, 87*(10), 1261-1274.

Huang, H. Q., Mok, P. Y., Kwok, Y. L., & Au, J. S. (2012). Block pattern generation: From parameterizing human bodies to fit feature-aligned and flattenable 3D garments. *Computers in Industry, 63*(7), 680-691.

Huck, J., Maganga, O., & Kim, Y. (1997). Protective overalls: evaluation of garment design and fit. *International Journal of Clothing Science and Technology, 9*(1), 45-61.

Hunter, L., & Fan, J. (2004). Garment drape. In J. Fan, W. Yu, & L. Hunter (Eds.), *Clothing Appearance and Fit: Science and Technology* (pp. 114-134): Woodhead Publishing Limited.

Hyo Kim, C., Hwan Sul, I., Park, C. K., & Kim, S. (2010). Automatic basic garment pattern generation using three-dimensional measurements. *International Journal of Clothing Science and Technology, 22*(2/3), 101-113.

Istook, C. L. (2002). Enabling mass customization: computer-driven alteration methods. *International Journal of Clothing Science and Technology, 14*(1), 61-76.

Jalil, M. H., & Shukhaila, B. S. S. (2019). *Adopting C2cad Model To Eco Capsule Wardrobe Design*.

Kidwell, C. B., & Christman, M. C. S. (1974). *Suiting Everyone: The Democratization of Clothing in America*: Smithonian Institution Press.

Kim, D.-E. (2009). *Apparel fit based on viewing of 3D virtual models and live models.* (PhD). University Of Minnesota

Kim, D.-E., & LaBat, K. (2013). An exploratory study of users' evaluations of the accuracy and fidelity of a three-dimensional garment simulation. *Textile Research Journal, 83*(2), 171-184.

Kim, S., & Kyu Park, C. (2007). Basic garment pattern generation using geometric modeling method. *International Journal of Clothing Science and Technology, 19*(1), 7-17.

Kim, S., Yeonhee, J., Yejin, L., & Kyunghi, H. (2010). 3D Pattern Development of Tight-fitting Dress for an Asymmetrical Female Manikin. *Fibers and Polymers, 11*(1), 142-146.

Kwong, M.-y. (2004). Garment design for individual fit. In J. Fan, W. Yu, & L. Hunter (Eds.), *Clothing Appearance and Fit: Science and Technology* (pp. 196-233): Woodhead Publishing Limited.

Labat, K., Salusso, C., & Rhee, J. (2007). Home sewers' satisfaction with fit of apparel patterns. *Journal of Fashion Marketing and Management: An International Journal, 11*(3), 429-440.

Leedy, P. D., & Ormrod, J. E. (2016). *Practical research : planning and design* (Eleventh edition. ed.). Boston: Pearson.

Li, J., Lu, G., Liu, Z., Liu, J., & Wang, X. (2013). Feature curve-net-based three-dimensional garment customization. *Textile Research Journal, 83*(5), 519-531.

Liechty, E. L. G., & Rasband, J. A. (2006). *Fabulous Fit: Speed Fitting and Alterations* (2 ed.). New York City, NY: Fairchild Publications, Inc.

Liechty, E. L. G., Rasband, J. A., & Pottberg-Steineckert, D. (2016). *Fitting and Pattern Alteration: A Multi-Method Approach to the Art of Style Selection, Fitting, and Alteration*: Bloomsbury Academic.

Loker, S. (2007). Mass customization and sizing. In S. P. Ashdown (Ed.), *Sizing in Clothing: Developing effective sizing systems for ready-to-wear clothing* (pp. 246-263): Woodhead Publishing Limited.

Lu, J.-M., Wang, M.-J. J., Chen, C.-W., & Wu, J.-H. (2010). The development of an intelligent system for customized clothing making. *Expert Systems With Applications, 37*(1), 799-803.

Maldini, I. (2019). *Can design confront consumerism?* (PhD). Vrije Universiteit Amsterdam

Maldini, I., Stappers, P. J., Gimeno-Martinez, J. C., & Daanen, H. A. M. (2019). Assessing the impact of design strategies on clothing lifetimes, usage and volumes: The case of product personalisation. *Journal of Cleaner Production, 210*, 1414-1424.

Maslow, A. H. (1943). A Theory of Human Motivation. *Psychological Review, 50*, 370-396. Retrieved from https://psychclassics.yorku.ca/Maslow/motivation.htm

McKinney, E., Gill, S., Dorie, A., & Roth, S. (2017). Body-to-Pattern Relationships in Women's Trouser Drafting Methods: Implications for Apparel Mass Customization. *Clothing and Textiles Research Journal, 35*(1), 16-32.

Mullet, K. K. (2015). *Concepts of Pattern Grading: Techniques for Manual and Computer Grading*: Bloomsbury Academic.

Naber, A. (2015). Qualitative Experiment as a Participating Method in Innovation Research. *Historical Social Research, 40*(3), 233-257.

Nayak, R., & Padhye, R. (2018). 5 - Artificial intelligence and its application in the apparel industry. In R. Nayak & R. Padhye (Eds.), *Automation in Garment Manufacturing* (pp. 109-138): Woodhead Publishing.

Niinimäki, K. (2010). Eco-Clothing, Consumer Identity and Ideology. *Sustainable Development, 18*, 150-162.

Pellen, D. (2014). *Le vêtement féminin, modélisme, coupe à plat. Tome 1. Construction des bases. Jupes, corsages, manches, cols*. Vottem, Belgique: dp studio.

Quantis. (2018). *Measuring Fashion. Environmental Impact of the GLobal Apparel and Footware Industries Study.*

Rahman, O., Fung, B. C. M., Chen, Z., & Gao, X. (2017). A cross-national study of apparel consumer preferences and the role of product-evaluative cues. *Asia Pacific Journal of Marketing and Logistics, 29*(4), 796-812.

Rhee, J., & Johnson, K. K. P. (2019). 'The wardrobe diet': teaching sustainable consumption through experience with undergraduates in the USA. *International Journal of Fashion Design, Technology and Education, 12*(3), 283-292.

Shen, L., & Huck, J. (1993). Bodice Pattern Development Using Somatographic and Physical Data. *International Journal of Clothing Science and Technology, 5*(1), 6-16.

Shin, E. (2013). *Exploring consumers' fit perceptions and satisfaction with apparel fit in general.* (1540128 M.S.). Iowa State University, Ann Arbor. ProQuest Dissertations & Theses Global database.

Simard-Lessard, I. (2017). *La gestion des connaissances en patron et ajustement dans l'industrie québécois du vêtement.* (M. Eng. Master). École de technologie supérieure, Université du Québec, Montréal.

Sohn, J.-M., Lee, S., & Kim, D.-E. (2020). An exploratory study of fit and size issues with mass customized men's jackets using 3D body scan and virtual try-on technology. *Textile Research Journal*.

Song, H. K., & Ashdown, S. P. (2012). Development of Automated Custom-Made Pants Driven by Body Shape. *Clothing and Textiles Research Journal, 30*(4), 315-329.

Sreejesh, S., Mohapatra, S., & Anusree, M. R. (2014). Business Research Design: Exploratory, Descriptive and Causal Designs. In *Business Research Methods: An Applied Orientation* (pp. 25-103): Springer International Publishing.

Su, J., Liu, G., & Xu, B. (2015). Development of individualized pattern prototype based on classification of body features. *International Journal of Clothing Science and Technology, 27*(6), 895-907.

Tao, X., & Bruniaux, P. (2013). Toward advanced three-dimensional modeling of garment prototype from draping technique. *International Journal of Clothing Science and Technology, 25*(4), 266-283.

Tao, X., Chen, X., Zeng, X., & Koehl, L. (2018). A customized garment collaborative design process by using virtual reality and sensory evaluation on garment fit. *Computers & Industrial Engineering, 115*, 683-695.

Threads Magazine. (2012). *Threads Fitting for Every Figure*: Taunton Press.

United States Environmental Protection Agency. (2019). *Advancing Sustainable Materials Management: 2017 Fact Sheet.*

Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States.

von Hippel, E. (2005). *Democratizing Innovation*. Cambridge, Massachusetts: The MIT Press.

Wicker, A. (2016, September 1, 2016). Fast Fashion Is Creating an Environmental Crisis. *Newsweek*.

Wicker, A. (2020). Fashion has a misinformation problem. That's bad for the environment. Retrieved from https://www.vox.com/the-goods/2020/1/27/21080107/fashion-environment-facts-statistics-impact

WRAP. (2017). *Valuing Our Clothes: the cost of UK fashion*.

Xiu, Y., Wan, Z.-K., & Cao, W. (2011). A constructive approach toward a parametric pattern-making model. *Textile Research Journal, 81*(10), 979-991.

Yang, Y., & Weiyuan, Z. (2007). Prototype garment pattern flattening based on individual 3D virtual dummy. *International Journal of Clothing Science and Technology, 19*(5), 334-348.

Yang, Y., Zhang, W., & Shan, C. (2007). Investigating the development of digital patterns for customized apparel. *International Journal of Clothing Science and Technology, 19*(3/4), 167-177.

Yang, Y., Zou, F., Li, Z., Ji, X., & Chen, M. (2011). Development of a Prototype Pattern Based on the 3D Surface Flattening Method for MTM Garment Production. *Fibres & Textiles in Eastern Europe, 19*(5), 107-111.

Yu, W. (2004a). Human anthropometrics and sizing systems. In *Clothing Appearance and Fit: Science and Technology* (pp. 169-195): Elsevier Inc.

Yu, W. (2004b). Objective evaluation of clothing fit. In J. Fan, W. Yu, & L. Hunter (Eds.), *Clothing Appearance and Fit: Science and Technology* (pp. 72-88): Woodhead Publishing Limited.

Yu, W. (2004c). Subjective assessment of clothing fit. In J. Fan, W. Yu, & L. Hunter (Eds.), *Clothing Appearance and Fit: Science and Technology* (pp. 31-42): Woodhead Publishing Limited.

Zhang, D., Wang, J., & Yang, Y. (2014). Design 3D garments for scanned human bodies. *Journal of Mechanical Science and Technology, 28*(7), 2479-2487.

Zhang, J., Innami, N., Kim, K., & Takatera, M. (2015). Upper garment 3D modeling for pattern making. *International Journal of Clothing Science and Technology, 27*(6), 852-869.

Zhang, J., Kim, K., & Takatera, M. (2017). Three-dimensional garment-size change modeled considering vertical proportions. *International Journal of Clothing Science and Technology, 29*(1), 84-95.

Zhang, Y., & Wang, C. C. L. (2011). WireWarping++: Robust and Flexible Surface Flattening With Length Control. *IEEE Transactions on Automation Science and Engineering, 8*(1), 205-215.