Cape Peninsula
University of Technology

The development of an Afrocentric apparel measurement size chart for young women's jeans through the use of 3D technology.

by

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Dissertation submitted for Master of Technology: Design

in the Faculty of Informatics and Design

at the Cape Peninsula University of Technology

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Date Submitted: December 2022

Declaration

I, *Deidre Luzina Windvogel*, declare that the contents of this design research report represent my own/group's unaided work and that the report has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my/our own opinions and not necessarily those of the Cape Peninsula University of Technology.

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Acknowledgements

I would like to express my deepest gratitude to my supervisor, Dr Elizabeth Pepler for her guidance and invaluable feedback. My co-supervisor, Dr Alettia Chisin for her encouragement and support. They both generously provided knowledge, expertise and time. I am also thankful to Mr Shamil Isaacs (Manager of the Technology Station: Clothing and Textiles Technology Department), for the use of the 3D body scanner and the donation of gift bags for the participants. I would also like to extend my sincere thanks to Prof Dr Michael Ernst for laying the foundation for this study by sharing his knowledge and skills.

I am extremely grateful to Stanley Lekata for the data analysis that proved to be a success. Many thanks to Claudine Bantom for sharing her textile knowledge so willingly and for being a critical reader of my work as well as Lisa van Rooi for assisting with the body scanning process. Additionally, this endeavour would not have been possible without the generous support from the HOD of our department together with my colleagues. I would also like to thank the participants of this study for their willingness to sacrifice their time and provide valuable input. Lastly, I want to thank my family and friends for their endless encouragement and support.

Dedication

This work is dedicated to my late stepfather, ***Simon Peter Davids***, for believing in me and encouraging me to follow my dream. He never failed to show how proud he was of my achievements.

To my daughters, ***Grace and Gabriella Windvogel***, who inspire me every day to continue to break boundaries and to never stop learning. I love you endlessly.

Abstract

This research is rooted in the academic and real-life challenges that local retailers and manufacturers experience when they need to provide their defined target markets with well-fitting clothing. Various literature studies confirm that universally women typically experience emotional turmoil when their designated sizes do not fit their bodies well. This is clearly the case in South Africa as well, where there is a pronounced lack of proper, authentic body measurement and body shape data in the South African clothing industry. The main research question explores the possible development of standard body measurement (SBM) size charts for use in the local industry, while improving the overall fit outcome of quality denim jeans for younger South African women. The study starts with a contextualization of the research by posing the research background, questions and objectives. A pragmatic paradigm was applied, using a mixed method of qualitative enquiry and a quantitative anthropometric analysis supported by a wide literature study. The body measurements of 210 female 18- to 35-year-old participants were collected with the application of 3D body scanning technologies through a random sampling method. Statistical analyses were conducted by means correlation and regression analysis to examine the relationships among the variables to create a standard body measurement size chart, a jeans size prediction model and numerical evaluation parameters to identify the various body shapes. The aim was to develop denim jeans in various sizes, incorporating both traditional sizing and a newly developed size chart. The findings indicate that comfort remains the dominant factor women when shopping for jeans. Most women find the process stressful and frustrating. The study established that the selected primary dimensions correlate well with most of the secondary dimensions and the methodology resulted in the successful creation of an improved size chart. These results were implemented in the 3D virtual fitting process as well as the development of physical denim jean prototypes. It is recommended that anthropometric research should be conducted regularly to ensure that the new findings of this study remain updated. The intriguing matter regarding outliers should be an important focus for future research studies. It has been verified that the use of 3D technologies has proven to be useful in the evolvement of an efficient product development process, and the primary research questions were all resolved.

Keywords: Anthropometrics, morphology, apparel fit, customer dissatisfaction, 3D technology, jeans-wear design, body cathexis, standard measurement system, South African women sizes, fashion design.

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Table of abbreviations

Abbreviation	Description
2D	Two dimensional
3D	Three dimensional
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CSR	Customer satisfaction rating
CSS	Customer satisfaction survey
CPUT	Cape Peninsula University of Technology
NPD	New product development
RTW	Ready to wear
SBM	Standard body measurements
SABS	South African Bureau of Standards
TPDP	Traditional product development processes

Glossary/Definition of Terms

Term	Definition
Anthropometry	The scientific study of the measurements and proportions of the human body.
Avatar	A static or moving image or other graphic representation that acts as a proxy for a person
Brand	A name that is given by the maker to a product or range of products, especially a trademark
Cathexis	The concentration of mental energy on one particular person, idea, or object (especially to an unhealthy degree)
Iteration	Substantive changes to an existing design, including new designs and concepts
Label	A piece of fabric sewn into a garment bearing the brand name, size, and or care instructions.
Mannequin	A styled and three-dimensional representation of the human form used in clothing product development and window displays; dummy
Morphology	The study of the forms of things (a particular form, shape, or structure)
Prototype	A first or preliminary version of clothing for exploration and testing purposes
Scanatar	An avatar of a person’s body that was scanned
Simulation	The production of a computer model of something, especially for the representation of reality
Vanity sizing	The labelling of clothing with sizes that are smaller than what the item's specifications and industry norms would suggest.
Virtual	Not physically existing as such but made by software to appear to do so

CHAPTER 1

Introduction and background for the study

1.1 Introduction

Having worked in the clothing industry for many years, the researcher has encountered many different challenges that required solutions to both in-house and other problems relating to the fit of clothing on different body shapes and consumers' preferences. It became vital to explore many of these broader defined issues causing these problems and challenges in the first place. One of the major challenges is the matter of authentic size charts for grading purposes related to South African bodies. The notion of size is inherently ambiguous and vanity sizing adds to confusing clothing labels.

Young South African women – but also many other segmented buyers and customers – who shop at the local retail apparel stores struggle to navigate the system regarding clothing sizes that are being provided. These sizes often vary not only between various in-house brands but also between the various retailers. With the spectacular rise of imported goods from the Far East, especially China, and other entities, the competitive intensity of various suppliers has created a major challenge for local suppliers. Local researchers postulate that the apparel is not manufactured according to South African women's body measurements or body shapes (Pandarum *et al.*, 2017). It is also surmised that the assessment of fit has been conducted according to experts' standards, rather than the consumers' fit preferences (ibid). Nonetheless, it is a well-known fact that female apparel buyers can react emotionally during and after a catastrophic shopping trip when it feels as if nothing fits and they feel that the problem is caused by their inadequate bodies (Kasambala *et al.,* 2015).

Anthropometry has been defined as the study of dimensions of the body and other physical characteristics and is conducted in a three-dimensional measuring process (Hedge, 2013). Surveys and small anthropometric studies have been conducted by local apparel retailers and manufacturers but are usually kept in-house as "trade secrets" and are not available as records in the public domain (Pandarum *et al.*, 2017; Ola-Afolayan *et al.*, 2021) for application by the apparel industry. Academic researchers have also conducted and analysed such studies, but with no successful integration into the industry yet (Mac Duff & Smith, 2014; Makhanya, 2015; Pandarum, 2015; Muthambi *et al.*, 2016). There is thus an explicit and

important need for a proper anthropometric study to collect empirical data on the South African population and for it to be disclosed in the form of size charts.

Size charts of indigenous women could ensure a more controlled and consistent South African clothing industry sizing system. This can be successful by using accurate body measurements to integrate with the pattern-making process (Ünal & Utkun, 2018). With the advancement of portable 3D body scanning technologies, data collection has become more feasible, more easily accessible, and less time-consuming (Ashdown, 2014; Gupta & Zakaria, 2014), and with the use of previous research studies to collect empirical data, the authors recommend that an anthropometric study be undertaken for the South African population with the use of technologies available (Mac Duff & Smith, 2014; Makhanya, 2015; Muthambi *et al.*, 2016). This will enable more accurate and in-depth details of the body's volume, posture, and shape. Such a study could add to building a database of our local bodies, combined with other entities that have conducted studies and collected anthropometric data.

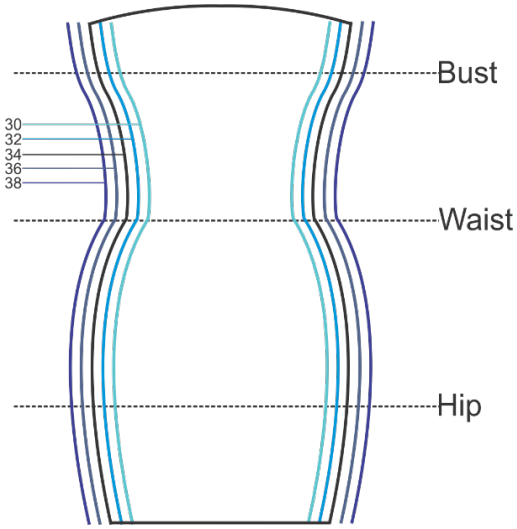
A possible solution to this problem could be to design size conversion charts which convert body measurements to various universal size labels, making it easier to match a designated size (Sheikh *et al.,* 2019). Consumers can find their sizes without taking off their clothes and due to the established database, it would fit their bodies (Robey, 2019). Guidelines for the development of a size chart for a specific group of young female students with very specific fit demands and clothing preferences can be utilized to develop denim jeans. Denim jeans have been selected as an instrument for this study as respondents have indicated that it is a staple garment for young female students and a fundamental component of the casual wardrobe (Hegarty, 2012).

1.2 Problem statement

Local retailers and manufacturers are often unaware of the trials and frustration that consumers experience when they cannot find flattering, well-fitting garments other than the standard sizes currently offered in the ready-to-wear apparel category. Female body shapes and proportions have changed over time due to changes in diet, lifestyle, and ethnicity (Makhanya, de Klerk *et al.*, 2014) but no current up-to-date body measurement size charts have been shared for application in the clothing industry (Pandarum *et al.*, 2017). The primary or ideal body type used for mass production in South Africa is the hourglass shape as represented in Figure 1.1 – which may explain why South African women are having fit issues. In local studies done by Ola-Afolayan and Mastamet-Mason (2013) and Makhanya *et al.* (2014), they identified five prevalent cohorts of body shapes in South Africa:

- the triangle or pear shape
- the inverted triangle
- the hourglass
- the rectangular or straight shape, and
- the apple shape

Both the size charts and fitting dummies used for educational purposes and product development applications represent this body shape. This hourglass or standard shape is then consequently graded with the same increments (sized up and down) to different sizes and the key body areas namely the bust, waist, and hip remain the same shape as seen in Figure 1.1.



Size	30	32	34	36	38
Bust	82	87	**92**	97	102
	-5	-5	**0**	5	5
Waist	62	67	**72**	77	82
	-5	-5	**0**	5	5
Hip	87	92	**97**	102	107
	-5	-5	**0**	5	5

Figure 1.1: The hourglass shape and the key areas are graded with the same increments
Source: Windvogel (2019)

As a result of this sizing system, women with different figure variations are excluded from ready-to-wear (RTW) apparel, many styles or designs and at times struggle to find their size in stores. Kasambala (2016) did a study on the evaluative criteria women use when

purchasing clothes and found an inherent relationship between clothing and the body. The results of the study established that fit/sizing and comfort are the most pertinent evaluative criteria that women consider when purchasing clothes, especially bottoms (pants or skirts).

1.3 Background to the research problem

The importance of clothing and its functions in our daily lives cannot be overstated. Most women want to dress in a manner that accentuates their body's appealing aspects for psycho-sociological intentions (Hidayati *et al*., 2018). These intentions include how one's own dress-related ideas, attitudes, perceptions, and feelings shape the behaviour of the self and the behaviour of others toward the self (Johnson, Lennon & Rudd, 2014). Along with positive responses elicited by a product's physical attributes, body image is also a key motivator in the decision of purchasing. Consumers are concerned about how a garment will look on their bodies and how others may perceive it (Rahman, 2015). The need for well-fitting clothing or apparel is among the most significant consumer needs (Strydom & De Klerk, 2010).

When shopping for clothing, in a retail store or online, consumers surmise that they know what their size is based on their purchasing history, fully aware that the sizing and fits differ sporadically across brands (Felsenthal, 2012; Gribbin, 2014). When their identified and usual sizes do not fit, consumers become frustrated and dissatisfied – and as a result, merchandise items are returned more frequently. Figure 1.2 shows a local South African blogger, Mira Hirsh, fitting two pairs of jeans in two assorted colours, under the same brand, and in the same size, but they fit completely differently. The disparity between the pairs of jeans left the consumer confused and averse to continuing with her shopping (London, 2017). She reported that many effects associated with diet culture and self-loathing took over when the maroon jeans did not fit. Consequentially, these negative emotions induced decisions to not purchase, and logically such losses in sales harm brand at large, suppliers and retailers (Chinomona & Dubihlela, 2014).

Figure 1.2: A local blogger, Mira Hirsch, in a South African retail store fitting two different denim jeans in the same size

Source: Sprunk, 2017.

For younger women, specifically students, denim jeans are a symbol of being ordinary, one of those garments that need to be comfortable and well-fitting as it is a staple fashion garment in most of their wardrobes (Hegarty, 2012; Hwang Shin *et al.*, 2013). People wear denim jeans for different reasons and in various ways. For some, it is comfortable, and durable, and for others, it answers the need to feel sexy, current, and yet timeless (Cartner-Morley, 2022).

Today, the variety of denim jeans fits available to women has become so wide that it is difficult to determine which jeans are most flattering for the individual's body. This is a concern to young consumers because denim jeans are items that should be easy to wear, without anxiety about how others perceive them or their bodies (Rahman, 2015). The famous Levi's brand has in fact created jeans for curvy women, but the focus demographic data used pertained to American women's sizes which do not relate to the uniquely South African body (Rudin, 2011). The fit of Levi's Eva jeans is a good benchmark in terms of fit for pear-shaped bodies, but for a university student, these jeans are usually not affordable.

1.4 Purpose statement

The purpose of this research, as motivated above, is to address the lack of a valid, reliable sizing system for young South African women wearing denim jeans, and to develop a body

measurement size chart for improved grading applications that could leave typical consumers happier.

Based on the above purpose statement, the steps for this research to achieve the envisioned outcomes are:

1. Assess young consumers' overall satisfaction with available RTW apparel fit;
2. Collect accurate and comprehensive body measurement data of the specified target group, using 3D Body Scanning technology;
3. Subsequently, create a body measurement size chart for garment pattern-making and grading applications (through the above statistical analysis);
4. Improve the overall fit based on the above outcomes, and by utilising a 3D virtual program to streamline the product development process;
5. Accordingly, develop an ideal pair of denim jeans for young South African females that fit well;
6. Evaluate the fit of the denim jeans over diverse sizes by using a traditional sizing system and compare them with the newly developed sizing system.

1.4.1 Significance of the study to the scientific field

This study will attempt to determine actual, authentic, and more accurate grading increments on key body parts by developing a South African sizing system and a model for predicting correct – meaning "successful" – jeans sizes. If productive, a retailer or manufacturer in possession of such size charts and the model formula could employ the system for effective and more successful consumer sizing, consequently ensuring well-fitting jeans and reducing the return rate of merchandise. It could also be implemented as a basis for improved and authentic fits of dummy ranges for use in product development for both physical and virtual use.

1.5 Research questions

According to Patino and Ferreira (2016), the core ingredient of knowledge development is the design of research questions. Well-structured questions have an impact on almost every component of the research process. It provides a goal towards which researchers can strive yet also defines the steps to be taken to achieve it (Hulley *et al*., 2013; Patino & Ferreira, 2016; White, 2017). To resolve any uncertainty in this study, Hulley *et al.*, (2013) recommend that the research questions be formulated using the mnemonic FINER criteria as detailed below:

Table 1.1: Expanded descriptions of the recommended criteria for developing a good research question

FINER Criteria for a good research question and study plan	
Feasible	Access to an adequate number of participants. The researcher has the technical expertise to conduct the study. The study is affordable in time and money: the costs are reasonable, and funding is available. The study can be completed in a reasonable time.
Interesting	The results of the study will be of interest to the relevant industry and research community.
Novel	The study provides new findings, and extends, or refutes previous findings. It may lead to new innovations in concepts and research methodologies.
Ethical	The risk to the participants is low or acceptable. The study is considered ethical by the Institutional Ethics Committee.
Relevant	To improve scientific knowledge and to impact future research.

Source: Hulley *et al.* (2013, p.17)

Considering these factors, this study seeks answers to the following questions.

1.5.1 Primary question

Why and how should a proper body measurement size chart be developed for young South African women, particularly using a 3D technology process for improved jeans wear?

1.5.2 Secondary questions

1. Why is there no South African body measurement sizing system and can this be developed?
2. How do young South African women feel about the current availability and fit of denim jeans across various brands and what aspects regarding fit and appearance do they experience as problematic?
3. How can 3D technology be utilised in this study of young South African female jean wearers to generate/develop an improved measurement size chart?

4. How could a more accurate body measurement chart enhance denim jeans' fit and appearance and consequently the user experience/satisfaction?

1.6 Brief literature background

The purpose of this section is to provide a brief description of the theoretical viewpoints and previous research discoveries that is related or connected to the research problem (Leedy & Ormrod, 2015:70), as discussed in the problem statement. The literature review will systematically and in a synthesized way evaluate previous research studies and provide an overview of contrasting areas (Snyder, 2019).

Most women do not possess the ideal body shape as depicted in the media, which causes a plethora of negative emotions when they cannot find well-fitting clothing. The problem could be related to many broader defined issues such as the current sizing systems, outdated size charts, clothing fit, and the fit preferences of young female consumers. This study will follow a methodological approach to review the available literature and will define and discuss these issues in more detail. The following topics will be unpacked:

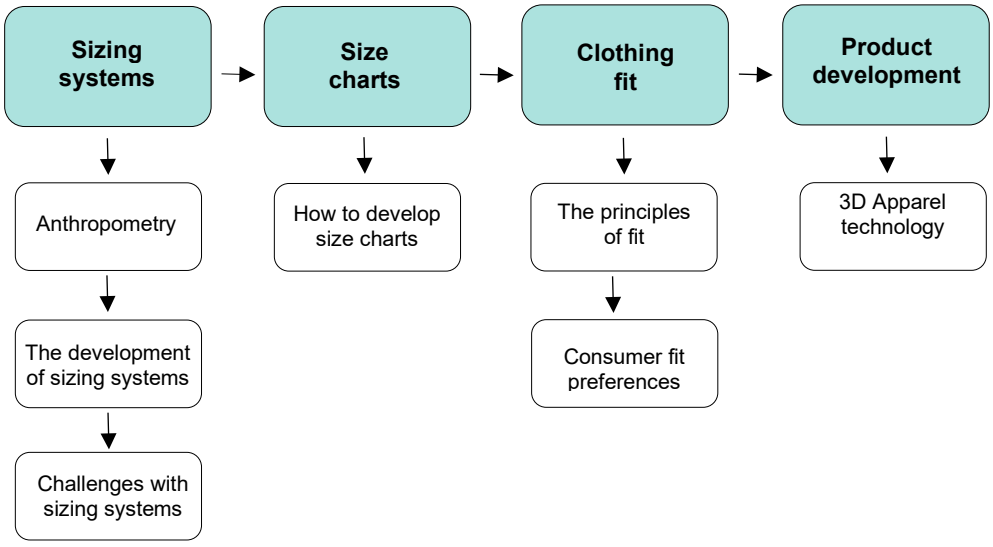


Figure 1.3: A flow diagram of the literature review for this study

Source: Windvogel (2022)

1.6.1 Sizing systems

Sizing systems were developed to provide customers with a range of possible sizes providing enough variation to accommodate all customers that would fit them but also limiting the number of sizes to create an efficient production or manufacturing system (Ashdown, 2014;

Chan, 2014). These systems are designed to define aspects such as the key body dimensions that should be used, how garment types are grouped, how figure/body types are defined, and how garment sizes are described or labelled for consumers to be able to read them (Pandarum & Yu, 2015)

Current sizing systems in use are still based on the ideal body shape which represents female consumers (Muthambi *et al.*, 2016; Pandarum *et al.*, 2017). The patterns are created from basic block patterns that have been created to fit this average body type. A sample garment produced from these patterns is then drawn on a flat surface in accordance with specifications and evaluated on a fit dummy that is also representative of the average size (Ernst, Boehm & Windvogel, 2016). Once the fit is approved, the patterns are graded in a range of sizes derived from a size chart and manufactured to fit a range of diverse customers (Pandarum & Yu, 2015).

In South Africa, there were repeated attempts at detailed surveys to obtain the size and shape of the South African population, but local manufacturers do not yet have or follow a standard proven sizing system (Pandarum *et al.*, 2017). It has proven a challenge to conduct anthropometric studies nationally due to cost constraints in addition to the fact that it has been restricted to specific demographic groups only. This study will trace the development of sizing studies over time and attempt to review the gaps for future research.

1.6.2 Size charts

A size chart is a body measurement table and can be defined as “the artificial dividing of a range of measurements which are concise and consistent” (Chan, 2014; Muthambi *et al.*, 2016, p.63). Pandarum and Yu (2015), defined it as a chart with a header that indicates the type of garment to be made, the size range consisting of all the sizes to be made and, the individual points of measurement such as the bust waist, etc. These measurements would be based on data collected in a scientific anthropometric study or survey and analysed statistically. It also acts as a means of communication between the manufacturer and the consumer as to what the designated garment size is that the consumer fits into (Ola-Afolayan & Mastamet-Mason, 2013).

Chan (2014) states that RTW apparel cannot fit each body perfectly. Therefore, the population must be categorised into groups and then into several sizes, each representing a different body size. Once the groups have been classified to their correct size, each group’s measurements can be averaged for all individuals in that particular size. The establishment of

a proper size chart also demands knowledge of the key body measurements that are needed for specific garments and where the specific landmarks are, that need to be recorded. It may consist of all or most of the measurements taken of a body over all the different sizes in an anthropometric study of a particular population (Xia & Istook, 2017).

The issues related to fit in South Africa can unfortunately not be addressed without proper authentic body measurements and the size charts that are currently in use within the clothing industry, are either outdated and it is surmised that it relates to European bodies (Muthambi *et al.*, 2016). This study will methodologically explain how to create a size chart using a statistical approach.

1.6.3 Clothing fit

Labat (1987 cited in Shin & Damhorst, 2018) defines clothing fit as the body-garment relationship, the visual analysis of clothing on the body, and the physical evaluation of comfort. The appearance of the garment relates to the look and style and the comfort aspects are decided by the wearer. In their research study, four themes emerged after concluding focus group interviews namely, physical fit, aesthetic fit, functional fit, and social context.

1. **Physical fit** relates to the tightness and length qualities of a garment.
2. **Aesthetic fit** is the visual self-evaluation of a garment's overall appearance to the body proportions.
3. **Functional fit** is the physical comfort of a garment while the body is moving, i.e., while walking, sitting, bending, etc.
4. **The social context** has to do with the social situation in which the garment is worn as well as the feedback received from others.

Song and Ashdown (2013) agree that physical comfort, psychological comfort, and appearance all play a key role in consumers' supposed satisfaction with clothing fit.

1.6.3.1 Fit testing

To measure the success of a newly developed sizing system, an anthropometric fit test must be done to assess the capacity of the sizing system to accommodate the specified size range of the target group. Such a fit test can be done both virtually using one of the many virtual sewing software programs on the market or by physically fit testing garments on a real person (Dabolina *et al.*, 2018). The intended function and fit requirements of the garments must also be evaluated. This study will mainly focus on testing the fit on real bodies to assess the levels

of comfort as this aspect cannot be vocalised by avatars. Chan (2014) clarifies the importance of psycho-physical fit testing and elaborates on the three stages involved namely:

1. The design and preparation stage – planning is essential to minimise time and cost.
2. The processing of the fit test on the representative participants – the participants must be from the anthropometric study done.
3. Reporting and analysing the results – to check the validity of the study and thus provide confidence for the ultimate use of the garments.

1.6.3.2 Fit preferences

The satisfaction of the fit of clothing is highly related to body cathexis because clothing is a tangible object, but clothing satisfaction is a mental encounter, and this means that the aesthetics do not indicate internal clothing or fit satisfaction (Gill, 2015). This is one of the primary reasons for conducting physical fitting tests and not virtual ones. Body cathexis refers to the satisfaction with one's overall body, this can either be positive or negative emotions and dictates our clothing fit preferences (Makhanya & Mabuza, 2020).

1.6.4 Product development

The product development process is defined as the activities related to the development of a new product from its inception to completion (Wijewardhana *et al.,* 2020). It is also defined as a structured process for new products which is centred around customers, as the key performance measure is customer satisfaction (Moretti & Braghini Junior, 2017). The process helps to dissect tasks and organize cross-departmental collaboration and involves the ideation/design stage, 2D patternmaking, prototyping, grading, marker making, manufacturing, and finishing stages. These processes will be elaborated on and discussed further in Chapter 2.

Due to globalisation, manufacturers and suppliers of the apparel industry are geographically dispersed and are challenged to create new opportunities to transform the traditional way of conducting their businesses (Fung *et al*., 2021). The traditional product development process consisted of many manual processes that were wasteful and the new product development processes use technology-driven methods to reduce waste and improve efficiency (Gill, 2015). Technology can be integrated into almost every step of the product development process to reduce the turnaround time. Wijewardhana *et al*. (2020), state that the apparel market demands innovation, shorter time-to-market, and higher quality products and that

novel virtual reality and augmented reality technology tools can be adopted by these businesses to improve their processes.

1.6.4.1 2D and 3D CAD prototyping technologies

Papahristou (2017), reports that the traditional product development process (PDP) has always been manual, time-consuming, costly, and dependent on the skills and experience of the people involved. When the new 3D visualisation technologies were introduced to the market, there were many challenges with the interface and functionality of the software, and it was expensive and the visuals could only be used for marketing purposes, not to test the fit of the garments. The PD process is still lacking as manufacturers are still developing five to six prototype iterations for each approved garment.

1.7 Theoretical framework for the study

In social psychology, clothing is seen as a symbol for people to build their identities and is used across most social situations due to its self-expressive or symbolic benefits. This is often the primary reason we purchase certain styles (Su & Tong, 2016; Arora & Aggarwal, 2018; Zwane & Dhurup, 2019). These symbolic benefits are non-product related and fulfil the underlying needs for social approval, personal expression, and outer-directed self-esteem (Iazzi *et al*., 2016). Iazzi *et al.* (2016), propose that these benefits can be classified into three categories namely functional benefits (intrinsic), experiential benefits (what it feels like), and symbolic benefits (the need for social approval or personal expression).

Arora and Aggarwal (2018) agree with this classification and highlight that the clothing we wear can also affect our behaviour and this in turn impacts our clothing preferences. The researchers state that clothing has long since crossed boundaries of being worn for only modesty, immodesty, protection and adornment and is now being worn for multiple other factors. These factors are physiological factors like body shape and size, psychological factors which are mood and self-esteem, and environmental factors which are factors like the weather, social situations, and cultural values. Clothing has become a buffer between people and the wider social and physical environment. The view of Rootman and Kruger (2017) is slightly different from their study of the South African retail environment claims that reference groups and culture have the biggest impact on our buying behaviour or clothing preferences. Arora and Aggarwal (2018) devised a theory of how the motivating factors affecting what we wear can be classified as Exogenous (external) and Endogenous (internal factors). They based their theoretical model on Kwon's (1991) Venn diagram model as seen below in Figure

1.4. This model can be used to make sense of the factors that influence clothing buying behaviour.

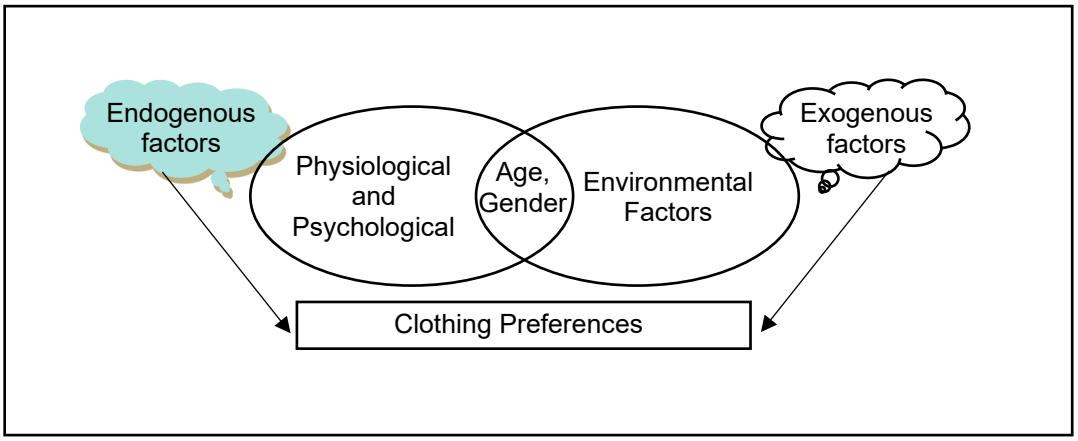


Figure 1.4: Factors influencing clothing preferences

Source: Arora & Aggarwal (2018, p.692)

This study is focused on the Endogenous factors affecting the choice of apparel. Brownbridge *et al*., (2018) explain how garment size and fit impact body image, self-esteem, and identity. These researchers did a study in which women were asked to choose between twenty-four dresses in various sizes to fit their bodies. All the dresses were made of woven non-stretch fabric, except one that had three (3) percent elastane which made it slightly stretchy. They could choose their own styles and the number of dresses they wanted to try on. Some of the women were disturbed when their designated size dress was too small, and they commented that it "did nothing for my self-esteem" (Brownbridge *et al.*, 2018). The women tended to go for the hourglass-shaped styles and avoided styles that made them feel larger. They sought dresses that would enhance their body shapes even though they were aware that their bodies were not that shape. Most of the women in this study chose the dress with elastane to purchase. Julien (2014) claimed that women harbour an idealised image of the body and that their bodies become lifelong renovation projects to try and conform to this ideal.

A negative connotation is often related to size and fits because of the social perception that a "smaller size is more socially acceptable" and that a slim body is the ideal female body *(Brownbridge et al.*, 2016). The thin body ideal of models is presented pervasively in the media and body image researchers emphasize that it can be harmful to many women (Betz & Ramsey, 2017). Customers have subjective and emotional experiences with RTW apparel, especially if they do not have the primary or ideal body and this can establish their personal level of satisfaction or dissatisfaction with their bodies (Iazzi *et al.*, 2016). The retail industry

has exploited woman's desires by creating a false beauty ideal that women aspire to, although it is unattainable for most females (Brownbridge *et al*., 2016). The industry is using unrealistic body forms, and this means that the product development process is compromised, leading to fit issues and dissatisfied customers.

1.7.1 Customer satisfaction

Customer satisfaction is defined as the consumer perception of a product before purchase and the expectation of the performance after purchase (Chinomona & Dubihlela, 2014; Iazzi *et al.*, 2016). Su and Tong (2016) build on this definition, stating that consumer satisfaction is a person's emotional judgment toward a product which is a result of comparing the product's expectation with the product's performance. Consumer satisfaction is thus a two-way construct of both emotional and informational responses towards a product. Informational responses arise when the consumer makes an objective evaluation of the initial expectation of a garment and emotional responses involve the consumer's feelings towards the garment when on the body (Zwane & Dhurup, 2019).

Consumers purchase products with pre-purchase expectations about how the product must perform. After the product is purchased and used, the perceived performance outcomes are compared with the initial expectations (Chen-Yu *et al.*, 2017). The expectancy disconfirmation paradigm suggests that consumers are satisfied when the product performs better than expected (positive disconfirmation). When consumers are satisfied with the product/brand, they are more likely to recommend the product to others, are less likely to switch to other alternative brands, and are likely to repeat purchases (Iazzi *et al*., 2016).

Most studies investigating customer satisfaction claim that the functionality of a garment is the key factor influencing consumers to re-purchase a similar or identical garment. The functionality of a garment is the intrinsic advantage that relates to a garment's fit, comfort, utility, and durability (Iazzi *et al*., 2016; Zwane & Dhurup, 2019). The theoretical stance of this study is thus focused on the emotional responses toward garments and the model of Arora and Aggarwal (2018), is vital since it serves as a determinant of customer satisfaction in clothing preferences.

For consumers, shopping for clothes is about making decisions about their appearance that are influenced by attitudes toward stores and clothing (Kasambala *et al*., 2014). This is known as the cognitive appraisal theory of emotions which is defined as a quick evaluation of a

situation concerning a person's well-being and the causes generating the emotions a person experiences. Kasambala *et al*. (2014) make use of an example of how an ill-fitting garment does not produce emotions but rather what is at stake for the consumer elicits a particular emotional response. Shin and Damhorst (2018) agree that because clothing is an extension between people and their environment, ill-fitting clothing causes an incongruent relationship between the garment and the body, resulting in dissatisfaction. Neves *et al.,* (2015) also add that with the direct integration of clothing with the skin and the topography of the body, the value that the clothing adds must be considered.

Customer satisfaction can occur during three different stages of the shopping experience namely the interest phase (the selection of the garment), the trial phase (in the fitting room during the fit and appearance of the body), and the purchase decision phase (whether to purchase or reject the garment based on fit, appearance, and styling) (Iazzi *et al.*, 2016; Brownbridge *et al.*, 2018). This proves that women clearly understand what they want from a garment when fitted to the body and thus, satisfaction happens after the decision to purchase.

1.8 Research design and methodology overview

The purpose of conducting research is more than just gathering information. It is also finding answers to unanswered questions and discovering and/or creating new knowledge. For this discovered or created knowledge to be recognized, the validity needs to be proven to others in the same discipline by using appropriate approaches (Kawulich, 2012). The population, sampling, data collection and data analysis methods will follow and discussed in detail in Chapter 3.

1.8.1 Paradigm and design

This study makes use of a quantitative-dominant mixed methods (where there is a bigger percentage of research time devoted to quantitative rather than qualitative methods) design that guides the practical process and includes collecting body measurement data from female students and consequently analysing them, both statistically and visually. This is an appropriate method in social sciences as the strategies, techniques and assumptions are used to study the psychological, social and economic processes through the exploration of numeric patterns (Coghlan & Bryden-Miller, 2014).

The theoretical component is driven by a qualitative approach to gain an understanding of how the fit and appearance of denim jeans can improve the user experience. Thus, it will also

be established using the qualitative interviews with open-ended questions, which emotional descriptors this group of respondents ascribe to their experiences around improving the fit of denim jeans.

1.8.2 Methodologies used for the study

Primary research data are collected using a survey questionnaire, conducting 3D body scans, analysing the empirical body dimension data, and developing size charts accordingly. The developed size charts are consequently then used to create a block pattern, grade the pattern into various sizes, and consequently develop prototypes. Secondary data are used to develop a second set of patterns and prototypes that were used in a comparative study with the primary research outcomes.

1.9 Basic assumptions

This study's fundamental premise is that if a representative sample of young South African women who wear jeans can be scanned and used to develop proper body measurement charts, local retailers and manufacturers can provide better-fitting ready-to-wear apparel, particularly the staple of denim jeans, to their consumers. The problem of various sizes between brands can be explored and a better sizing system can be identified, researched, and utilised. But primarily, this study’s research questions and objectives were answered and achieved.

It can also be assumed that if a database of authentic South African bodies can be established, and the statistical model is successful in predicting jeans sizes, retailers and manufacturers can employ this system to provide a better shopping environment for their consumers both in stores and online.

If this objective can be fulfilled, the same research process and steps can be used to determine better sizing systems for all segments of the South African population.

1.10 Delimitations/scope

This research focused on:

- Young women between the ages of 18 and 35 years of age willing to participate

- Only South African citizens were considered because of SA culture and typical body types.
- Existing software that is already in use either locally or was utilised internationally; no new software was developed as part of the study or process.
- Only female denim jeans were developed and tested as a product.

1.10.1 Ethics

This study required young women to have their bodies scanned in a free-standing, portable body scanner. Their participation was voluntary, and the process, relevant risks, and benefits were clearly explained to the students before the process commenced. There are several reasons why a researcher needs to adhere to ethical norms when conducting research, especially throughout the process of data collection and presentation (Resnik, 2020; Bouchrika, 2021). Some of the ethical considerations that the researcher must be mindful of are that:

1. **It promotes the research aims/objectives:** The participants should be informed about what the research aims to achieve, the procedure involved, and the duration of the process. Body measurements will need to be collected through a 3D body scanning process and the researcher conducting the scans must have proper knowledge of how the technology works to avoid falsifying data and minimise errors. This prohibits fabricating or misrepresentation of data and its validity.
2. **Accountability:** The researcher must take accountability if any of the participants' body data and personal information is made known to the public or other entities. Limits of confidentiality, such as data analysis, disposal, sharing, and archiving, and when confidentiality must be broken must be discussed, and whom the participants may contact for any queries.
3. **Moral and social norms:** The basic human rights of the students involved in the study must be respected and the researcher must comply with the basic health and safety regulations during the body scanning and fitting processes. The prospective benefits of the study and future research must be disclosed.

The scanning was conducted in their underwear or gym clothes by the researcher or an assistant operating the computer connecting to the body scanner. The following should be discussed beforehand:

Table 1.2: Descriptions of ethical issues relevant to this study

Ethical issue	Description
Voluntary participation	Participants can join or recuse themselves from the survey at any time.
Informed consent	Participants know the purpose, benefits, risks, and funding behind the study before they agree or decline to join.
Anonymity	Data which is identifiable or personal is not collected.
Confidentiality	Only the researcher knows who the participants are, with their identities withheld from everyone else. Identifiable and personal data is concealed and protected to prevent anyone to make connections between the data and the respondents.
Potential for harm	All kinds of harm, whether it be social, physical, or psychological, are minimised.
Results communication	All plagiarism is eliminated as is research misconduct, and results are presented accurately.

Source: Windvogel (2022), adapted from Bhandari, (n.d.)

The most important requirement of empirical and scientific research is that it implies validity and credibility. Having been employed in the clothing industry for many years, the researcher ensured that researcher bias was minimised by remaining aware of potential involvement during the entire process. To eliminate possible bias, multiple people were involved in the process to evaluate data. In light of the above, the researcher applied for ethical clearance from the CPUT Institutional Ethics Committee to conduct the study. This was granted and the documentation can be seen in Appendices A and B.

1.11 Concluding summary

Chapter 1 gives an overview of the concerns that young women face when having to shop for denim jeans in local retail stores, and the issues relating to their body shape and dimension data. This study hopes to contribute to the existing research on sizing systems and size charts for young South African women and attempt to predict the size of the correct jean before having to fit.

This study will attempt to answer the research questions within the following chapters by firstly reviewing the available literature in Chapter 2, selecting the appropriate methodologies in Chapter 3, reporting on the data collection in Chapter 4, and thereafter discussing the results in chapter 5, and conclude the study in Chapter 6.

CHAPTER 2

Literature Review

2.1 Introduction

Women and clothes are an important consideration in the academic disciplines of customer satisfaction. For all humans, it is an intangible variable that varies among individuals, depending on the involved features or characteristics of a product that can satisfy the need or want of the individual consumer (Chinomona & Dubihlela, 2014). This satisfaction relates very closely to body cathexis.

Clothes fulfil two basic functions: dressing the body and providing protection, which is accompanied by the social conditions of subjectivity and the construction of identity. Considering its contact with the body's structure, clothing is like a second skin and is essential in improving the interface between the garment and the body to prevent discomfort (Neves *et al.*, 2015).

Clothes and the fit thereof can generate judgments about value. The latter is based on user experiences of confidence, comfort, and satisfaction of individual needs (Laitala *et al.*, 2011; Neves *et al.*, 2015). This is especially important with denim jeans because they fit so close to the body. As denim is rigid in construction; thus the body shape is of more importance than measurements in determining if a pair of jeans fits well (Gribbin, 2014). To develop a garment with aesthetic and ergonomic quality that fits the body appropriately, specific characteristics of the niche group must be used. In addition, the users' preferences and responses must be observed, as the subsequent confusion about sizing. The irrationality in the clothing shopping process causes customers to feel frustrated and dissatisfied, and leads to higher return rates and lost customers on the business side (Gribbin, 2014; Neves *et al.*, 2015).

In light of the previous, this chapter will describe some theoretical perspectives and academic views. Furthermore, relevant research discoveries related to the research problem offered in the previous chapter are discussed. This literature review commences with relevant literature on the topics of sizing systems, anthropometrics, size charts, apparel fit, and new product development techniques that are being used in conjunction with new technologies. A paradigm

explaining the application of ergonomics and anthropometry to clothing design will also be discussed to fulfil the users' requirements concerning comfort and appearance.

2.2 Sizing systems and theoretical developments

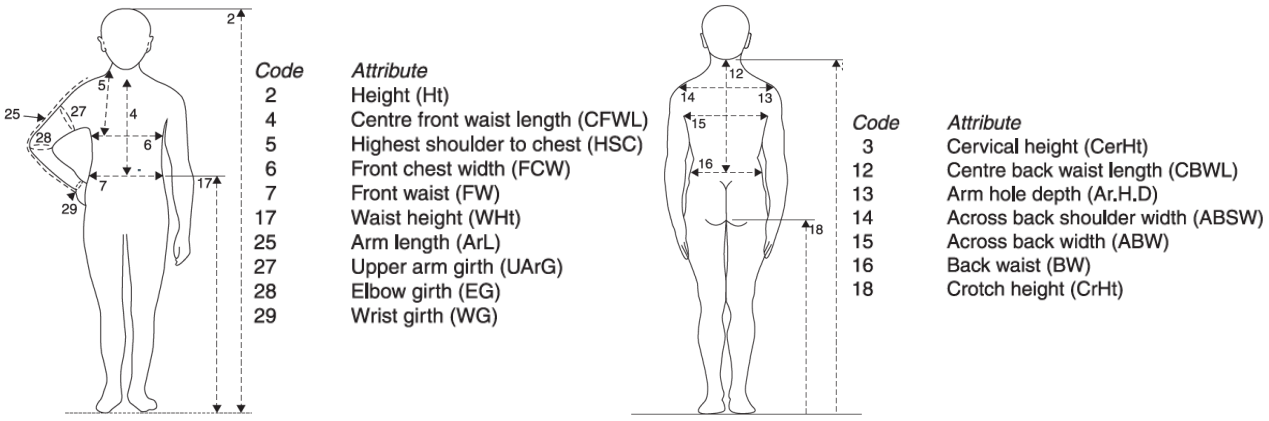
Sizing implies that the population is divided into subgroups, based on common physical characteristics such as age and gender that are often proportionally distributed to facilitate the production of RTW garments (Chan, 2014; Zakaria, 2014; Gill, 2015). Thus, the sizing system most used for RTW clothing uses a base size, often fitted to a standard fit model, and a set of sizes graded linearly from this size. According to Ola-Afolayan, Zwane and Mastamet-Mason (2021), the current sizing systems do not cater to diverse consumer groups with different ethnic backgrounds and demographic factors. It is critical to understand the body shapes and sizes of the target demographic as it is significant when garments are mass-produced (Gupta, 2014), but this can only be realized with a scientific anthropometric survey.

2.2.1 Anthropometry

An anthropometric survey or study is essential to understand 3-dimensional bodies and proportions and is aimed at providing the correct body dimensions for a quality fit (Zakaria, 2014). Anthropometric surveys record different body measurements for each person in the survey and can yield thousands of data points for various applications. The gathered information can be analysed and utilised to extract relevant information such as the body shape data, the key body dimensions, clusters within similar size categories, and the precise size designation (Gupta & Zakaria, 2014). Hedge (2013), and Gupta (2014), in their overview of anthropometry, clarify the two types of anthropometric measurements that can be collected namely:

In 2014, Zakaria and Gupta reviewed past apparel sizing systems in detail and listed all the systems that have been developed from 1941 to 2012. They discuss the various statistical methods that were used by various researchers and what their outcomes were. Many countries (like Germany, China, America, Sweden, and France) have been conducting extensive anthropometric studies to get authentic measurements of their respective population groups, but none have managed to integrate this worldwide (Pandarum & Yu, 2015). After many attempts to conduct surveys, the challenges to conducting a proper and scientific anthropometric study were realised, with the associated insight that ensuing research should be limited to a specific demographic group, such as military personnel, scholars, nurses etc. (Zakaria & Gupta, 2014).

2.2.1.1 **Static or structural anthropometry**. This is the traditional method of collecting body data by using the skeletal points of the body beneath the skin as landmarks or anchor points for measuring tools to ensure consistency and accuracy (Bragança *et al.*, 2016). These are linear measurements between two points, circumference measurements as seen in Figure 2.2, and body form methods which entail the body's surface, shape, and volume. The body is without clothes and measurements are taken in a standard standing, still and fixed position as seen in Figure 2.1.

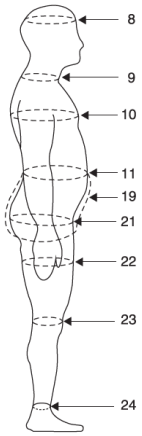


Code	Attribute
2	Height (Ht)
4	Centre front waist length (CFWL)
5	Highest shoulder to chest (HSC)
6	Front chest width (FCW)
7	Front waist (FW)
17	Waist height (WHt)
25	Arm length (ArL)
27	Upper arm girth (UArG)
28	Elbow girth (EG)
29	Wrist girth (WG)

Code	Attribute
3	Cervical height (CerHt)
12	Centre back waist length (CBWL)
13	Arm hole depth (Ar.H.D)
14	Across back shoulder width (ABSW)
15	Across back width (ABW)
16	Back waist (BW)
18	Crotch height (CrHt)

Figure 2.1: Standard body measurements recorded on the front and back of the body

Source: Gupta (2014, p.40)



Code	Attribute
8	Head circumference (HC)
9	Mid-neck girth (MNG)
10	Chest girth (CG)
11	Waist girth (WG)
19	Crotch length (CrL)
21	Hip girth (HG)
22	Thigh girth (TG)
23	Knee girth (KG)
24	Ankle girth (AG)

Figure 2.2: The body girths or circumference measurements

Source: Gupta (2014, p.40)

2.2.1.2 Dynamic or functional anthropometry. These measurements are taken while the body is in motion or performing specific tasks. For this study, the bending of the leg while walking,

squatting, or sitting will be considered. Figure 2.3 is a representation of dynamic anthropometry when the body is measured in different moving positions.

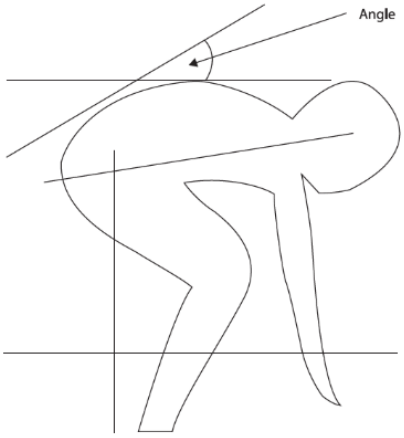


Figure 2.3: Dynamic anthropometry – recording measurements while the body is in specific postures
Source: Gupta (2014, p.46)

Collecting anthropometric data may pose several challenges: the instruments utilised, and the techniques used by the operator; the instruments, including measuring tapes, callipers, sliding compasses; and more recently, 3-dimensional body scanners. All of these require calibration to control the accuracy of the measurements being collected (Bragança *et al.*, 2016). In addition to this, Gupta (2014) explains that the human body is highly unpredictable in either static or dynamic positions and that the time of day when measurements are collected is equally important.

2.2.2 The history of sizing systems

Before sizing systems or graded patterns were developed, tailors/sewers in the late 19th century used to make bespoke clothing for individuals to their body dimensions. Alternatively, tailors simply shaped or draped the cloth roughly on the body and thus the garments would fit perfectly according to the client's needs or desires (Hernandez, 2018). The challenges with sizing began with the demand for mass-produced clothing, which was needed for categorized groups, like military uniforms in pre-designated sizes (Zakaria & Gupta, 2014).

These were known as RTW garments and were only available in average sizes based on the proportional scaling method (Gill, 2015; Xia & Istook, 2017). This method scales patterns proportionally from smaller to larger sizes, using the same increments in key locations as explained in Chapter 1. The chest circumference was used as a variable for sizing in male RTW clothing, but women still needed to appoint personal tailors for their fitness requirements.

This is how the necessity for standard sizing systems arose, especially for women, and anthropometric surveys were launched.

2.2.2.1 Sizing systems in the South African context

In South Africa, local manufacturers do not yet have or follow a standard or empirically proven sizing system as the studies conducted have mostly been by researchers within their academic capacity and have been limited to specific demographic groups (Smith & Mac Duff, 2014; Makhanya, 2015; Pandarum, 2015; Muthambi *et al.*, 2016; Pandarum *et al.*, 2017; Phasha *et al.*, 2020; Ola-Afolayan et al., 2021). This section will provide an overview of a few of these studies with their objectives and some of the methodologies used to conduct the research.

In 2004 an initiative called “African Body Dimensions” ABD was started by Lorraine Mac Duff and Jan Ryno Smith after a *Clothing Size and Fit Symposium* held in 2000 at the University of Pretoria. The project's objective was to establish, maintain and manage a national anthropometric database of all ethnic groups, ages, and genders in South Africa. (Smith & Mac Duff, 2014). In 2014 the ABD initiative was still applying for funding from local stakeholders as the requirements from the clothing and textile industry have become more urgent due to the demographics of the consumer that have changed rapidly within South Africa. Due to the change in politics, culture, and economics in the country, the change in demographics of the local consumers post-1994, has made a huge impact on the retail sector (Ola-Afolayan, Zwane & Mastamet-Mason, 2021).

In 2013, Ola-Afolayan and Mastamet-Mason did a pilot study with 50 visually identified pear-shaped women from Pretoria to develop a size chart for the specific body shape. According to their results, a significant portion of the South African population can be classified as being plus-size and pear-shaped. The results showed that there is a noteworthy difference between the traditional size chart used for manufacturing and the newly developed one. However, they also note that the sample was very small and could be different if there are more participants or when using technology such as 3D body scanning.

A similar study was conducted in 2015 by Muthambi *et al.*, where the researchers aimed to develop a size specification for South African women of African descent with triangular or pear-shaped bodies. They used a subset of anthropometric data from a study done by Makhanya *et al*. in 2014. The database consisted of 233 female students, and they identified

that 58,7% of their bodies were pear-shaped. Their study proved that the grade between the key body measurements, especially the waist and the buttocks area, do not grade linearly and that is why primarily the reason why the RTW clothing in stores does not fit the local women's bodies. In 2016, Muthambi *et al.* conducted a follow-up study to validate their proposed size specification and the results were an improved overall quality of fit for women. However, the sample used was non-representative with only one participant per size (Muthambi *et al.,* 2016).

In 2017, Pandarum *et al.* examined the body shapes and apparel fit incongruities experienced by a convenience sample of 155 South African women. The research objective was to establish the extent to which SA women were aware of their body shape and size and how they translated this into RTW apparel size labels, and the resulting apparel fit difficulties they experienced. Body shape analysis was conducted by three experts (two of the authors and one post-graduate fashion student), and the results were that (n=86) women had pear-shaped bodies (Pandarum *et al.*, 2017).

Phasha *et al.* (2020), agree that the prevalent body shape in South Africa is the pear-shaped body. Their study aimed to develop upper and lower body measurement size charts for a sample of 200 petite SA women in the Gauteng region. They highlight that there is no current data for petit women in South Africa as the last studies date back to 1988. The study uncovered that the prevalent body shape among their participants was also the pear-shaped body and the methodology used has shown that size charts created from 3D body scanned data resulted in an improved fit for apparel.

A more recent study conducted by Ola-Afolayan *et al.* (2021), specifically focused on developing a size chart for South African full-figured pear-shaped women, by using a statistical model of key body measurements. They employed a correlation research method from 150 purposively selected women from churches, malls, and offices whose body measurements met the requirements. Anthropometric data were collected using a non-stretchable metallic measuring tape and the size chart was developed using principal component analysis, descriptive statistics and multivariate analysis. Furthermore, the bust is used as an independent variable to predict the waist and hip measurements (dependent variables), using ridge regression. The results of the study indicate that the bust measurement is significant in predicting the waist and hip dimensions and that the bust measurement can be utilised to predict certain apparel sizes such as skirts and dresses (Ola-Afolayan *et al.*, 2021).

In most of these reviewed studies, it is revealed that the prevalent body shape of South African women is the pear-shaped body. However, the data from these local studies can not be generalised to all women in South Africa as a national sizing study will be more representative. Most of these researchers also recommend that the analysis of a larger sample will provide more accurate results to optimise the sizing systems.

2.2.3 The development of sizing systems

As mentioned before, in 2014, Gupta and Zakaria reviewed previous apparel sizing systems in detail and listed them all. They discuss the plethora of statistical methods used by various researchers and their outcomes, as well as nonlinear methods. According to them, sophisticated computer programs have certainly proven to be more efficient in population analysis and classification, concerning accuracy and time consumption. Chan (2014) agrees that any reliable sizing system starts with scientific anthropometric body data that is accurate for processing into meaningful information. Many researchers (Gupta & Zakaria, 2014; Chan, 2014; Pandarum & Yu, 2015; Xia & Istook, 2017) have continued to develop comprehensive methodologies for creating sizing systems and size charts as seen in Figure 2.4 below. There are three visible stages each with associated steps in this process:

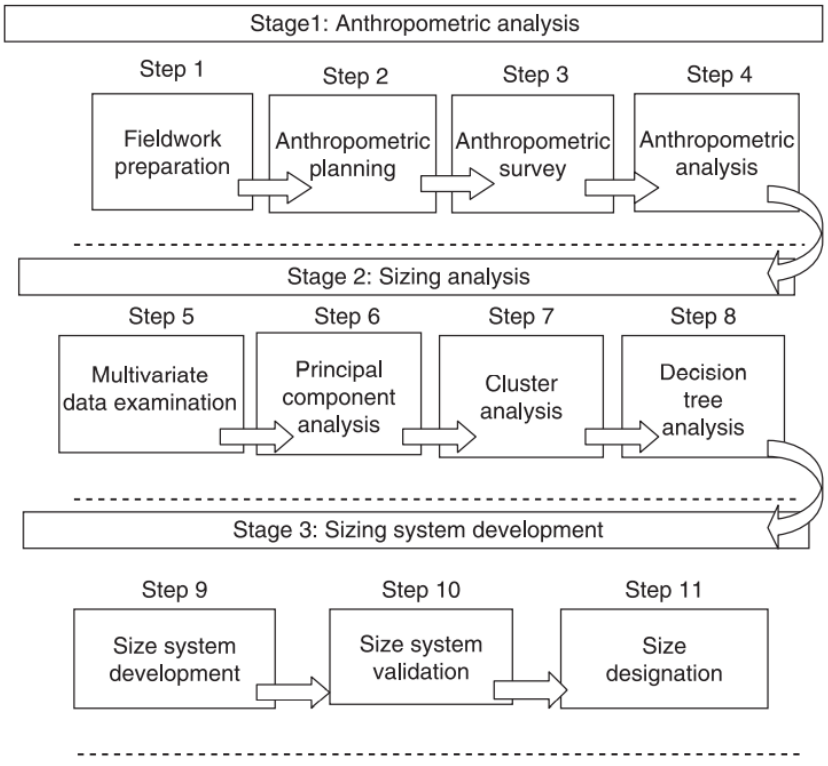


Figure 2.4: A methodology for sizing system development

Source: Gupta & Zakaria (2014, p.16)

Some of these methods will be reviewed and employed within this study for the development of an Afrocentric size chart for local women.

2.2.4 Challenges with sizing systems

Providing a good fit for an excessive amount of people using only a few sizes, bearing in mind the deviations in body shape from the Western ideal shape and size within the population, is limited to only a few target groups (Ashdown, 2014). Furthermore, the number of sizes provided by companies is minimal as it does not provide for the plus-size market or in-between (odd numbers) sizes (Xia & Istook, 2017).

Thus, sizing systems must be continuously updated or improved to include more recent anthropometric data for companies to remain competitive and satisfy their target customers (Pandarum & Yu, 2015; Bruniaux, Hamad & Thomassey, 2017). However, the cost of conducting anthropometric sizing studies and analysing/translating the data into useful information (Ashdown, 2014; Gupta & Zakaria, 2014), is a considerable expense to companies; unfortunately, smaller businesses are unable to acquire this very valuable information.

2.3 Size charts

The definition of a size chart is discussed in Chapter 1.5.2 and is further explained as a list of average measurements of body sizes for a range of garment sizes by Knight (2012 cited in Pandarum & Yu, 2015). Anthropometric surveys record different body measurements for each participant and yield thousands of data points. Therefore, the information is analysed to distinguish the critical measurements which can be utilized to divide the sample populace into clusters having comparable body measurements (Gupta & Zakaria, 2014). Currently, two types of size charts are being used in the industry namely:

1. **The standard body measurement size chart.** This derives from actual body measurements from data collected in anthropometric studies, and this, in turn, serves to create (Chan, 2014),

2. **The RTW size chart.** This system derives from an SBM chart with added ease or tolerance and, uses prototypes to test for fit (Xia & Istook, 2017). Ease is the difference between the body measurements and the measurement of the garment. This is discussed more comprehensively in Section 2.4.1.5. In some instances,

manufacturers purchase garments from various retailers and record the measurements to acquire the key measurements needed to create a size chart. The challenge with this is that defects during the manufacturing of garments are not considered and may lead to incorrect garment measurements.

However, this needs to be communicated clearly during the product development process to avoid the incorrect chart being used for a specific garment.

2.3.1 How size charts are developed

Many researchers have suggested the following stages to set up successful size charts (Muthambi, 2014; Zakaria, 2014; Xia & Istook, 2017):

1. Collecting raw anthropometric data that are reliable and valid
2. The key or primary body dimensions should be selected
3. Selecting the secondary dimensions needed for specific garment types
4. The body types must be established, and
5. Calculating the size ranges and grade increments needed between sizes.

2.3.1.1 Collecting raw anthropometric data

Traditionally manufacturers, retailers, and home sewers measured their clients or subjects with a tape measure or calliper but taking manual body measurements has a lot of disadvantages such as tape measure handling, information being lost, and the invasion of the privacy of the subject (Braganca, Arezes & Ashdown, 2014; Ernst *et al.*, 2016). The apprehension of people being measured using a tape measure and calliper, which is very invasive, has led to the development of non-contact body measurement technologies. One of the advantages of the new technology comes from the ability to analyse the body in new ways that were difficult to achieve with traditional manual tools (Gill, 2015).

3D Body scanning is a technology that produces a 3D model by scanning the surface of the body. The machine captures a body image and produces 3-dimensional images with full body measurements and human body surfaces within seconds, by using light sensors (Gill, 2015; Daanen & Psikuta, 2018). This data is archived for further processing and inspection of measurements. Once a person's body measurements are captured with the use of a body scanner, it can be retrieved and any part of the body could be measured any number of times without actual contact with the measured person (Gill, 2015; Ernst *et al.*, 2016) as can be seen

in Figure 2.5. The emergence of 3-dimensional body scanning has instigated a new way of apparel retailing in finding possible solutions to their fit issues and reducing the return rate (Daanen & Psikuta, 2018). The data from the body scanners can also be transferred for other applications such as additive manufacturing, by exporting files in applicable formats.

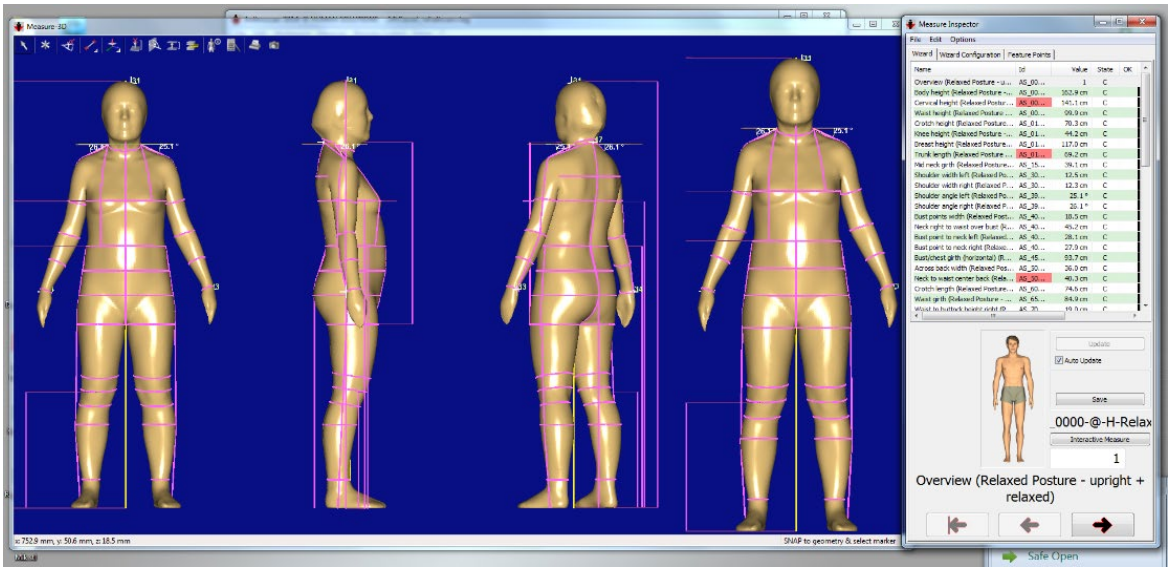
The primary purpose of the body scanner is to allow the efficient collection of much larger, replicable body data sets which are more consistent than the manual collection methods (Reid *et al.,* 2020). It provides detailed information on the 3D human form and can be successfully integrated to speed up the product development processes (Gill, 2015; Ernst *et.al.*, 2016; Daanen & Psikuta, 2018).

The 3D body scanner is mainly used for:

- Anthropometric studies for mass customisation of apparel
- Empirical body data collection studies
- Creating avatars of actual human bodies

a) Collected data can be used for the following applications:

- Creating models by scanning the body surface area and extracting body measurements. Measurement allocations may be customised to only extract certain specified measurements. This is especially useful when doing studies to print key body measurements for participants as a reference guide. The body can also be sliced horizontally to obtain cross sections for circumference dimensions and to view the weight distribution of the body as seen in Figure 2.5 below (Gill, 2015).



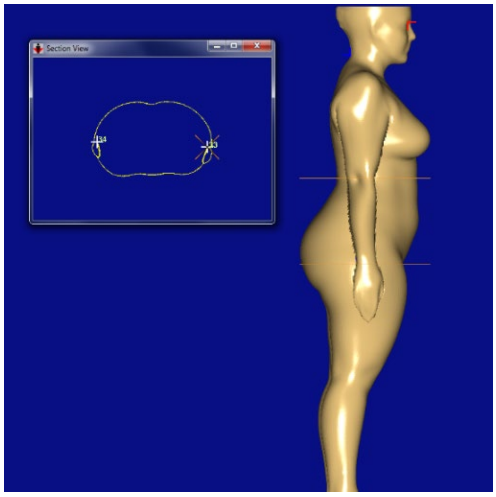


Figure 2.5: Actual 3D body scans were taken with the Human Solutions body scanner

Source: Windvogel (2019).

- Create avatars based on extracted body measurements in various 3D visualisation programs to represent various sizes and body types as seen below in Figure 2.6.

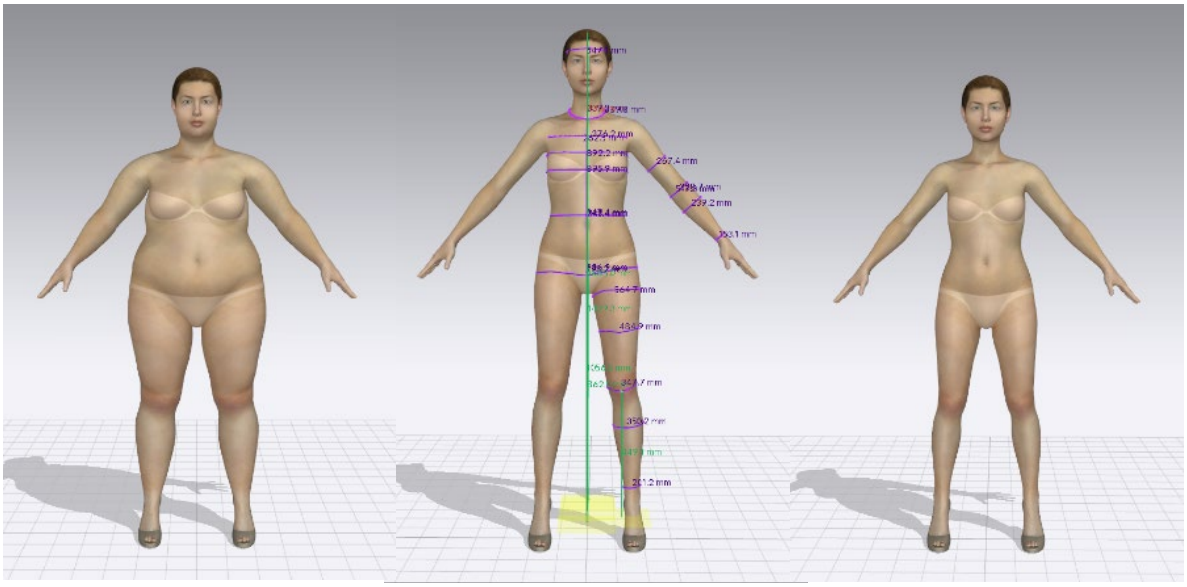


Figure 2.6: Statistical avatars created in CLO3D

Source: Windvogel (2019).

- Create scanatars extracted from an actual human body. Body data is extracted from the body scanner program and exported in the relevant file format. This file information is then imported into a 3D virtual stitching program and can now be used for virtual garment fitting as seen below in Figure 2.7.

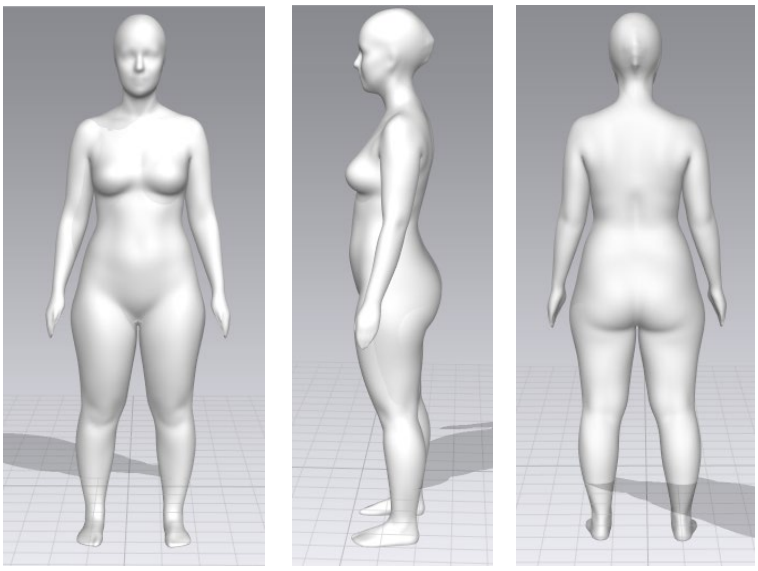


Figure 2.7: A scanatar imported into CLO 3D

Source: Windvogel (2019).

- Visual and statistical data inspection can classify different body shapes (morphotypes). This is important for specific target markets.

- The body dimension data could also be used to develop authentic mannequins for use in the apparel industry.

b) Challenges with 3D body scanners

Some of the disadvantages of 3D body scanners are issues such as the following:

- The operator must be knowledgeable about and use the proper techniques and procedures (Braganca *et al.*, 2016)
- The posture position of the scanned subject. The body being scanned must stand in a static position for the machine to capture the body without error (Apeagyei, 2010).
- The position/point of measurement may vary between bodies. The point/position of measure when measuring the human body is very important to maintain the consistency of key body measurements on size charts (Daanen & Psikuta, 2018).
- The measurements may not always be accurate. For example, the accuracy may be compromised when participants wear very dark or reflective underwear or clothing. In addition, the body scanner cannot scan the area correctly when the body parts are shaded or on closed surface areas (armpits, inner leg area, etc.).

This can be prevented by spreading the arms and legs wider while being scanned (Reid *et al.*, 2020).

It has, however, shown great potential as an effective tool for measuring the human body for anthropometric applications. For example, it has been reported that in 2010 Levi's jeans company scanned approximately 60 000 women worldwide to improve the fits of their denim jeans (Rudin, 2011; Gribbin, 2014).

2.3.1.2 Determining the key of primary body dimensions

Key or control dimensions on a size chart indicate the designation of the body and will be used by manufacturers and consumers to identify a selected size (Gill, 2015). Control measurements ought to be picked so they can portray the body shape of the person for whom an article of clothing is being made (Zakaria, 2014). The quantity of sizes is associated with the number of control measurements and the size of each control measurement (Xia & Istook, 2017). Since there is a variety of body shapes in the population, the control dimensions will increase tremendously and should be decreased. One way to do this is to classify which part of the body the garment will cover. This could be either the lower body or the upper body, and the size chart will be prepared considering this. For this study, the lower body will be covered so the control measurements will be the waist and hip/buttock girth dimensions.

According to Zakaria (2014), due to the nature of the measurements, one height and one girth measurement should be chosen to represent the group. Previous anthropometric studies show that the girth dimensions generally correlate well with each other and the length dimensions with each other. It is also assumed that as the body grows in width, so too does it grow in length or height, and this is one of the reasons that only 30 to 40% of the population fits into most sizing systems (Cools, Da Raeve & Bossaer, 2014). The four key body part measurements to use for whole-body garments are generally the bust, waist, hip, and height even though there is a poor correlation among the length and girth parameters, they have a good correlation with most of the other dimensions as seen in table 2.1 (Zakaria, 2014). The correlation between the variables will be discussed in further detail in Chapter 3.

Table 2.1: The correlation status between various body parts

Body Part	Correlation status
1. Bust	Has a mild to strong correlation with seven other body dimensions
2. Waist	Has a mild to strong correlation with six other body dimensions
3. Hip	Has a mild to strong correlation with seven other body dimensions
4. Height	Has mild to strong correlation with three major length body dimensions

Source: Gupta & Gangadhar, (2004, p.463); Zakaria, (2014).

Based on this table the critical measurements for the upper body are the bust and the waist and for the lower body the waist, hip, and height measurements. According to Strydom and De Klerk (2010:76), these key measurements must be current, accurate, well-defined, and are also important for the following reasons:

a) To draft block patterns for specific garment sizes,
b) The body measurements with the correct amount of ease added are essential in creating correct garment measurements, and
c) These measurements are also very important for fit tests to ensure that it meets the requirements of the manufacturer.

The bust, waist, and hips are typically regarded as important proportions, and it is crucial that these measurements are accurate for the body sizes they reflect (Apeagyei, 2010).

2.3.1.3 Selecting the secondary dimensions

Secondary dimensions on a specification are all other measurements needed to be able to construct a pattern for a specific garment. They serve to define the body shape in more detail than the key measurements and needs to be selected in a way that the secondary measurements correlate well with at least one primary measurement. While the control dimensions are of use to the customer because of labelling, these measurements are only of use to the manufacturer for the construction of garments (Zakaria, 2014). Phasha *et al*. (2020), recommend the analysis of larger samples will improve the correlations between the primary and secondary body dimensions.

2.3.1.4 Body shape classification techniques

The clothing industry has consistently utilised individuals with ideal figure types for fitting garments so manufacturers can get measurements for pattern making and to maintain fit standards (Muthambi *et al.*, 2016, Pandarum *et al.*, 2017). Literature suggests that the industry uses these unrealistic body templates, which comprise the product development processes, potentially leading to fit issues (De Raeve *et al.*, 2011; Webster *et al.*, 2012; Kim et al., 2016). The assumption is that women's bodies are naturally hourglass or slightly triangular and these body shapes have a proportionately smaller waist when compared to the hip and bust measurements.

Assessing and classifying a woman's body shape is inherently subjective and problematic because the body is not always mathematically proportional (Pandarum, *et al*., 2020). Most women fit into one group of figure types that are identified by the shape of their body and the ratio between the shoulder width to the bust, waist, and hips (Gill, 2015). The study of human body types is called 'somatotyping'.

a) Somatotyping

Somatotyping is an approach to measuring body shape and composition by analysing anthropometric data (Chiu *et al.*, 2021). It was developed by William Sheldon in the 1940s to classify human physical types according to their appearance and can be classified into three categories namely endomorph, mesomorph, and ectomorph (Sokhetye, 2017; Chiu *et al.*, 2021).

1. **Endomorphs**: They have more fat on the body and are usually shorter in height.
2. **Mesomorphs**: They are of medium build and have athletic, solid, and strong bodies.
3. **Ectomorphs**: They are long and lean, with little body fat, and little muscle. Fashion models fit this category.

Sheldon proposed that people inherit a body type based on their skeletal frame and weight distribution from birth. He evaluated the degree to which a body type was present on a 1 to 7 scale where 1 is the minimum and 7 is the maximum. An individual is scored by each body type to give three (3) numbers represented as "endomorph rating – mesomorph rating – ectomorph rating". A rating of 7-1-1 is a pure endomorph, 1-7-1 a pure mesomorph, and 1-1-7 is a pure ectomorph (Carter, 2002). Most people have combinations of the three body types.

b. Female figure identification technique

A computer software program called the “Female figure identification technique (FFIT) for apparel”, was developed in 2004: p1 by three researchers namely Karla Simmons, Cynthia Istook, and Priya Devarajan from North Carolina State University as a starting point to analyse anthropometric data statistically and characterise female body shapes. They used mathematical descriptors to identify a set of body shapes. These researchers and many others have classified and identified five prevalent body shapes through their research (Makhanya *et al.*, 2014; Hidayati *et al.*, 2018). These body shapes are described below as seen in Figure 2.8:

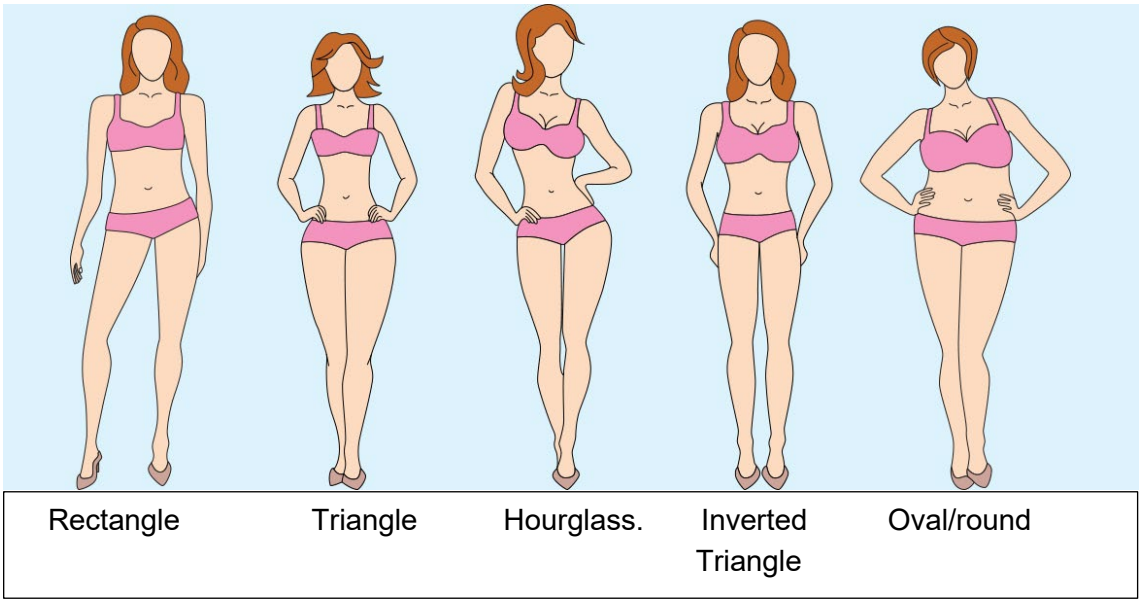


Figure 2.8: The 5 identified body shapes

Source: https://sewing.com/body-type-right-clothing/ (2016)

1. **The rectangle shape:** The hips, waist, and bust are approximately the same size. Your body is well-proportioned and athletic in appearance. Bust-to-waist and hip-to-waist ratios are low.
2. **The triangle shape:** triangles are bottom-heavy, mainly in the buttocks, and have a slim upper body that is typically wider than the shoulders. Their waist is not clearly accentuated. The waist-to-hip ratio is small, and the bust girth is less than the hip girth.
3. **The hourglass shape:** The bust and hips are proportional and balanced, and the waist is clearly defined. The bust-to-waist and hi-to-waist ratios are equal and significant.

4. **The inverted triangle shape:** Inverted triangles have a thin waist and a correspondingly greater upper body. Your chest and shoulders are broad, yet your hips are narrow. The bust-to-waist ratio is small, or the bust girth is more than the hip girth.
5. **The oval/round shape:** This body shape has a full bust and hips/buttocks without a defined waistline or the waist girth are bigger than the bust and hip girths.

This classification guideline could also be used to visually categorise body shapes from collected 3D body scanning data. This could however be subjective to the person evaluating the images and will be addressed in the next chapter.

c. Bust-to-waist-to-hip ratios

In addition to the body morphotypes identified by Sheldon, a study done by Pandarum *et al*., (2020), using the bust-to-waist and hips-to-waist girth ratios, nine body morphotypes can be created as seen in Figure 2.9 – however, many women (not only in South Africa but in other cultures and ethnic groupings as well) could even be a combination or variation of these. This would be if "B" indicates bust girth, "H" the hip girth, and "W" the waist girth, then, using "W" as a base, the ratios B/W (=b) and H/W (=h) may be defined (Pandarum *et al*., 2020).

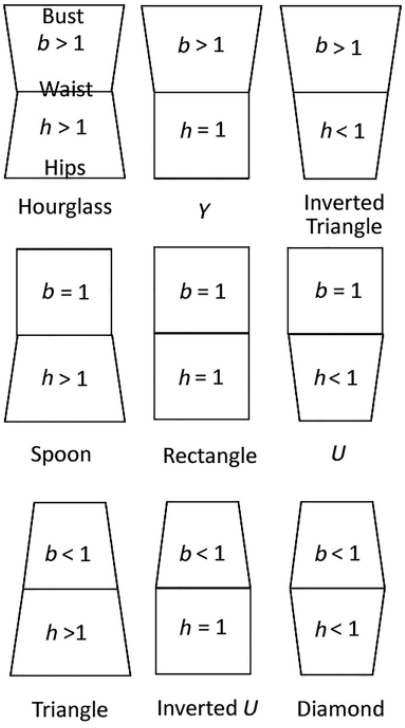


Figure 2.9: The B/W (b) ratio = H/W (h) = hip ratio

Source: Pandarum *et al*. (2020, p.424)

This is done by calculating the differences between the bust, waist, and hip girth measurements. For morphotype definition, the waist is divided by the bust and hip as upper and lower boundaries, respectively.

As mentioned previously in this chapter in section 2.2.1, most local studies have identified the triangular/pear-shaped bodies as the most prevalent shape in South Africa and, according to an ongoing study by Ola-Afolayan *et al.* (2021) about 60% of South Africa's black and white women population, aged between 18- and 56-years old fit in this category. However, due to the different types of body shapes and proportions in South Africa – combined with a lack of information about their different measurements – most women struggle to find clothes that accommodate their curves, and this is one of the reasons that body shape analysis should be considered when setting up size charts (Muthambi *et al.*, 2016).

2.3.1.5 Calculating the grade increments or size ranges

Once the primary and secondary dimensions have been established, a body size roll/range can be established. This is done by calculating the averages of all the collected statistical data per size. Zakaria (2014) argues that the key dimensions will have fixed size intervals between sizes while the secondary dimensions can have intermittent increases or size breaks. Chan (2014) agrees with this but also suggests that all the size intervals should be uniform throughout the entire size chart.

The size ranges should be flexible enough, from one perspective, the biggest conceivable scope of sizes so that even speciality producers can allude to them conveniently and, on the other, by removing the less popular sizes, mass producers can decrease the number of sizes to cater for their market. Chan (2014) argues that the size intervals will determine the number of sizes within a sizing system. A means of size designation decided by the manufacturer to fit all their customers but also for them to remain economically sustainable.

2.4 Clothing fit

Fit has been defined by many researchers as the appearance (visual analysis) and comfort (physical evaluation), of a garment (Boorady, 2011; Shin & Damhorst, 2018; Dabolina *et al.*, 2018) and is a major concern for consumers. It promotes consumer perceptions of quality and dependability, which leads to recurring purchases of garment products (Hergeth, Khairnar, & Rothenberg, 2022). The feeling of well-being and comfort in a particular piece of clothing is

the most important prompt for a consumer to purchase and clothing that fits well feels comfortable and flattering to the wearer (Cools *et al.*, 2014; Shin & Damhorst, 2018).

Since garment fit is a complex issue, the perspectives of the designer, pattern maker, and finally the consumer concerning fit may differ. Manufacturers should consider the various aspects of functionality such as garment fit, comfort, utility, and durability of the garment in the design process. It is challenging to ascertain a properly fitting garment without the proper empirical knowledge and experience that comes from trial and error (Liu *et al*., 2018). It is ultimately the subjective opinion of the consumer to accept a suitable fit and this differs from expert standards (Shin & Damhorst, 2018). The standard that is being used by experts in the manufacturing of apparel to evaluate fit, is by analysing the physical characteristics namely the grain, line, balance, set, and ease (Shin, 2013; Shin & Damhorst, 2018; Seo & Namwamba, 2017; Hernández Matilla & Berglin, 2018). These are known as the designer-mediated elements or the principles of fit as discussed below:

2.4.1 Principles of apparel fit (visual analysis)

2.4.1.1 **Grain**

The grain of the pattern must always be parallel to the centre back and centre front of the garment being created, or perpendicular to the floor or at a 45º angle if cut on the bias. (Shin 2013).

2.4.1.2 **Line**

The design lines, if used strategically, create illusions, and could be used to improve body shapes and proportions. Vertical lines give the illusion of a slimmer or taller person, and they should be parallel to the centre of the body (Shin, 2013). Horizontal lines that are used unequally in a garment could also make it appear slimmer and diagonal lines also make it appear slenderer.

2.4.1.3 **Balance**

How a garment is distributed on the body from left to right and from front to back determines its balance. For a symmetrical garment, the distance from the centre of the garment will be equal on either left or right sides.

2.4.1.4 **Set**

The set of a garment refers to the absence of stress folds and puckering or the smoothness of the fabric on the body (Shin & Damhorst, 2018).

2.4.1.5 **Ease**

According to Shin and Damhorst (2018), ease is added to patterns for different reasons namely **wearing ease** (to allow movement for everyday tasks), **design or style ease** (to create the desired silhouette), and **functional ease** (to allow the body to sit, squat, bend, and perform work duties) (Boorady, 2011; Seo & Namwamba, 2017). Ease is the amount of extra fabric that is built into a pattern to allow the garment to fit in a relaxed position and acts as a buffer when the pattern does not conform to a specific body shape (Gill, 2015; Hernández, *et al.*, 2018). A woven pattern would have a positive amount of ease, whereas a knit pattern could have either a negative or positive amount, depending on the amount of stretch in the fabric. Some fashion knit garments purposely have an excess of positive ease to create drape, movement, and comfort.

Pattern construction of garments is considered the highest technical work in the product development process and all five of these principles need to be considered when patterns are created. Effective patternmaking requires the knowledge to produce a flat 2D shape that follows the body contours without restricting movement (Dove, 2016). However, Unal & Utkun (2018) argue that even using these principles, the pattern needs to be compatible with diverse body shapes and forms. The variation in body shapes makes it extremely difficult to establish a standard for a good fit and that is one of the reasons that a well-balanced sizing system is needed to provide a range of sizes that fit most consumers (Hernández *et al*., 2018).

The proper figure needs to be analysed by understanding the anatomy of the figure variations as discussed in section 2.3.1.4. Retailers are often very resistant to change because it is also difficult to meet the needs of every individual in terms of fit preference since RTW apparel is designed for consumers with “ideal” bodies (Shin, 2013; Gribbin, 2014). Levi’s is one of the few companies that have jeans as their core business that could afford to explore body shapes and styles and could provide their consumers with the confidence to walk into a store and know that they will find the ideal shape, fit, and flatter for their bodies (www.levi’s.co.za, 2022). They made it easy for their consumers to purchase jeans online and in-store with their new “Levi’s curvy range”.

2.4.2 Comfort (physical evaluation)

In the scope of clothing, comfort is the impression of well-being that results from the body's psychological, physiological, and physical balance with its environment, and is a fundamental necessity (Kamalha *et al.,* 2013; Matte *et al.,* 2018; Raeve *et al.,* 2018). Dong *et al*., 2016, theorise that “clothing serves people” in a manner where it must adapt to the demands of daily tasks and therefore, the theory of the endogenous factors (physiological and psychological) as discussed in Chapter 1 and depicted in Figure 1.4, is corroborated. It can also be described as an approach by the wearer to evaluate the physical performance of clothing. Reave *et al.* (2018), describe the physiological and psychological conditions as follows:

a) **Thermo-physiological comfort:** This involves the thermal-regulating capacity of the garment in certain environmental conditions. It is strongly influenced by the fabric, the style and the fit of a garment.
b) **Skin sensorial comfort:** When a textile comes into contact with the skin, factors like softness, mobility, tolerance of the skin, and adhesion effects are considered. This is also strongly impacted by the fabric, the fit, and the garment assembly techniques.
c) **Ability to move (functionality):** This is affected by the fit and ease allowances of the garment.
d) **Aesthetics:** This is the visual self-evaluation of a garment’s overall appearance to the body proportions as it relates to the style, fit, and construction of the garment.

Due to the popularity of denim jeans among students, it is not just worn for their aesthetic appearance, but also act as a functional garment and must therefore be comfortable in either static or dynamic positions. However, when working with functional clothing, the five principles of fit are not always practicable because it is not always realistic to evaluate them in bottoms. Furthermore, mobility and motion can be restricted if the denim fabric is too bulky or rigid, even with ease added (Boorady, 2011). Therefore, analysis of movement must be considered in the product development process.

2.4.2.1 Fabric properties

Denim is one of the most common fibrous products and contains special properties that make it popular like durability, easy wearability, and longer washability (Akter *et al.,* 2021). One of the most important concerns for fabric quality is its comfort properties, which are heavily impacted by the fabric's construction and for this purpose, proper and developed fabric

constructions have been designed. Denim fabric is primarily made from cotton fibres and is a rough twill fabric in its raw state. However, adding spandex yarn (lycra) or using a cotton-polyester blended spun yarn, improves the elasticity and the set of the garments manufactured (Csanak, 2014).

Due to the physical tasks that the legs need to perform every day, it is expected that the denim fabric will not restrict these movements and have the relevant stretch capacity. According to Bedez Ute (2018), to enhance comfort when moving about in denim jeans and the recovery of the fabric, 10-35% elasticity is needed. To achieve the desired elasticity, elastic-core-spun weft yarns must be used in the weaving process (Akter *et al*., 2021). Core-spun yarns consist of at least two different components, a staple sheath, and a filament core. Dual-core yarns consist of three components namely an elastic polyurethane filament (such as LycraR, CreoraR, or InviyaR) and a multifilament (such as LycraR T400R) used in the core, covered by a staple sheath (Bedez Ute, 2018). This makes double-core yarns preferable for high-quality denim fabrics. Akter *et al.* (2021) also recommend that denim fabric should be lightweight, flexible, smooth, and not too thin, to provide a pleasant feel.

2.4.3 Fit satisfaction

The satisfaction of the fit of clothing is highly related to body cathexis because clothing is a tangible thing, but clothing satisfaction is a mental encounter, which means that the aesthetics do not indicate internal clothing or fit satisfaction (Gill, 2015). According to Song and Ashdown (2013), physical comfort, psychological comfort, and appearance play a key role in consumers' supposed satisfaction with clothing fit. They also suggest that the two external influences on clothing fit are the social message of the ideal body and the idealised models used in the industry, and the internal factors are the body cathexis and the physical dimensional fit of clothing.

Clothes that do not fit properly can focus negative attention on the body, from oneself as well as others. We tend to feel "fat" if our clothing feels too tight even if we are a small size and generally if it appears too tight, it will expose and emphasise body deviations. Ill-fitting clothing that is too tight will also restrict movement, appear immodest, and will be noticed by others. This will also emphasize figure variations that you might not want to be noticed. The same goes for clothing that is too big if it is too baggy and just hangs on the body, even if you are a bigger size. Equally, a good fit is supposed to be flattering and enhance the appearance of the wearer by making the body look well-proportioned.

2.4.3.1 Body cathexis

Body cathexis is closely related to body image but more precisely refers to the level of contentment with one's body or parts of their own body, and this is an integral part of the self-concept (Shin, 2013; Rahman, 2015; Makhanya & Mabuza, 2020). These may be positive or negative feelings and may vary from body part to body part. For example, women can screen changes in body size by the fit of their garments and when clothes do not fit, they blame their bodies as they can identify with their clothes size (Brownbridge *et al*., 2018). This creates negative feelings about their body size when it is perceived to be larger than what it is (Song & Ashdown, 2013).

Previous studies have suggested that a positive body cathexis is associated with being satisfied with your body and negative cathexis, is the opposite (Shin, 2013; Rahman, 2015; Makhanya & Mabuza, 2020). This means that a woman with a larger body, confidence, and a positive attitude, likely possesses a greater bodily cathexis than a smaller-bodied woman with negative feelings. The socially accepted norm of an ideal body has been found to create body image aggravations and add to negative body cathexis among women (Makhanya & Mabuza, 2020).

Women with a higher body cathexis will also choose more fitted clothing to accentuate the body parts that they are satisfied with and those with lower body cathexis will prefer clothing that is looser fitting to hide what they feel are flaws. The theoretical explanation of this phenomenon is that consumers' values lead to their emotions when it comes to making purchasing decisions. Personal values are the goals or criteria that an individual uses to guide their actions and thoughts. Individuals use clothing to express themselves, hence communicating their values to others and garment fit enhances the appearance, leading to positive emotions (Laitala *et al.,* 2011; Kasambala *et al.*, 2015).

Considering body cathexis and fit satisfaction of consumers in apparel design and manufacturing, can lead to well-fitting styles of apparel. These, in turn, can lead to improved garment fit, fit satisfaction, and subsequent customer satisfaction and loyalty (Makhanya and Mabuza, 2020). Fit is considered successful in apparel when the required functionality of a garment satisfies the needs of the wearer (Boorady, 2011) and enables the person to focus on their day instead of worrying about their clothes.

2.5 Consumer fit preferences

From a consumer's perspective, fit is based on how they feel in a garment and how they perceive fit and comfort after performing various movements such as walking, bending, etc. (Shin & Damhorst, 2018). It is important that when purchasing clothes, the clothing item fits well in their designated size (Hernández *et al.*, 2018), regardless of their definition of fit. In addition to body measurements as a basis for apparel sizing, manufacturers and retailers must understand their consumers' perceptions of physical comfort, psychological comfort, and appearance, which all impact the consumer's decision to purchase process (Dabolina *et al.*, 2018). Understanding customers' interior moods will be helpful in understanding consumer viewpoints and attitudes toward personalized products because the purchase process is strongly dependant on individual psychological values (Seo & Lang, 2019).

Johnson *et al.* (2014), concluded that clothes affect one's behaviour and also reflect clothing purchase preferences. The researchers use the phrase 'social psychology of dress' to refer to studies that try to address issues such as how one's own and other people's dress-related ideas, attitudes, perceptions, feelings, and behaviours affect one's conduct. Arora and Aggarwal (2018) classified these factors based on three human needs namely: Physiological (age, gender, skin colour, body shape and size, and physical self-perception), Psychological (mood, self-esteem, appearance importance, body satisfaction-dissatisfaction, etc.) and environmental factors (weather, social situations, and demographics). These factors can be classified further into exogenous factors (environmental) and endogenous factors (physiological and psychological). This is depicted in figure 1.4. Kwon (1987, cited in Arora & Aggarwal 2018), termed these factors under two categories namely: temporal and constant. Temporal factors are those that are situational in nature and fluctuate over time or vary from one day to the next, while constant factors are those that remain constant (invariant) over all days and periods of time (Arora & Aggarwal, 2018).

Endogenous preference: These are the variables which are not visible, less obvious, and are not attributable to external or environmental factors (Shin, 2013). These have been identified as constant factors (Arora & Aggarwal, 2018).

Exogenous preference: These factors can only be reflected through one's behaviour and are temporal (Arora & Aggarwal, 2018). These factors can change over time based on daily experiences and the sociocultural context in which they belong (Park, 2017).

The endogenous factors are found to be relevant to this study because it makes assumptions that resonate with the envisioned outcomes of the study. However, both factors simply record the visual interaction between the body and the clothing, making it challenging to fully capture the consumer's opinion on fit. Expectations of the garment and knowledge of its features can alter perceptions of its qualities and preferences, which in turn shapes how consumers evaluate and value the product (Iazzi *et al.*, 2016). Consumer satisfaction is a two-way construct of both emotional and informational responses towards a product and consumers (Zwane & Dhurup, 2019), which is confirmed by the guiding theoretical framework for this study. The actual power is in the hands and minds of the consumer as a result of his or her feelings about specific clothing items. A consumer could discourage others to buy a certain brand, based on their feelings and experience. Conversely, this would urge a consumer to repurchase and recommend it to friends and relatives.

2.6 Product development

In product development, an existing product may be modified, its presentation may be tweaked, or a completely new product may be developed for a specific customer or niche market in the marketplace. A product development cycle involves all the activities related to the development of a product, including idea generation, prototyping, testing, and getting customer approval (Wijewardhana *et al.,* 2020).

Traditionally apparel products were developed locally, and physical fit and production meetings were held regularly to iron out many challenges arising during the product development process (Liu et al., 2018). This is still the case with some local manufacturers but with globalisation today, products are manufactured worldwide and physical production meetings are limited to online sessions or emails because of the supplier’s geographical locations (Dos Santos, 2014). This system creates many challenges as it requires time, trials, and errors and every product developer knows how time-consuming and costly the process is, as well as how dependent it is on the designers' and pattern makers' abilities and experience (Papahristou, 2017; Liu *et al.,* 2018; Spahiu *et al.*, 2021).

For many years, the new development process of denim jeans has been purely manual and wasteful because to confirm the design and achieve a suitable fit, it is necessary to repeat the sample-making, sample fitting, and pattern alteration cycles repeatedly (Papahristou, 2017). This process can be repeated up to five times to achieve the desired fit and style in the ready-to-wear market. This process can be iterative, time-consuming and sometimes complicit but is critical to maintaining high-quality levels in terms of fit (Papahristou, 2017), and for various

washes. Innovative and upgraded solutions are essential to shorten response time and satisfy this challenging industry. Manufacturers should look at their current product development processes and find new solutions to remain innovative and competitive, while remaining sustainable (Bishop, 2014; Dos Santos, 2014). The development process of denim jeans wear has always used a lot of water for washing. Waterless solutions can now be eliminated to view the various washes created virtually.

Making physical samples becomes a tedious task when patterns need redoing and prototypes demand remaking to get to the point of having a final product and throughout the entire process, an average of between 15 and 25% fabric waste is created (Rissanen, 2013 & Runnel *et al.*, 2017 (cited in McQuillan, 2020). A prototype takes a lot of time, effort, and money, even with conventional processes and highly skilled technicians. Manufacturing companies are challenged to improve the new product development (NPD) process to improve customer satisfaction, and all want to cut the cost of these processes by seeking alternatives without compromising sustainable development (Rangarajan & Del Corral, 2014:35). This does not mean that physical prototypes will ever become obsolete as many designers want tactile interaction with prototypes and samples (Bye & Sohn, 2010), but these processes must change if the industry wants to secure a future in clothing manufacturing.

2.6.1 3D Apparel technology

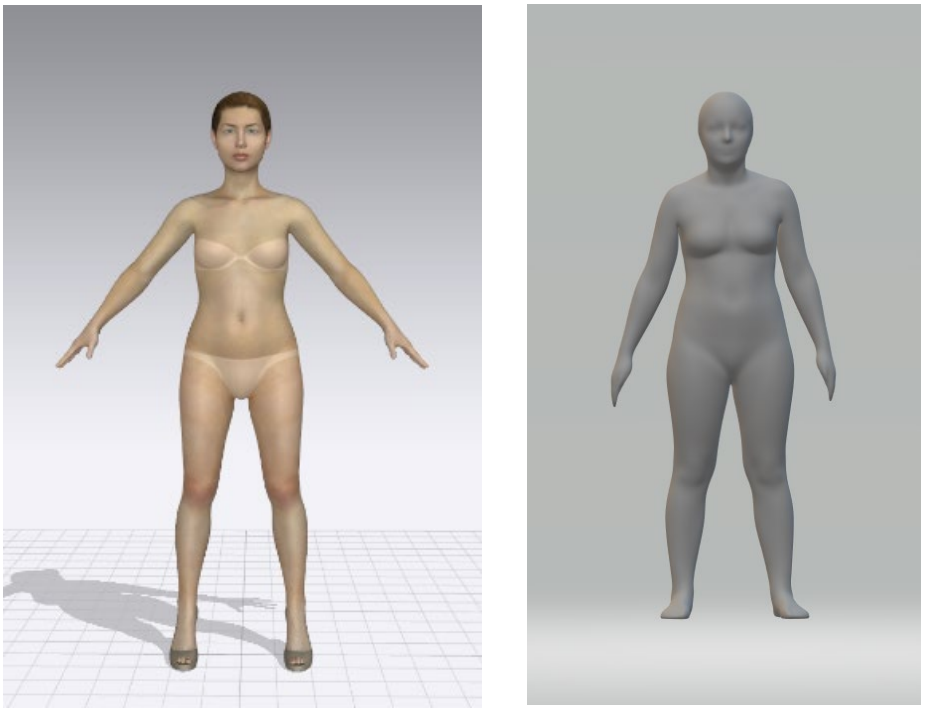
The preassembly process is where most innovations are taking place in the apparel product development lifecycle (Wijewardhan *et.al.,* 2020). This is essential for a company's growth in terms of turnover and profit. Therefore, Wijewardhan *et.al*. (2020), advise that companies investigate developing best practices and adopt concurrent engineering processes to develop products to keep cost low and increase their efficiency (Kamal, 2015). For example, with the help of 3-D virtual fitting technology, clothing manufacturers may create two physical samples instead of the three to five that were typically required in the past for each item (Song & Ashdown, 2015).

3D imaging software is becoming a useful tool for both designers and pattern makers in the design and product development sectors to help create faster turnaround of garments and eliminate waste (Song & Ashdown, 2015), cutting the prototyping time to approximately 50 minutes on average. Virtual prototyping can serve as a tool for assessing the form and fit of garments before real production and deciding whether to make changes in ease values, pattern cut or fabric parameters. The use of 3D prototyping tackles several other problems

with product development, including misinterpretation of technical packages and patterns, a lack of confidence between different organizations working together, and information gaps that cause process delays. Therefore, using 3D prototyping helps speed up and increase the effectiveness of the product development process. The need for fit models during development is also diminished or eliminated when using 3D prototyping if the correct size or body measurements of the consumer are available (Prather, 2017).

2.6.1.1 Avatars

There are two ways of creating an avatar in the virtual prototyping systems: using the parametric avatars available and manipulating it, or a custom avatar could be created from body measurements from gathered anthropometric data (Prather, 2017; Liu *et al.*, 2017; Lapkovska & Dabolina, 2018). Gill (2015), however, says that often the avatars are only available in certain static poses which are slightly different to the standard pose of the body while being scanned. The variation in poses can be seen below in Figure 2.10. A way of eliminating this is by importing an avatar directly from the 3D body scanner but sometimes there are technical limitations such as missing data points.



(1) (2)

Figure 2.10: A parametric avatar pose (1) and a 3D body scanning pose (2)
Source: Windvogel (2022)

Prather (2017) also adds that modifying existing parametric avatars does not necessarily create an avatar that reflects the true body. The creation of accurate avatars that is as close to the actual body shape of the sample as possible is essential to the process of creating new products as the tightness and comfort of a garment are two fit characteristics that are challenging to evaluate using virtual avatars (Wang & Liu, 2020).

2.6.1.2 Virtual fit assessment

As mentioned before, assessing fit is a complex issue as both experts and consumers have different views on the subject. This dichotomy makes it more difficult to assess virtual fit and its adoption of it. It is challenging to determine fit in the 3D simulation environment as the operator cannot tell how the garment relates to the body and the avatar cannot verbalise its comfort or discomfort with the garment. Depending on the software being used, 3D simulations have varying levels of capabilities for this purpose (Gill, 2015; Prather, 2017). Wang and Liu, (2020), in their study using CLO3D, discussed fit maps, pressure maps and strain maps showing a virtual garment's strain distribution to overcome this limitation.

a) Fit map

The yellow-coloured parts of the garment indicate specific areas that feel tight and represent the overall proportion of the garment. The red parts represent the area where it can't be worn under normal circumstances. The yellow areas can be adjusted with added ease but for both colours, the pattern needs to be adjusted and re-simulated (Wang & Liu, 2020).

Figure 2.11: Fit map in CLO3D

Source: Wang & Liu (2020, p.42)

b) Pressure map

The pressure map can reflect the stress level of the clothes when worn by indicating various colours on the body. The red areas indicate that the garment is stretched severely and green would be less pressure on the body. This distribution is demonstrated in Figure 2.12. The units used to indicate the pressure is in Kilopascal or kPa. 1 kPa is approximately the pressure exerted by a 10-g mass resting on a 1-cm^2 area.

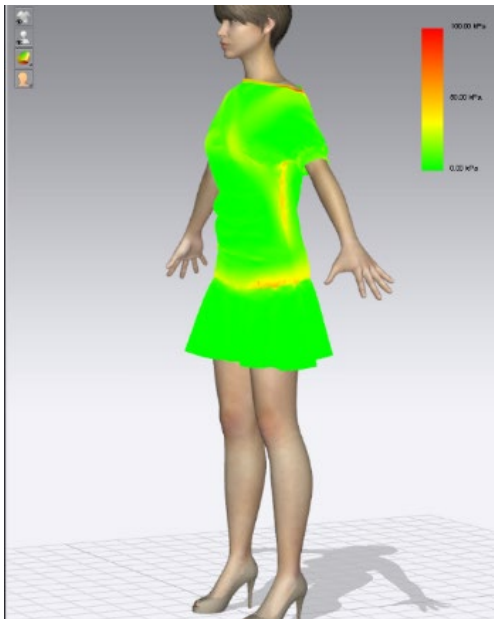


Figure 2.12: The pressure map in CLO3D

Source: Windvogel (2017).

c) Strain map

The strain map (Figure 2.14) is similar to the pressure map in the intuitive view but the pressure map shows the amount of pressure there is on the body whereas the strain map indicates the degree of tension caused by the pressure (Wang & Liu, 2020). The strain map also shows the deformation of the fabric when worn. The red area indicates more than 120% of pressure and this means that the garment is not wearable.

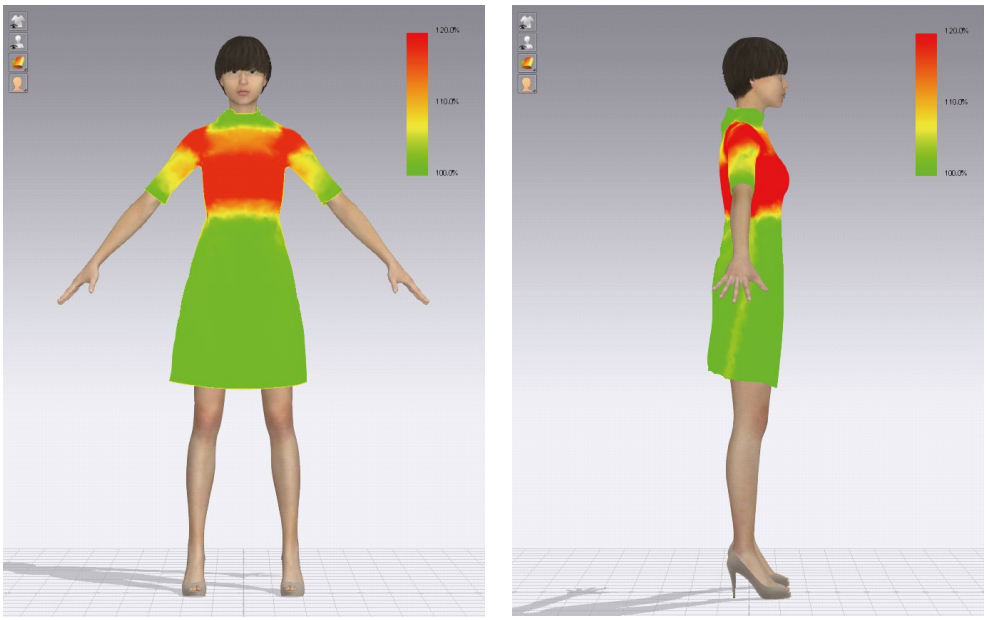


Figure 2.13: The pressure map in CLO3D

Source: Wang and Liu (2020, p. 44)

To virtually represent the fabric is another complexity that needs to be considered. There is a huge variety of materials with various aesthetic and functional properties available in the software, but truly realistic simulations cannot be delivered (Gill, 2015; Prather, 2017; Wang & Liu, 2020). The fabric parameters can however be altered to assimilate the real fabric being used to create the desired visual effect (Lapkovska & Dabolina, 2018). However, 3D apparel simulation is useful as a tool for evaluating fit, due to time constraints and convenience. This study will contribute to the body of knowledge on evaluating fit using 3D virtual simulation tools and the potential cost savings to be made as well as the increase in sustainability within the product development process.

2.7 Concluding summary

The review of the literature shows the most pertinent factors relating to anthropometry and the aspects that need to be considered when establishing a sizing system for properly fitting garments. The various aspects that play a part in clothing purchases for consumers such as comfort, functionality, aesthetics, and body image was discussed as well. The emotional and informational aspects are also what drive customers to recommend a product to other people.

The product development process can be improved and shortened with the use of 3D virtual software programs to improve fit but also communication between entities, especially if

clothing is manufactured globally. This process will be discussed in further detail in Chapter 3 and implemented to create a suitable size chart and well-fitting denim jeans.

CHAPTER 3

Research design, paradigm and methodology

3.1 Introduction

The purpose of this chapter is to describe the paradigm, design, and methodology in response to the research aims and objectives. Cameron (2011) confirms that it is challenging to undertake mixed methods research, but it provides more comprehension and innovation to those who follow and use it. The validity and reliability of the primary research are heightened because results are obtained from two different approaches to the same topic and problem.

The main research question and aim of this study transpired as a result of an apparent inability of local retailers and manufacturers to provide well-fitting clothing to local women, particularly those who do not necessarily have an hourglass body shape. Women feel confused and frustrated when choosing their designated size in stores or online, and it does not fit their bodies. There is an apparent lack of a valid, reliable sizing system for the typical young female wearer of denim jeans in South Africa. In light of this, there is a critical need for local manufacturers to investigate why fit incongruities exist and for a proper, authentic body measurement size chart to be developed to keep their customers satisfied and for local clothing businesses to remain economically sustainable.

The primary question of this study asks how a scientific size chart can be developed for South African women, by using 3D body scanning and virtual simulation technology. With this question in mind, this chapter will explore the topic in more detail and clarify the aim of this research, which is to create a valid, reliable sizing system as well as assemble a body measurement size chart for improved grading applications. The chosen research strategy aligns with the research aims and secondary research questions and will be outlined in this chapter.

3.2 Research design

The research design for this study was devised to answer the primary research question using empirical data. It was chosen to guide the overall objective and approach for the data collection and analysis methods. This study was exploratory sequential in nature and was associated

with deductive approaches (based on logic) (Bhandari, 2022). This was designed to first explore the initial responses of the participants and then continue with the quantitative data collection (George, 2022). Deductive research begins with a known theory and expands upon it with obtained facts; hence, these investigations are typically confirmatory.

3.2.1 Research paradigm

The primary objective of conducting research is the production and expansion of knowledge based on evidence (Hussain, Elyas & Nasseef, 2013). For this reason, the practical component of this study is based on a pragmatic paradigm as it is committed to generating and validating useful knowledge that will solve actual problems (Kawulich, 2012; Maarouf, 2019). Pragmatism is a manner of approaching problems or circumstances that emphasises practical approaches and solutions—ones that will work in practise, as opposed to being ideal in theory (Weaver, 2018). This does not necessarily mean that there will be a definite solution to the research problem, but the results of the study may be open to interpretation. The aim is to explore existing knowledge and build on that by using an organised process of inquiry.

According to Datta (2010), the **strength** of pragmatic investigations is that they can:

- easily be described and characterised
- be valuable when unexpected results arise from a previous study appear;
- aid in generalising data; aid in building and verifying an instrument;
- enable a researcher to produce a holistic analysis to completely incorporates numerous significant elements into the study.

Datta (2010) also elucidates that pragmatism has its **drawbacks** as well:

- it may take longer to design and conduct the experiments than with more conventional paradigms;
- there may be disparities between different types of data that are difficult to interpret;
- it can be challenging to determine how to organise different methods of data gathering and when to proceed with sequential designs, which include studying distinct groups over an extended period.

Utilising a pragmatic paradigm has the benefit of focusing on, analysing, and altering characteristics of actual psychological, social, and educational processes (Weaver, 2018). My understanding of and experience in the clothing industry may provide an objective basis for

the evaluation and implementation of processes in this study. To investigate and come to realistic results the following paradigm and methods will be used to design the study.

3.2.2 Mixed methods research

Mixed methods research is known to include both philosophical and investigative methodologies and is encapsulated within the pragmatic paradigm (Kawulich, 2012). It uses philosophical presumptions as a technique, directing the direction of data collection and analysis which speaks to the endogenous factors of consumer preferences (Cameron, 2011). Its fundamental tenet is that it explicates how combining qualitative and quantitative data collecting and analysis techniques in a single study can help us gain a greater grasp of the causes of social reality (Haq, 2014). This approach generates a more complete picture and is more useful than using only quantitative or qualitative methods (George, 2022). It can also help to generate questions for further research (Haq, 2014). Due to the lack of existing data about South African body measurements and shapes (Smith & Mac Duff, 2014; Makhanya, 2015; Pandarum, 2015; Muthambi *et al.*, 2016; Pandarum *et al.*, 2017; Phasha *et al.*, 2020; Ola-Afolayan *et al.*, 2021), this fundamental study aimed to explore and identify the boundaries in which the problems and salient factors that might be of relevance to this research, can be found.

3.2.2.1 Quantitative research methods

Quantitative research is defined as an inquiry into an identified problem, based on testing a theory, measured with numbers, and analysed using statistical techniques (Bouchrika,2021). The goal of a quantitative investigation can be to generate knowledge that can be applied to other phenomena and to generalise findings from a sample population, quantify data and make inferences (Bouchrika, 2021). It follows a structured process and calls for a thoroughly planned, repeatable study that is conducted in controlled settings (Kawulich, 2012). This empirical study will apply quantitative research methods, through means of collecting measurements of female students and consequently analyse these, both statistically and visually. Quantitative data for this chapter, will be to collect measurement data through 3D body scans, apply correlation analysis to measure variables, and employ a linear regression model to predict jeans sizes. Virtual garments will be created in both 3D virtual programs namely, CLO3D and physical samples will be created to be utilised for physical fit sessions.

3.2.2.2 Qualitative research methods

Qualitative research is defined as research focusing on how individuals and groups view and understand the world and construct meanings out of their experiences (Haq, 2014). It is essentially narrative-orientated and uses non-numerical data to understand concepts, opinions, or experiences (Bhandari, 2022). Qualitative data includes surveys with open ended questions, observations and recording the processes, interviews, focus groups, and secondary research (Bhandari, 2022). To gain better insight into possibilities for future improvement of the developed size chart, the study will also include qualitative research, as can be seen in the methodology outline in Figure 3.1.

3.3. Research methodology

The methodology section discusses the research process systematically, that is, how the research proceeded or was conducted. In response to the secondary research questions, certain types of data needed to be collected and analysed and will be discussed methodically. The choice of the research strategy, sampling methods, data collection, data analysis and presentation, and validity and reliability of the study needed to be addressed. The study was divided into three phases (see Figure 3.1). The analysis section considers both quantitative data (numerical size and body data) and qualitative data (user needs/opinions for co-designing) in the survey questionnaire. The body scanning data was analysed by means of statistical analysis to calculate the actual sizes and body shapes of the participants. The product development section focused on the process of creating an avatar and SBM size charts, based on the results from the quantitative analysis. Using the size charts, 2D CAD patterns were developed and graded into various sizes and virtual prototypes were developed with the use of technology as well as physical prototypes (quantitative data). The review section indicated the final evaluation of the process. This included a qualitative comparative analysis between the old sizing system in contrast with the new sizing system. The process was documented with photographs of the participants in both pairs of jeans. A qualitative feedback questionnaire would conclude the methodology.

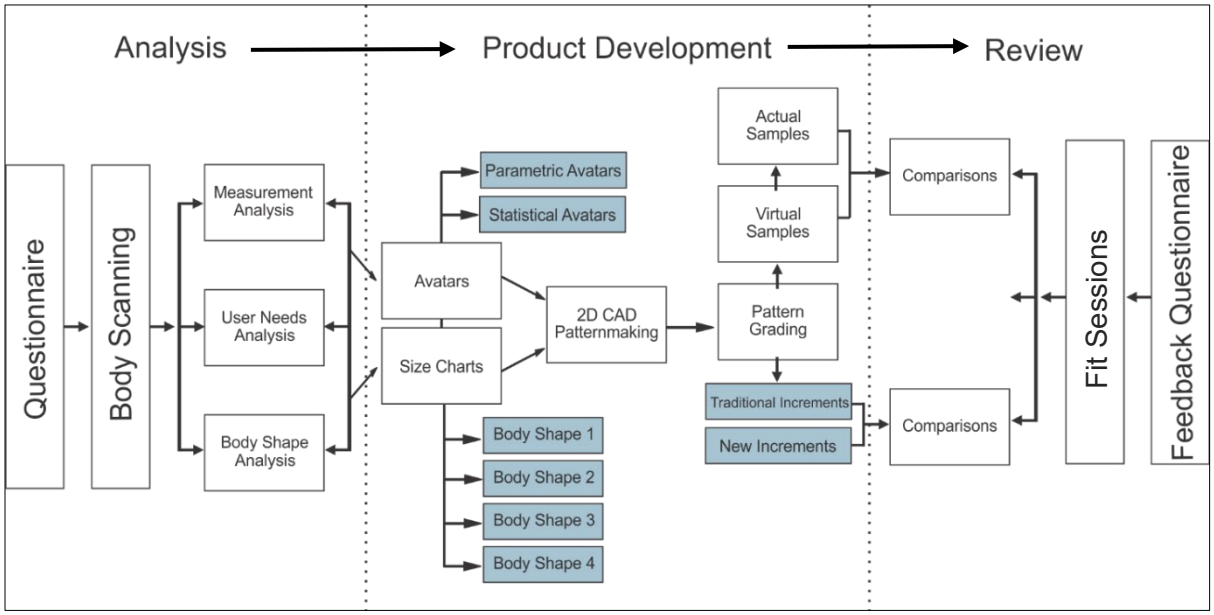


Figure 3.1: Research Methodology Plan/Outline

Source: Windvogel (2017)

If this research can answer and validate the research questions, proper evidence is required. The methods used for the data collection are an integral part of the methodology and therefore needed to be logical and extensive if it is to make a worthwhile contribution to the existing body of knowledge. The next section aligns with the research strategy and will systematically discuss the methods that were used to answer the secondary research questions.

3.3.1 ***Secondary research question 1:*** *Why is there no South African body measurement size chart and can this be developed?*

This question needs secondary information from relevant literature on South African sizing systems and body shape data. This would arise from chronologically reviewing similar local research studies and the methodological approaches within them. The objective of this is to investigate why there exists a lack of body dimension details and what the reasons are but also how SBM size charts can be developed and to identify the possible limitations regarding creating/developing a sizing system.

3.3.2 ***Secondary research question 2****: How do young South African women feel about the current availability and fit of denim jeans across various brands and what aspects regarding fit and appearance do they experience as problematic?*

3.3.2.1 Population and sampling

The population for this study was South African women. The sampling frame within this population were females between the ages of 18 and 35 years. A probability sampling design was used to recruit the participants using a random sample method. Probability sampling means that everyone within the sampling frame will have an equal probability of inclusion in the study (Taherdoost, 2016). This method was chosen as a simple random sample would lower the cost of recruiting participants.

To attract the respondents, marketing material was developed by the researcher through a flyer (as seen in Appendix D). The flyer was created to attract the relevant group of young females needed for the research and was distributed around the research site, on notice boards in all public settings as well as female residences. Individual volunteers from other institutions also requested to be part of the study as the information was spread through word of mouth. As part of the incentives for their participation, the subjects were offered a goodie bag as a means of appreciation. These goodie bags were donated by the Technology Station in the Clothing and Textiles Department of CPUT and consisted of an A4-sized document bag in a choice of four colours, with useful goodies inside.

The population for the final fit analysis section were experts in the academic field with experience working in the South African clothing industry. The researchers personally approached some of these experts and two of the researcher's colleagues volunteered.

3.3.2.2 Survey questionnaires

The purpose of conducting a survey is to find solutions to certain, significant questions (Taherdoost, 2016). The main objective of the survey was to gain more qualitative knowledge on the women's experiences with the available jeans on the market to better understand and explore in-depth, their experiences and expectations. Useful quantitative data such as demographics and lifestyles were also collected. This was achieved using a survey questionnaire aimed at the target group that was administered either before or after the body scanning process. A survey questionnaire was used for the following advantages:

- According to Patten (2017), questionnaires are an efficient way to collect data. This is because they can be administered to many participants at the same time. It is also easy to tabulate or score and the primary quantitative data are easy to analyse.
- To collect sensitive data on issues related to size and preferences. The participants were aware that their answers would remain confidential and anonymous, and their

names would not be used for publishing, and they could therefore answer the questions honestly.

There are also some disadvantages to be considered when administering namely:

- If a questionnaire is administered physically, there is a chance that it may not be completed in the time allowed and may not be returned when necessary. To eliminate this, the questionnaire could be completed online but this also poses a challenge because if anything is unclear, the researcher is not on hand to clarify (Taherdoost, 2016).
- Participants could also misinterpret a question, and this could lead to exclusion during the analysis process (Taherdoost, 2016)

Questionnaire designing and planning are of utmost importance to gather useful and relevant information. There are four different types of questionnaires designed for a survey and are applied according to the purpose of the survey (Roopa & Rani, 2012).

I. **Contingency questions:** This is when a respondent gives a particular response to an earlier response.
II. **Matrix questions:** Multiple questions have the same response categories placed one under the other, forming a matrix with response categories along the top and a list of questions down the side.
III. **Closed-ended questions:** Respondents' answers are limited to a fixed set of responses and include (yes/no questions, multiple choice and scaled questions).
IV. **Open-ended questions:** The respondent responds in their own words without being limited by a predetermined range of answers and this includes completely unstructured questions, word association, sentence completion, story completion, picture completion and thematic apperception test.

The questionnaire designed for this study consisted of open-ended questions that required the participants to give their opinion. The open-ended questions were designed to be unstructured.

*3.3.3 **Secondary research question 3:** How can 3D technology be utilised in this study of young South African female jean wearers to generate/develop an improved measurement size chart?*

3.3.3.1 Collecting raw anthropometric data

Anthropometric surveys record different body measurements for each person measured and can yield thousands of data points for various applications (Hedge, 2013). The 3D technology scanner yields quantitative data.

3.3.3.2 Body scanning

The instrument used for collecting the quantitative anthropometric data is a portable body scanner that enables more flexibility about locations and spaces that will be used for the 3D body scans. The available full-body scanner belongs to the Technology Station in Clothing and Textiles on the CPUT Bellville campus. It is from Anthroscan of Human Solutions (System administrator, 2015), that are compatible with anthropometric norms. Figure 3.2 is an image of a person being scanned by the body scanner that is used for the study.

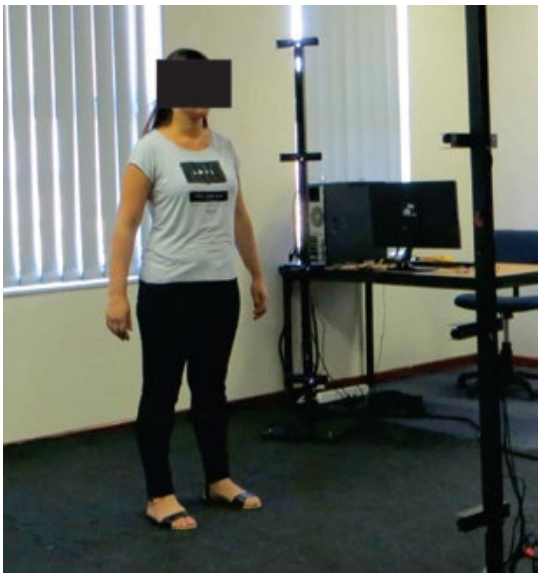


Figure 3.2: A person being scanned in the Anthroscan body scanner
Source: Windvogel (2017)

Under normal circumstances, the person being scanned needs to wear either underwear or gym clothing that is not too tight to compress the body to ensure accuracy. Participants who enquired to participate were asked to wear the correct attire prior to the scanning process. The challenge with this was that many students arrived in their everyday wear and were asked to return but in certain cases they did not return.

During the scanning procedure, the individual stands centred on the designated markings and remains still for a few seconds so that the body scanner may gather photos from all sides. The body scanner then generates a detailed 3D model of the person.

From these scans, body measurements were collected and used in a point cloud system to be able to set up body measurement charts for grading purposes as well as create generic avatars. Primary control measurements were needed to develop the denim jeans, but other secondary measurements must also be collected to enable the setup of a proper size chart (Gupta & Zakaria, 2014). Indemnity forms were created in line with the CPUT ethical norms for the participants to complete before the body scanning could be conducted.

3.3.3.3 Measurement analysis and size chart development

The process for creating/developing a size chart is comprehensively outlined in Chapter 2 and some of those steps were implemented in this study. The gathered measurement data from the 3D body scans were analysed statistically, with key measurements identified using Microsoft Excel. An external expert performed the following analysis:

I. **Correlation analysis:** The use of correlation analysis is to explore the degree of association between two variables/datasets. Correlation analysis is a statistical method that is used to discover if there is a relationship between two variables, and how strong that relationship may be. This is useful to explore the relationship between independent and dependent variables and is mostly used to establish the primary and secondary dimensions for a size chart (Senthilnathan, 2019). Since a greater correlation coefficient reflects a better prediction of the dependent variable with the fewest errors possible, the correlation becomes crucial in this situation.

II. **Linear regression:** In this research project, we used a linear regression model to assess the relationship between jean size and a wide range of independent variables. To correct the effects of non-constant variance in error terms, we employ methods of weighted lease square regression (Lekata, 2021). Furthermore, ridge regression was used to correct the possibilities of inflated parameter estimates. Once this was solved, each size could be calculated using the primary and secondary dimensions of each participant. This means that the predicted size is extracted from the established dataset of this study, and not based on the existing size the participant wears.

The size range or mean needed to be established and explored within this project. With all the collected body measurement data, a size chart was developed to use for grading the denim jeans patterns. Ridge regression was used to determine the size range as well as the grade increments. This was done by calculating the grading increments and size breaks to create

sizes that will fit most body shapes. This size chart was used as an application to create the full-size range needed and compared to the traditional grading increments.

The initial plan for the study was to develop a size chart for every body shape. However, this was not possible due to the small sample set as discussed in Chapter 6.

3.3.3.4 Body shape analysis

Body shape analysis needed to be conducted to establish the shape of the South African female. In Chapter 2, it was highlighted that there are a few methods that could be employed for this purpose. The waist-to-hip ratio technique was utilised using the subjects' bust, waist, high hip, and buttock girth measurements from the collected body scanning data. This is another area where body scanning technology plays a major role in the process. The extracted measurements from the system were calculated and recorded and the same body types were clustered.

Visual analysis of the body shapes was conducted to corroborate the results from the mathematical analysis. This method could be subjective to the person conducting the analysis and can therefore not be used solely for this purpose. The body scanning information was archived and re-opened in Paint 3D to visually inspect the scanned body images. This was performed by the researcher and supported by experts in the Clothing and Textiles Technology academic department.

3.3.3.5 Developing 2D CAD patterns and grading applications

This primary quantitative research was done using Gerber Accumark 2D pattern design software. Gerber AccuMark is a 2D/3D digital patternmaking software that simplifies the design process. This software allows the creation of digital patterns that can be printed onto paper to create physical fit samples or converted to a dxf file format that is compatible for use in 3D visualisation software programs. The CAD patterns were developed after the size chart was established and the base or sample size have been identified. The denim jeans patterns will be evaluated in terms of fit, design features and fabric use. Two sets of patterns will be made to conduct a comparative analysis. The first set was created using the newly developed size chart and the second set was created using the traditional specifications being used in the industry (secondary data). The process started with a basic block pattern to verify the fit of the denim jeans before continuing with the design styling details. This computerised pattern was exported from Accumark as a dxf file to enable virtual sewing/construction.

3.3.3.6 Creating virtual avatars and fit samples

The market has many software programs available for the visualisation of garments. CLO3D is one of them and is used to virtually simulate a garment to evaluate the fit parameters. In addition, it offers convenience for designing, pattern making, adjustment and modification of existing patterns, fabric selection, and displaying of new or existing prototypes (Wang *et al*., 2020).

The first step in this quantitative section was to create an avatar that is representative of the sample (n=210) used as a basis (Wang *et al.*, 2020), according to the body measurement size chart, to simulate the denim jeans block. A parametric avatar in the system was used and her body measurements were modified for this purpose. This digital pattern from Accumark PDS was imported into CLO3D and virtually sewn and simulated. The fit was checked by evaluating the fit map as discussed in Chapter 2.6.1.2.

The purpose of creating the virtual avatar was to do a virtual fit evaluation to streamline the product development process and to save on fabric costs. This was a faster and more efficient way to do the fit evaluation before making physical samples. Various changes could now be added or modified to ensure a proper fit. Actual fabrics were scanned into the system and added to the virtual prototypes to create a more realistic image.

3.3.3.7 Creating physical fit samples

Once the jeans basic block patterns were approved in the virtual fit assessment process, the digital pattern was altered in Gerber Accumark with the necessary changes and the design/ styling details were added. The next step grading the patterns to the sizes identified for the study. The traditional pattern was graded according to the standard linear method and the newly developed block pattern was graded according to the size chart with measurements from the collected and analysed data. It is of utmost importance that these grade rules are added correctly to the patterns for accurate results. Two (2) digital markers were created with each set of patterns consisting of 5 sizes each. The digital marker-making system ensures efficient use of fabric and eliminates wastage. The marker was made according to the width of the selected denim fabric. The samples were cut and manufactured following the standard construction breakdown for denim jeans. The purpose of these samples will be to fit the selected subjects to get feedback on the feel/comfort, fit, and size of the garments.

3.3.4 ***Secondary research question 4:*** *How could a more accurate body measurement size chart enhance the fit and appearance of denim jeans and consequently also the user experience/satisfaction?*

3.3.4.1 Physical fitting sessions

To evaluate the fit of the denim jeans over various sizes both the traditional specifications and the newly developed system were manufactured in sizes 30 to 38. The purpose of this was to do a comparative scale with selected participants who were scanned in the initial process. Part of the study was to investigate whether a more accurate body measurement size chart can enhance the fit and appearance of denim jeans. The process was also documented utilizing photographs to use for inspection after the fit sessions.

As is required in qualitative research, a smaller sample were chosen. Ten participants that were part of the initial body scanning process and whose measurements were in tolerance (close to) of the manufactured sizes, were asked by the researcher to participate in the fitting session and give feedback on specific areas of interest while fitting the jeans. The researcher ensured that each size had a physical body to fit a pair of jeans and for some of the sizes, there was more than one body but in a diverse body shape. The traditional sizing samples were labelled A-samples and the new proposed fit was labelled B-samples. The participants were asked what size they “normally” wear and were handed that size in both samples A and B to fit. To test their comfort levels, they were asked to perform basic tasks like walking, sitting, bending, and squatting in the jeans.

Considering the complexity of evaluating fit on a body, two experts and colleagues from the Clothing and Textiles Technology Department were asked to assist the researcher in evaluating the visual fit of the jeans on the selected participants. This was important to minimise subjectivity and to measure the correlation between the answers.

3.3.4.2 Feedback survey

A qualitative feedback survey questionnaire (Appendix H) was created by the researcher for the 10 participants to complete after the fitting sessions. It consisted of 9 open ended questions that relate to the comfort, size, and fit aspects of the jeans that they could give their opinion on. A paired comparison scale was used to ascertain the differences between the two pairs of jeans that each participant needed to fit. This was to establish the degree or level of

success gained with this research project and it will also allow for corrective measures or future research studies.

3.4 Conditions for scientific research: validity, reliability, and trust

The level of rigour describes how hard the researcher tried to improve the quality of the study. According to Heale and Twycross (2015), the rigour of a study is measured through the validity and reliability of quantitative research.

3.4.1 Validity and reliability

Validity is known as the degree to which a concept is precisely measured in a quantitative study. Although validity is more difficult to evaluate than reliability, it is nonetheless extremely important. The methods you use to gather your data must be valid to produce meaningful results; the study must measure what it purports to measure. This guarantees that the data you discuss and the conclusions you draw are valid (Heale & Twycross, 2015; Middleton, 2022). To ensure validity, an expert statistician from the CPUT Centre for Post Graduate studies were commissioned to interpret the quantitative data of the study.

Reliability refers to the consistency of a measure (Middleton, 2022). In this study, the reliability of the body scanning process was crucial as each scan needed to be conducted identically and accurately. In some instances, the body scans were not valid due to technical errors and those scans needed to be discarded for the study to remain valid. For this reason, the instrument needed to be calibrated frequently between scans to ensure accuracy.

Furthermore, the primary research methods should also be conducted by individuals with the required knowledge to not just operate the systems but to create correct patterns as well as interpret and apply the correct grading methods. In this study, most of these processes were conducted by the researcher who has 18 years of experience within the product development environment.

Due to the subjective nature of the visual analysis, this study employed an objective mathematical system to identify the various body shapes to ensure validity and reliability.

3.5 Ethical clearance and considerations

Due to the nature of this study, the researcher applied for ethical clearance from the CPUT Institutional Ethics Committee to conduct the study on its Bellville campus. Ethical clearance was obtained and can be seen in Appendix B and C.

It was essential that before the body scanning process, the researcher give each participant a thorough explanation of the study's objectives and requested their informed consent before body scanning and questionnaire completion. They were also informed that their names or any identifying traits would not be used at any point in the research process to ensure anonymity. Participants were not compelled to participate in the study and could withdraw from the study at any time during the process without any bias from the researcher.

3.6 Concluding summary

This chapter has focused on the research design and methodology that underpin this study. Detailed information regarding the quantitative and qualitative design approaches, their relevance to this study and their general characteristics, were explored in this chapter. The following chapters build on the methodological suggestions made in this chapter by employing the proposed data presentation and analysis approaches.

This information could prove to be a very useful tool for the local industry to try and improve overall fits of RTW clothing for their defined target markets, rather than catering for an undefined number of consumers. This standard sizing system could also be the beginning of building up an authentic database for all age groups, body types and both genders. The outcome of this research will determine whether it is at all possible to try and solve clothing fit issues by undertaking research and if successful may be a very useful methodology to the local clothing industry.

CHAPTER 4

Data collection and results

4.1 Introduction

This chapter presents the results of this mixed-method empirical study. The research questions, as set out in Chapter 1, are driving the search for answers in this research design and methodology.

The research objectives that led the study, were as follows:

- to explore the reasons for the lack of a valid, reliable sizing system for the typical young South African female,
- to develop proper, accurate body measurement size charts for young South African women to implement as a basis for clothing grading systems, and
- to use such a new clothing grading system and body measurement chart to design a garment that can improve the overall fit of ready-to-wear apparel, especially pants and denim jeans.

To achieve these objectives, the process as set out in Chapter 1 and the previous Chapter 3, was followed, backed up by literature findings in the secondary research phase.

4.2 Assessing consumers' overall satisfaction with the available apparel fit

4.2.1 Recruiting and selecting the participants

The targeted research group and respondents for this study were young females between the ages of 18 and 35 years old. The total number of participants that were recruited was 252, although only 210 females were selected for the study. The 42 participants that were not included in the study were either not from South Africa, not within the specified age range, or did not submit the completed consent forms. The participant's ages ranged from 18 years to 30 years even though the criteria were from 18 years to 35 years.

4.2.1.1 Participant profile data

To identify their ethnicity and the distribution of the races across South Africa, the consent form asked for their race and their home province. Statistics SA (2016) provided four racial categories in which the population could be classified and the results for the females on a

national basis were grouped into Black South African females at 80.6%, Coloured South African females at 8.9%, Indian South African females at 2.4%, and White South African females at 8.1%. For this study, the total black females amounted to 84%, 25% were coloured, 0,5% were white, and 0,5% were Indian. From the collected data for this study, the following information was uncovered:

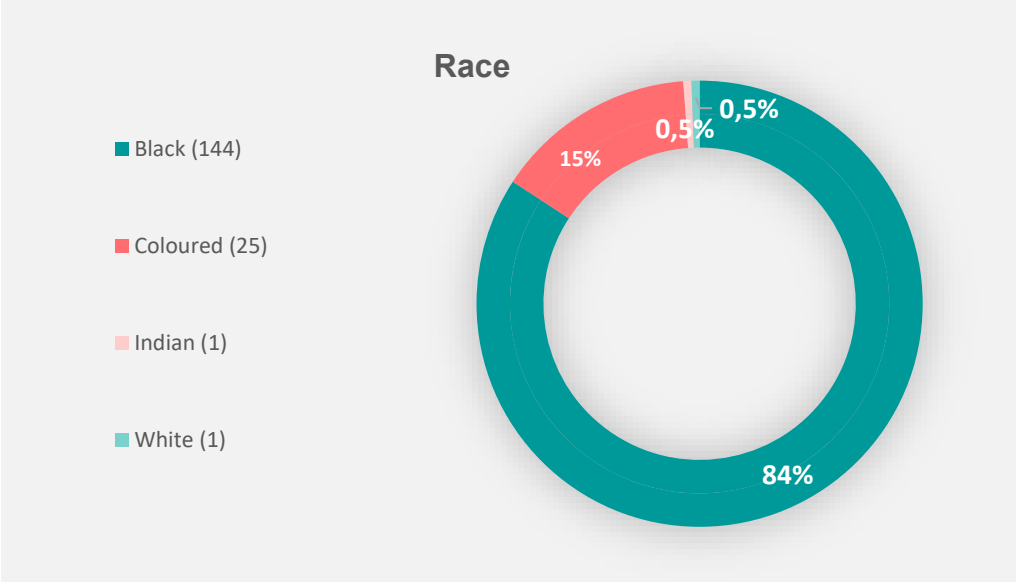


Figure 4.1: Participants' ethnicity

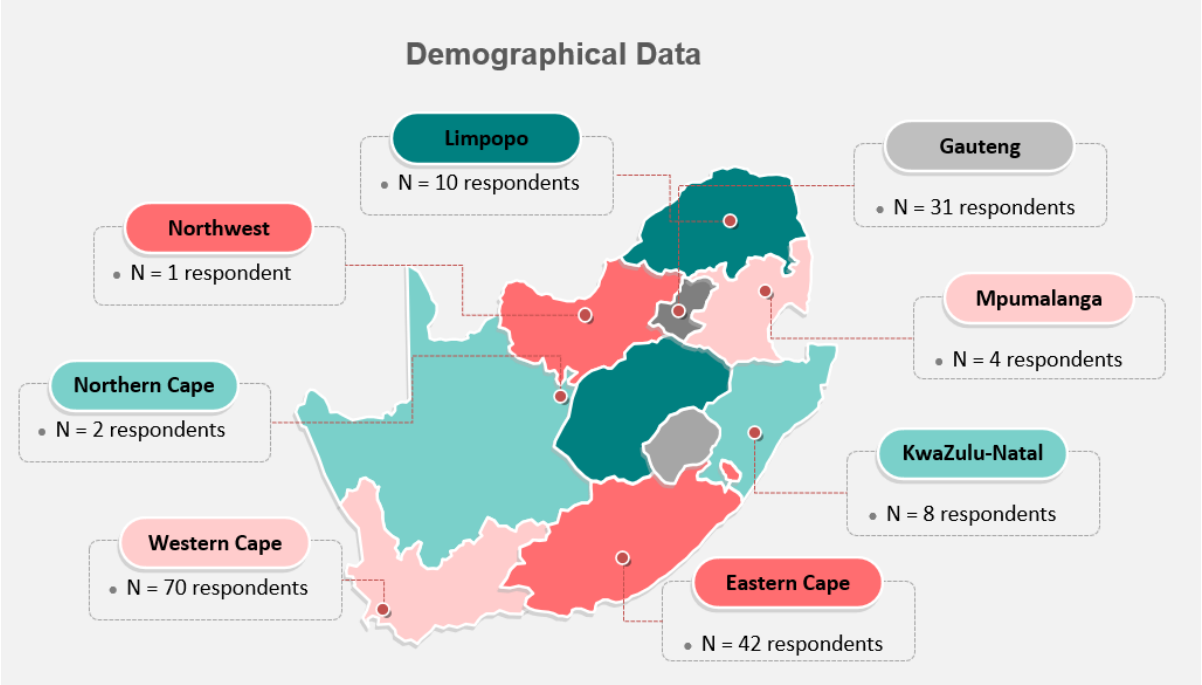


Figure 4.2: Provincial distribution of participants

4.2.2 Survey conducted

The researcher prepared a questionnaire as part of a more extensive survey to gather initial relevant information for the study (see Appendix E). It was designed to probe consumers' opinions about the available denim jeans in stores and online. The questions were designed according to the purpose of the survey which was to establish the user needs analysis.

4.2.2.1 User needs analysis

To establish user needs it is important to understand why people would want or need to use a specific product or service. Their motivations may seem obvious and could relate to simple necessity. The purpose of this survey was to focus on the users' actual needs for an item of clothing rather than the industry's perception of what they need. The researcher wanted to establish whether their physical, practical, financial, or emotional needs were being met through available products – jeans – in the South African market for young females. The survey was focused primarily on the size and fit of their current jeans.

In some instances, the answers were unclear and the total number of answers varied significantly as well. In addition, not all the participants that completed the survey answered every question. The results of the questions are as follows:

- Question one had 150 responses from the 171 respondents that answered the question, and these were divided into four categories as seen below.

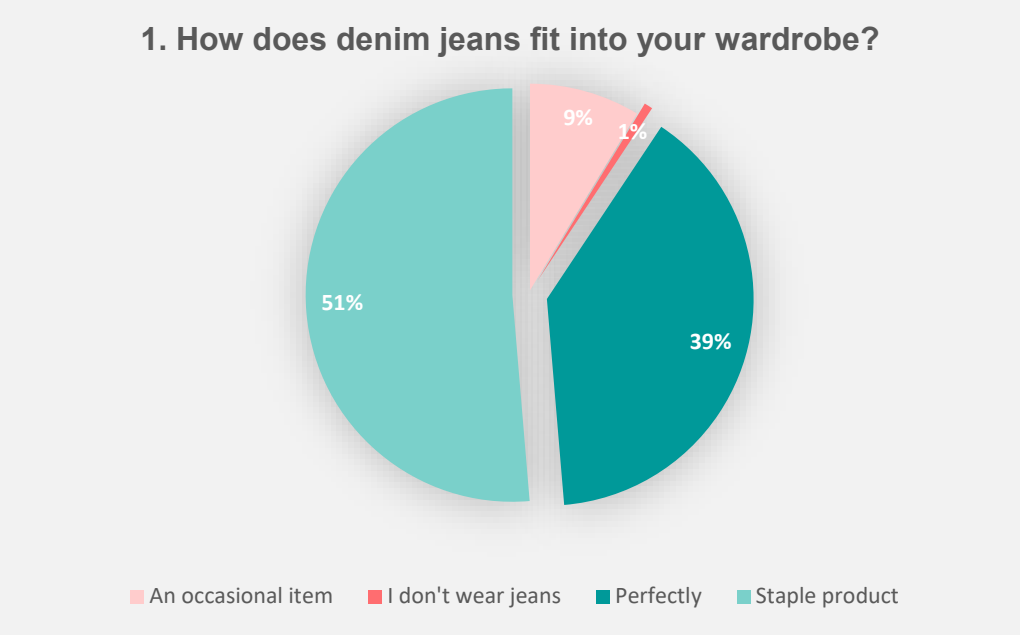


Figure 4.3: The importance of jeans in my wardrobe

2. Please give your opinion on the following in terms of your current preferred denim jeans

- Question two had 156 responses and was divided into four categories as seen below.

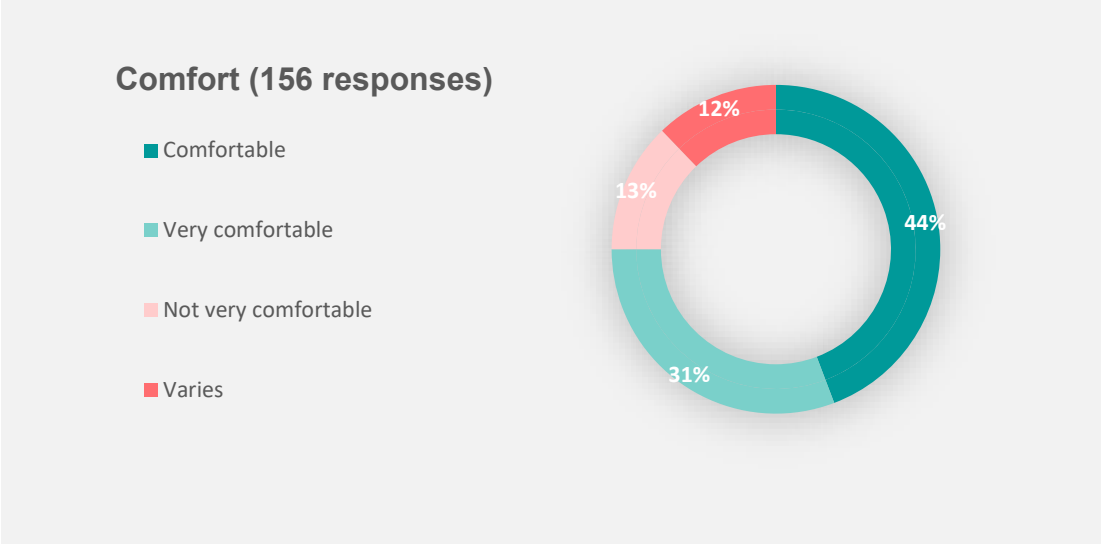


Figure 4.2: Current Jeans - Rated for Comfort

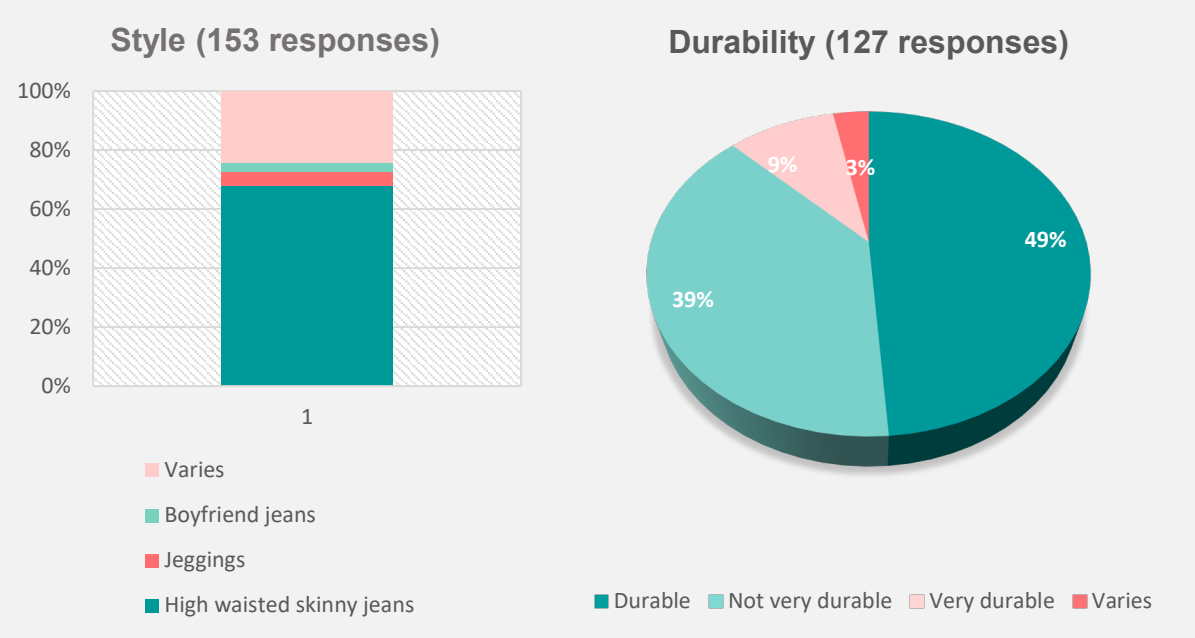


Figure 4.3: The results of question 2 (three categories only)

- The fourth category was related to the size of the jeans currently being worn by the participants and the purpose of this question was to gain information that was compared to the newly developed size prediction model that was developed for this study using Ridge

Regression Analysis (Lekata, 2022). The model could predict the actual jeans size of the wearer according to the anthropometric database obtained in this study.

- Question three had 164 responses and was divided into three (3) categories but with a variety of opinions.

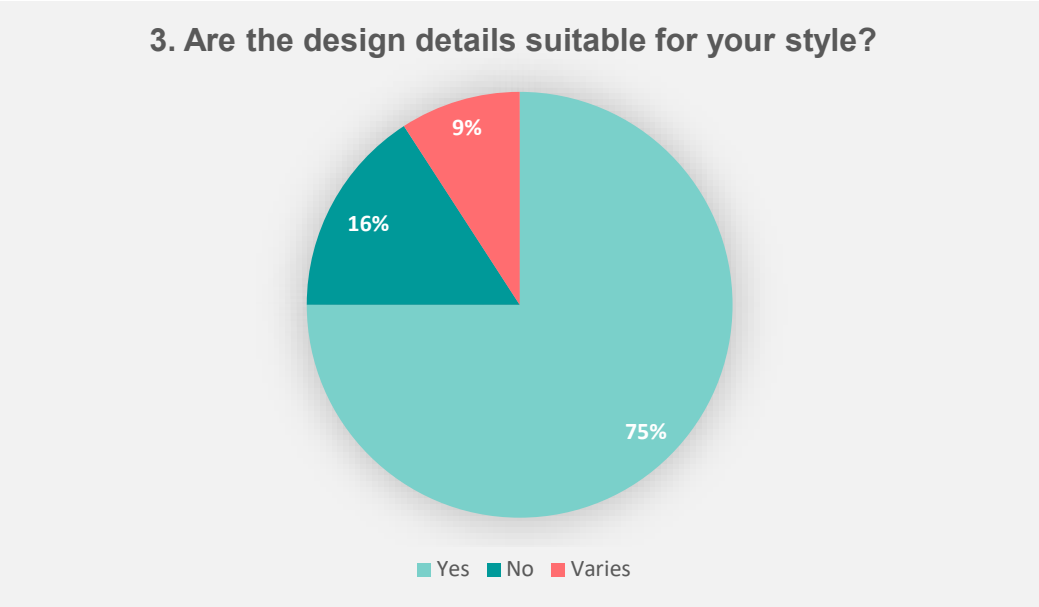


Figure 4.4: Question 3 - design details being suitable for style

4. **Could the currently available denim jeans be improved and how would the improvements be made?**

- Question four had 164 responses from the participants and this open-ended question delivered a wide range of suggestions and opinions. These suggestions were utilized in the product development section to improve the prototypes that were manufactured for fitting purposes.

- Question five had 156 responses and had the following results:

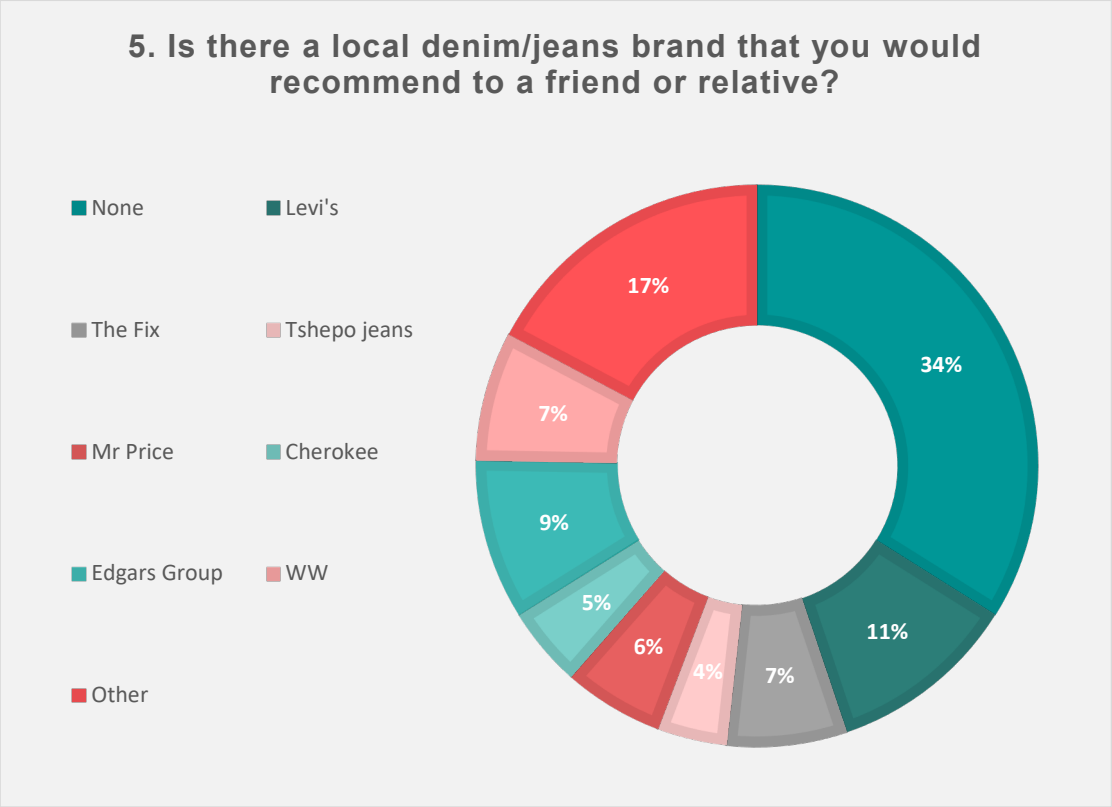


Figure 4.5: The results of question 5

- Question six had 155 responses and was divided into three categories as seen below.

Figure 4.8 The shopping experience of participants

The questionnaire was administered with the consent forms before the body scanning process to ensure that all the women being scanned had indeed completed the required documents. The researcher was present with the completion of the forms to provide guidance and answer possible questions from the participants.

4.3 Anthropometric data collection

This part of the study sought to address sub-objective 2, which aimed to collect accurate and comprehensive body measurement data of the specified target group, using 3D body scanning technology. The purpose of collecting this data was to create denim jean prototypes to test the fit of selected participants.

4.3.1 3D body scanning

The participants were invited to the Technology station at the Clothing and Textiles department on the Bellville campus for the body scanning process as this is where the 3D body scanner is housed. The available scanner used was a depth sensor body scanner from a company called Human Solutions in Germany (System administrator, 2015). The researcher prepared consent forms for the participants to complete if chosen to be scanned and this form can be viewed in Appendix A. The consent form contained important information about the body scanning process and was aimed to gather important information about the participants but also to ensure that the scanning process remained ethical.

The machine must be calibrated regularly to ensure that the 3D body scanner works efficiently and accurately. Calibration is a process in which a standard scale is used to adjust the scanner's software to its hardware to maintain high accuracy (thor3dscanner.com, n.d.).

The purpose of the body scanning was to collect accurate body measurements and shape information from the participants to create 2D patterns and prototypes. It was important for the participants to wear fitted gym clothes that were not so tight that they compressed the body, or to be scanned in their underwear. This ensured that accurate and authentic body dimension data was collected for the study. The body scanning process took approximately five minutes per individual. This included time for the participant to undress and the operator to conduct the actual scanning process. This would allow the researcher to conclude approximately fifty (50) scans during a working day including calibration time. The scanning was conducted intermittently over a period of 18 months from July 2018 until December 2019. As mentioned

previously, 252 women were recruited, but only (n=210) were selected for the body scanning process.

According to Gupta and Zakaria (2014), a total of 49 key body measurements should be collected for anthropometric surveys for clothing manufacturing purposes. This is based on the ISO 8559/1989 standard. This standard is a guide on anthropometric definitions for body measurements and was updated in 2017. For this study, because the list of selected measurements could be customised, 52 body dimensions were chosen because it is more comprehensive, and the template with the list of body allocations can be seen in Appendix F. The template was created in Microsoft Excel and one document was used for everyone's data. The collected data from all (n=210) scanned bodies were then combined in another Excel spreadsheet to ensure it is more efficient and could streamline the next step – which was to analyse the data statistically.

4.4 Statistical analysis of body measurement data

In 2014, Gupta and Zakaria compiled a list of sizing systems according to the dates these were developed by researchers globally. This list also consists of the methods and techniques that were used to develop these sizing systems, ranging from basic mathematical techniques such as statistical techniques, correlation coefficients, principal component analysis (PCA), and data mining techniques (Gupta & Zakaria, 2014). During the exploratory research, it became clear that expert statistical assistance would be required for this section, which was consequently outsourced to CPUT's Centre for Postgraduate Studies' analysis section. This part of the research aimed to answer sub-objective 3 which was to analyse the body scanning data collected, both statistically and visually.

4.4.1 Correlation analysis

Correlation analysis is a statistical method that is used to discover if there is a relationship between two variables/datasets, and how strong that relationship may be. This is useful to explore the relationship between independent and dependent variables and is mostly used in social science studies (Senthilnathan, 2019). This is discussed in detail in Chapter 2 because it is a means of selecting the primary and secondary dimensions for specific garment types.

This study is focused on jeans; therefore, all the measurements relating to the bottom part of the body were analysed to check whether they correlate with each other. A positive correlation indicates that both variables increase in tandem, whereas a negative correlation indicates that

when one variable drops, the other variable increases. Table 4.1 below shows the correlation between all the required variables (Lekata, 2022).

The correlation coefficient ranges from +1 to -1 and the measurement is *r.* If r=+1, then it shows a positive covariance, and if r=0, it means that there is no covariance. If r=-1, then it means that there is a negative covariance. In this regard, if r<0,5, then there is no relationship between the two variables; if 0,5<r<0,75, there is a mild relationship and if r>0.76, it indicates that there is a strong relationship between the two variables (Senthilnathan, 2019). From the table below, there is a very strong positive correlation of 0.991 between variables “O” and “N”. There is a very weak negative relationship between Variables “D” and “G” because “D” is a vertical measurement and “G” is a girth or horizontal measurement.

Table 4.1: Key for correlation

A:	Current jeans size	J: High hip girth
B:	Body height	K: Buttock girth
C:	Waist height	L: Side seam at waist R
D:	Crotch height	M: Thigh girth R horizontal
E:	Knee height	N: Knee girth R
F:	Bust chest girth horizontal	O: Upper knee girth R
G:	Crotch length	P: Lower knee girth R
H:	Waist girth	Q: Calf girth R
I:	Waist to buttock height R	R: Min leg girth R

Table 4.1: Correlation table (n=210)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
A	1	0.172	0.155	-0.02	0.128	0.242	0.485	0.512	0.214	0.573	0.601	0.199	0.578	0.535	0.541	0.533	0.532	0.434
B	0.172	1	0.971	0.891	0.942	-0.166	0.078	-0.024	0.606	0.004	0.036	0.964	-0.018	0.02	-0.024	0.003	-0.002	-0.013
C	0.155	0.971	1	0.949	0.977	-0.204	0.002	-0.094	0.605	-0.063	-0.038	0.99	-0.098	-0.062	-0.111	-0.081	-0.094	-0.099
D	-0.02	0.891	0.949	1	0.937	-0.298	-0.226	-0.34	0.522	-0.326	-0.313	0.922	-0.37	-0.334	-0.38	-0.35	-0.356	-0.342
E	0.128	0.942	0.977	0.937	1	-0.16	-0.03	-0.054	0.456	-0.056	-0.057	0.95	-0.127	-0.074	-0.133	-0.097	-0.113	-0.098
F	0.242	-0.166	-0.204	-0.298	-0.16	1	0.34	0.602	-0.292	0.572	0.53	-0.21	0.525	0.46	0.491	0.444	0.47	0.335
G	0.485	0.078	0.002	-0.226	-0.03	0.34	1	0.667	0.135	0.725	0.758	0.066	0.779	0.732	0.752	0.718	0.724	0.602
H	0.512	-0.024	-0.094	-0.34	-0.054	0.602	0.667	1	-0.23	0.977	0.918	-0.074	0.856	0.805	0.816	0.779	0.784	0.635
I	0.214	0.606	0.605	0.522	0.456	-0.292	0.135	-0.23	1	-0.077	0.052	0.68	0.075	0.107	0.089	0.125	0.101	0.131
J	0.573	0.004	-0.063	-0.326	-0.056	0.572	0.725	0.977	-0.077	1	0.977	-0.022	0.928	0.873	0.886	0.852	0.852	0.699
K	0.601	0.036	-0.038	-0.313	-0.057	0.53	0.758	0.918	0.052	0.977	1	0.017	0.975	0.922	0.938	0.908	0.909	0.764
L	0.199	0.964	0.99	0.922	0.95	-0.21	0.066	-0.074	0.68	-0.022	0.017	1	-0.036	0.001	-0.046	-0.016	-0.032	-0.039
M	0.578	-0.018	-0.098	-0.37	-0.127	0.525	0.779	0.856	0.075	0.928	0.975	-0.036	1	0.954	0.978	0.942	0.943	0.802
N	0.535	0.02	-0.062	-0.334	-0.074	0.46	0.732	0.805	0.107	0.873	0.922	0.001	0.954	1	0.991	0.993	0.98	0.917
O	0.541	-0.024	-0.111	-0.38	-0.133	0.491	0.752	0.816	0.089	0.886	0.938	-0.046	0.978	0.991	1	0.985	0.981	0.886
P	0.533	0.003	-0.081	-0.35	-0.097	0.444	0.718	0.779	0.125	0.852	0.908	-0.016	0.942	0.993	0.985	1	0.992	0.946
Q	0.532	-0.002	-0.094	-0.356	-0.113	0.47	0.724	0.784	0.101	0.852	0.909	-0.032	0.943	0.98	0.981	0.992	1	0.935
R	0.434	-0.013	-0.099	-0.342	-0.098	0.335	0.602	0.635	0.131	0.699	0.764	-0.039	0.802	0.917	0.886	0.946	0.935	1

Like the Correlation tables, below is the scatter symmetrical plot matrix. This is useful to visually look at the pairwise relationships from different perspectives. From the plot, we see that there is a positive linear relationship between Q and R, P and Q, O and P, etc.

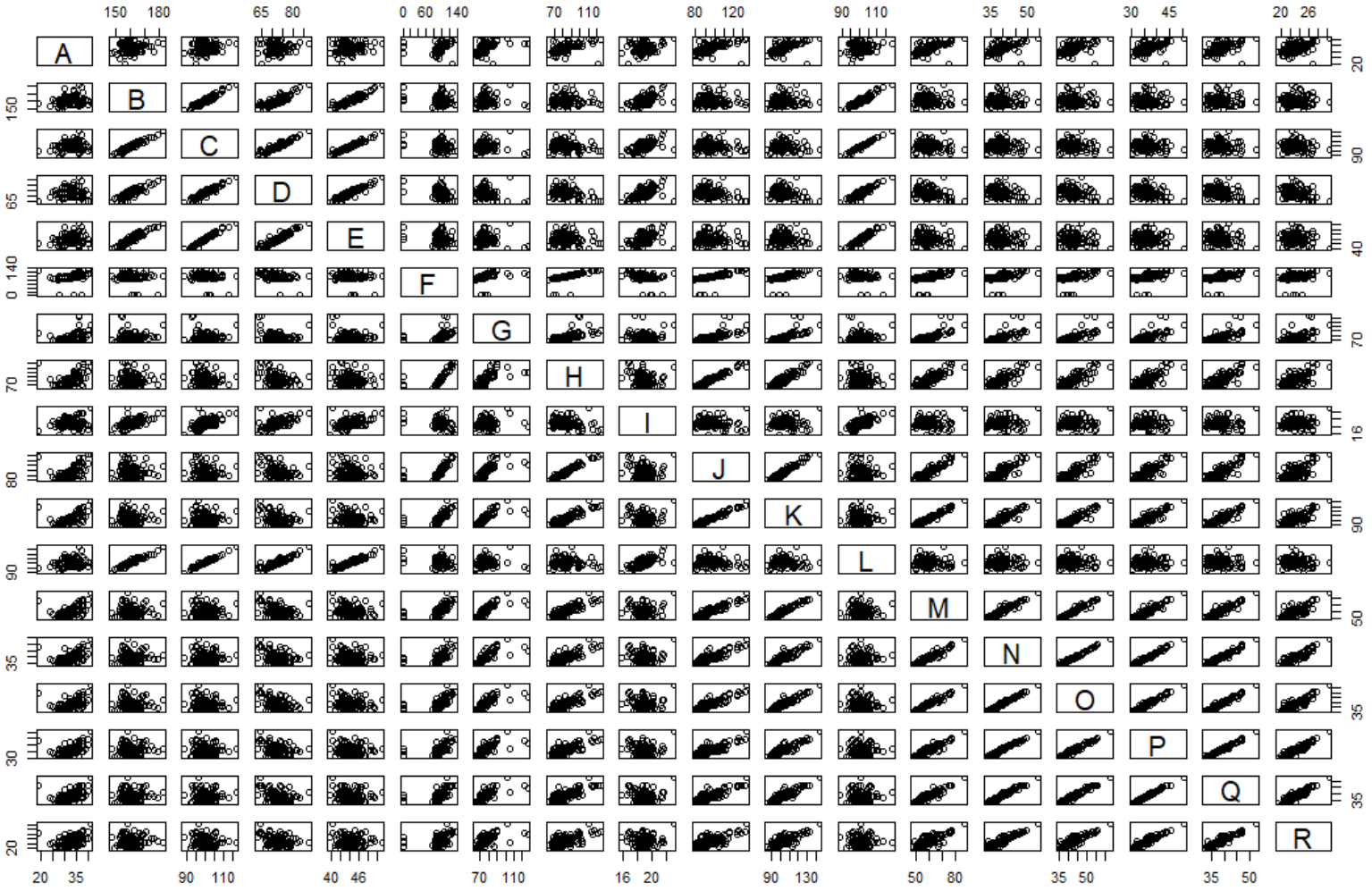


Figure 4.9: The scatter plots for the primary and secondary data

4.4.2 Linear regression approach

4.4.2.1 Relationship between jean size and other variables

In this research project, a linear regression model was used to assess the relationship between jean size and a wide range of independent variables. In addition, weighted lease square regression was employed to correct the effects of non-constant variance in error terms. Furthermore, ridge regression was used to correct the possibilities of inflated parameter estimates (Song *et al*., 2017).

According to the linear regression model summary, there are no significant predictors of jean size. Therefore, results were generated for a weighted linear regression model. According to this model, there are seven (7) parameters that are significantly different from zero: Knee Height, Waist Girth, Waist to Buttock Height R, High Hip girth, Buttock Girth, Lower Knee Girth R, and Min Leg Girth R. They are all significant at a 5% significance level. A positive coefficient of 4.557 for Knee Height implies that a unit increase in Knee Height increases jean size by 4.557 units; also, a positive increase of 1.48 for Buttock Girth coefficient means that a unit increase in Buttock Girth increases jeans sizes by 1.48 units. On the other hand, a negative coefficient of -1.592 for High Hip Girth means that a unit increase decreases the jean size by 1.592.

The model has a very high R-squared of 0.8817. It seems that 88.17% of the variation in the response variable, jean size, has been captured by the variation in the covariates. The high R-squared implies that the model fits the data well, and the model can probably be used for prediction purposes.

4.4.4 Ridge regression

To further improve regression results, a ridge regression with different lambda values was explored. Ridge regression was used to address the problem of multicollinearity in regression. This occurs when two or more independent variables are highly correlated to each other, such that they do not provide unique or independent information in the regression model (Xia & Istook, 2017). Multicollinearity can cause the coefficient estimates of the model to be unreliable and have high variance. The ridge regression estimates are seen in Tables 4.2 and 4.3 below.

Table 4.2: Model Parameter Estimates for all models used

Variable	Linear model	Weighted Liner Regression	Ridge (0.25) Regression	Ridge (0.05) Regression
Intercept	4.959494	20.83139	4.479757324	5.02164294
Body height	-0.262676	-0.27999	-0.280087977	-0.275381731

Waist height	-0.082772	-1.27007	0.038281445	-0.030793603
Crotch height	-0.459876	0.54594	-0.249975615	-0.40224499
Knee height	1.642002	4.55718	1.141433517	1.5031257
Bust/chest girth horizontal	-0.008269	-0.02221	-0.008508618	-0.008338853
Crotch length	0.008451	0.02568	0.013567831	0.01049868
Waist girth	-0.130392	0.86312	-0.044531087	-0.097616972
Waist to buttock height R	0.778556	2.61646	0.742724078	0.773968364
High hip girth	0.250195	-1.59274	0.110752151	0.191753229
Buttock girth	-0.051113	1.48024	0.07296897	0.004107489
Side seam at waist R	0.117887	-1.2068	0.07382968	0.098378363
Thigh girth R horizontal.	0.309549	-1.0507	0.188479325	0.251063419
Knee girth R	-0.487186	-2.49495	-0.463053412	-0.525139062
Upper knee girth R	-0.682364	1.28222	-0.349963568	-0.53626349
Lower knee girth R	0.626426	4.01061	0.357102626	0.56232883
Calf girth R	0.839978	-1.22536	0.578777655	0.751387516
Min leg girth R	-0.872326	-1.98509	-0.529487995	-0.775918398

Table 4.3: Model Evaluation Criterion

Model	MAE	MAPE	RMSE
Linear Regression	5.4019854%	5.79018%	0.082744
Weighted Linear Regression	7.7856241%	9.17010%	0.119805
Ridge Regression (0.25)	5.3745588%	5.76870%	0.082911
Ridge Regression (0.05)	5.3853238%	5.77643%	0.082763

Using MAE, the difference between the true values and predicted values is 5.50%, 7.786%, 5.375%, and 5.385% for linear regression, weighted linear regression, ridge (0.25), and ridge (0.05) respectively. According to the MAE value, ridge (0.25) is the best model since it has the lowest value of MAE. Similarly, MAPE values still indicate that ridge (0.25) is the best model for prediction purposes because it has the lowest values of MAPE. According to the results, Ridge (0.25) should be used for prediction purposes because it generally has the lowest values of MAE, MAPE, and RMSE (Lekata, 2022).

4.5 Creating body measurement size charts

This section of the chapter seeks to answer sub-objective 4 which was to create body measurement size charts through statistical analysis. This derived from the main objective which was to improve the overall fit of RTW apparel, especially jeans and pants for young

South African women. As mentioned before in this chapter, from the 52 body measurements collected from the participants, only the measurements relevant to the manufacturing of jeans or pants were considered for this study.

4.5.1 Selecting the control dimensions

The first part of the analysis was to establish the primary measurements needed to set up a size chart. Since there were 52 key body measurements collected from each participant, they needed to be categorised according to the target market. The primary measurements on a size chart indicate the designation on the body and will be used by manufacturers and consumers to identify a selected size (Gill, 2015). These measurements ought to be picked so they can portray the body shape of the person for whom an article of clothing is being made. According to the correlation results in Table 4.1, the horizontal control dimension will be the buttock girth. The waist, high hip, and hip/buttock girth are the secondary control dimensions as they correlate well with each other. The vertical control dimension is the height measurement. The other secondary dimensions used for this study relate to the bottom part of the body for the development of denim jeans prototypes. These dimensions can be seen in Table 4.4.

Table 4.4: Primary and secondary dimensions needed for the creation of a size chart

Primary dimensions	Secondary dimensions
Body height	Waist height
Bust girth	Crotch height
Waist girth	Knee height
Buttock girth	Crotch length
	Waist to hip/buttock height
	High hip girth
	Side seam at waist
	Thigh girth
	Knee girth
	Upper knee girth
	Lower knee girth
	Calf girth
	Ankle/leg girth

4.5.2 Calculating the size range and grading increments

In previous sizing studies, the size range was determined by establishing the minimum and maximum values for the primary control dimension (Muthambi, 2014; Makhanya, 2015). This was done with simpler statistical methods due to the small number of participants in their studies. For this study, however, ridge regression was used to determine the size range as well as the grade increments. This was done by extracting the anthropometric data for all the participants and calculating their actual size based on the collected database. The model was created by using this statistical method to predict the actual jeans size of each individual and this could be compared to their actual size as indicated on the completed questionnaire.

Once the actual size of the participant was determined, the size range was uncovered, and it became clear what the base or sample size is, what the spread of each size was and how many sizes were in all the categories. Below is a diagram with the results of the size spread from this anthropometric survey.

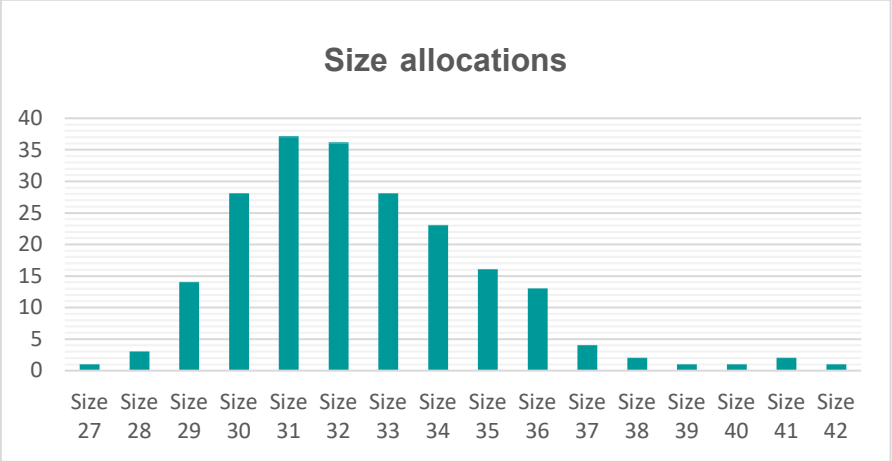


Figure 4.10: The number of sizes in the range (n=210)

After the size range was established, the various sizes were clustered, and the mean values for each size were calculated. This uncovered the dimensions for each size in the range but also the grade increments that would be used for grading between these sizes. These increments would be used for grade rule development as a basis for pattern drafting and garment construction. This is critical information for the development of the master pattern and the grading to the smaller and the bigger size patterns but also to identify the size breaks. The goal of this was to grade the newly developed patterns with these increments and compare these to the traditional increments used for grading.

4.6 Body shape analysis

Numerical evaluation parameters were used to identify the various body shapes objectively and the visual analysis could be more subjective in identifying the body shapes within the specified group of participants. The inherent ambiguity of body shape analysis makes visual analysis challenging and therefore, it must also be calculated by using a mathematical formula.

4.6.1 Body shape classification using the waist-to-hip ratio

Various techniques of classifying body shapes have been discussed in Chapter 2 and the researcher chose to employ the waist-to-hip ratio categorisation of participants. This was conducted using the subjects' bust, waist, high hip, and buttock girth measurements from the collected body scanning data. The total of (n=210) participants were scanned, and their waist-to-hip and hip-to-waist ratios were calculated. This was done by dividing the waist girth measurement by the hip girth measurement and the bust girth measurement by the waist girth measurement. The results can be seen in Figure 4.11.

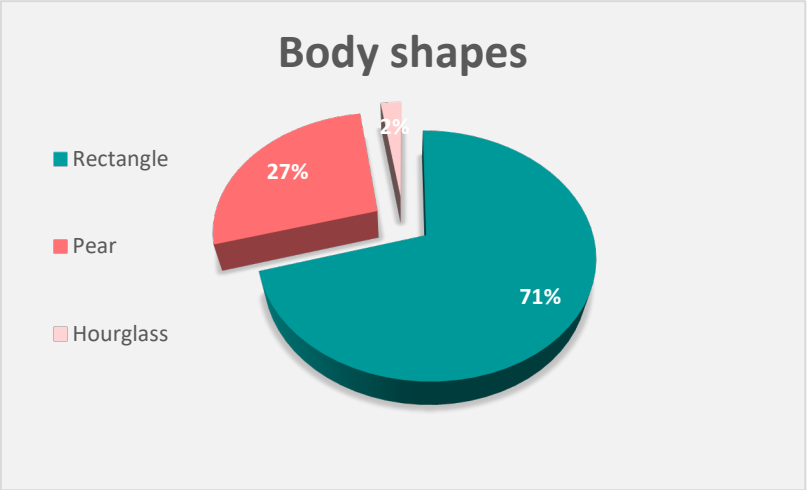


Figure 4.11. Body shape classifications (n=210)

4.6.2 Visual analysis of body shapes

To achieve the objective of visually analysing the body shapes, the next step was to revisit the anthropometric data. The body scanner used for the study was issued with a unique software package from the supplier and is installed on a computer specifically allocated for body scanning. The data could however be extracted and saved to an external storage device for further inspection on any other computer. Each participant's file contained a variety of information and data that is compatible with other more commonly used computer programs.

This enabled us to open the extracted data, stored as a PLY extension file, in Paint 3D for visual analysis as seen in Figure 4.12. Each participant's file needed to be opened, and inspected in Paint 3D, and screen images were taken of all the body data. The front views and lateral views were captured for further inspection.

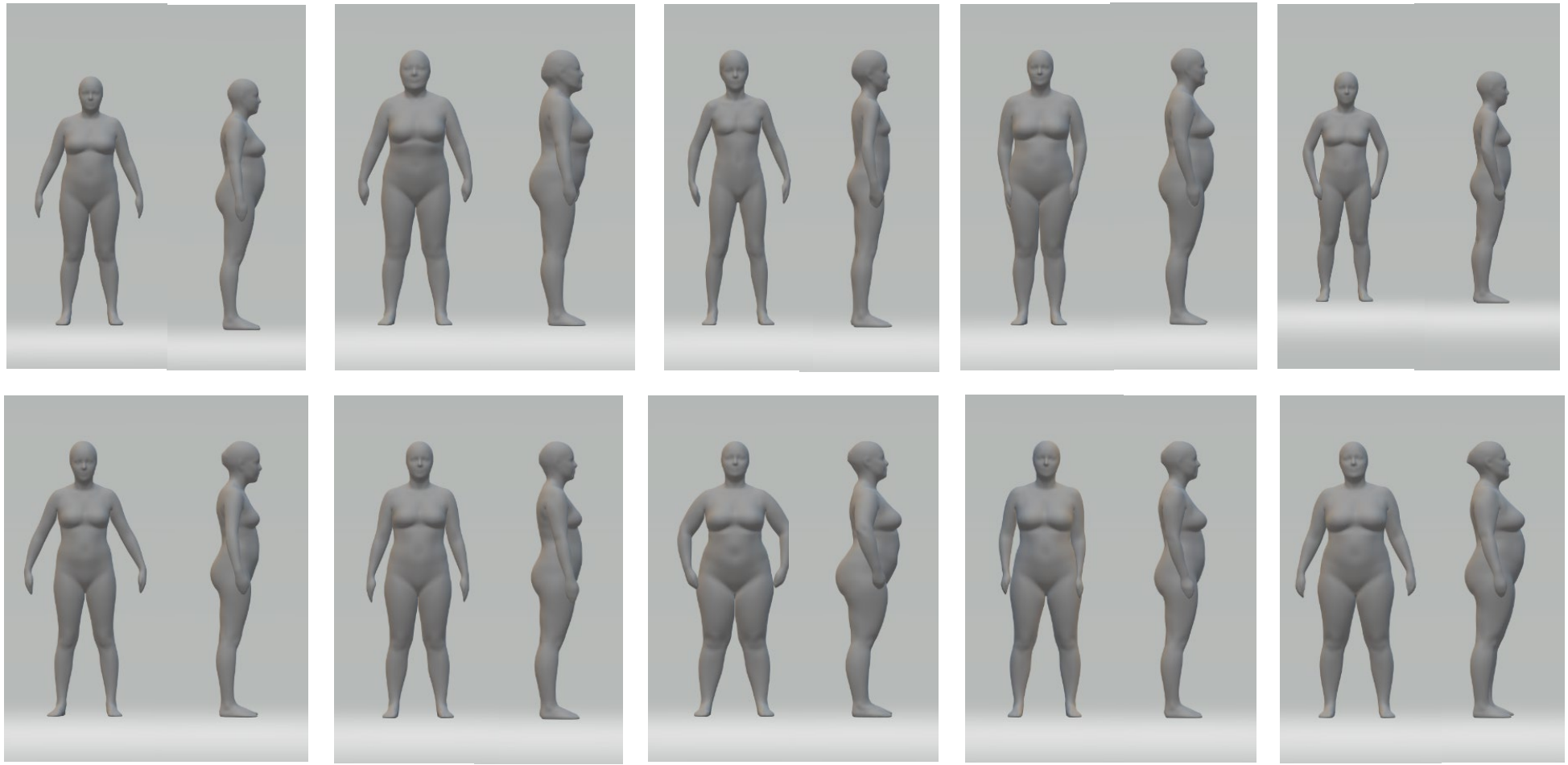


Figure 4.12: Front and lateral view images of participants' body scan data

Source: Windvogel (2022)

4.7 Product development of denim jeans

The next step in the research process was to test the newly developed sizing system by responding to sub-objective 5 which was to develop a pair of denim jeans that would fit them well, with the use of technology. For this purpose, the opinions given by the participants in survey question 4, were employed for the design style and details. Prototypes needed to be manufactured utilising both the traditional sizing system, which is currently still being used in the industry and the newly developed sizing system for comparative testing.

4.7.1 Fabric selection and testing

The selected denim was sent to the textile testing lab at the Technology Station in the Clothing and Textiles Technology Department of CPUT. The following tests were conducted:

1. The elasticity of the fabric (26.89%)
2. The modulus of the weft yarns only (0.297N/mm)
3. A solubility test to check the fabric composition (6% spandex, 72% cotton, and 22% polyester)
4. Dimensional stability to test the shrinkage of the fabric (warp = -0.5% and weft = 2%)
5. Seam slippage to determine the resistance to slippage of weft yarns over warp yarns, or warp yarns over weft yarns (Bantom, 2022).

The results of the test can be seen in Appendix G, a detailed discussion of which can be found in Chapter 5.

4.7.2 2D CAD Patternmaking

The first part of the product development stage was the 2D pattern construction. Gerber's 2D pattern design software, Accumark, was used for this purpose. This software was easily accessible to the researcher because the university subscribes to the licenses for the staff and students. The use of this patternmaking technology streamlined the process as a manually drafted pattern normally takes up to three times the amount of time to complete. This is also a more sustainable method of patternmaking as it minimises the wastage of paper and fabric.

A template or block for a basic 5-pocket high-waisted pair of jeans was drafted based on the instructions from the pattern book, *Patternmaking for fashion design* by Helen Joseph Armstrong (2014). The instructions for the draft pattern specify the ease needed

to ensure a properly fitting garment. The base size used was a size 32 according to the newly developed size chart. The first prototype pattern was exported from Accumark and virtually sewn in CLO3D to test the fit of the template pattern. This prototype was fitted on a virtually created avatar. A screenshot of the actual digital pattern can be seen below in Figure 4.13.

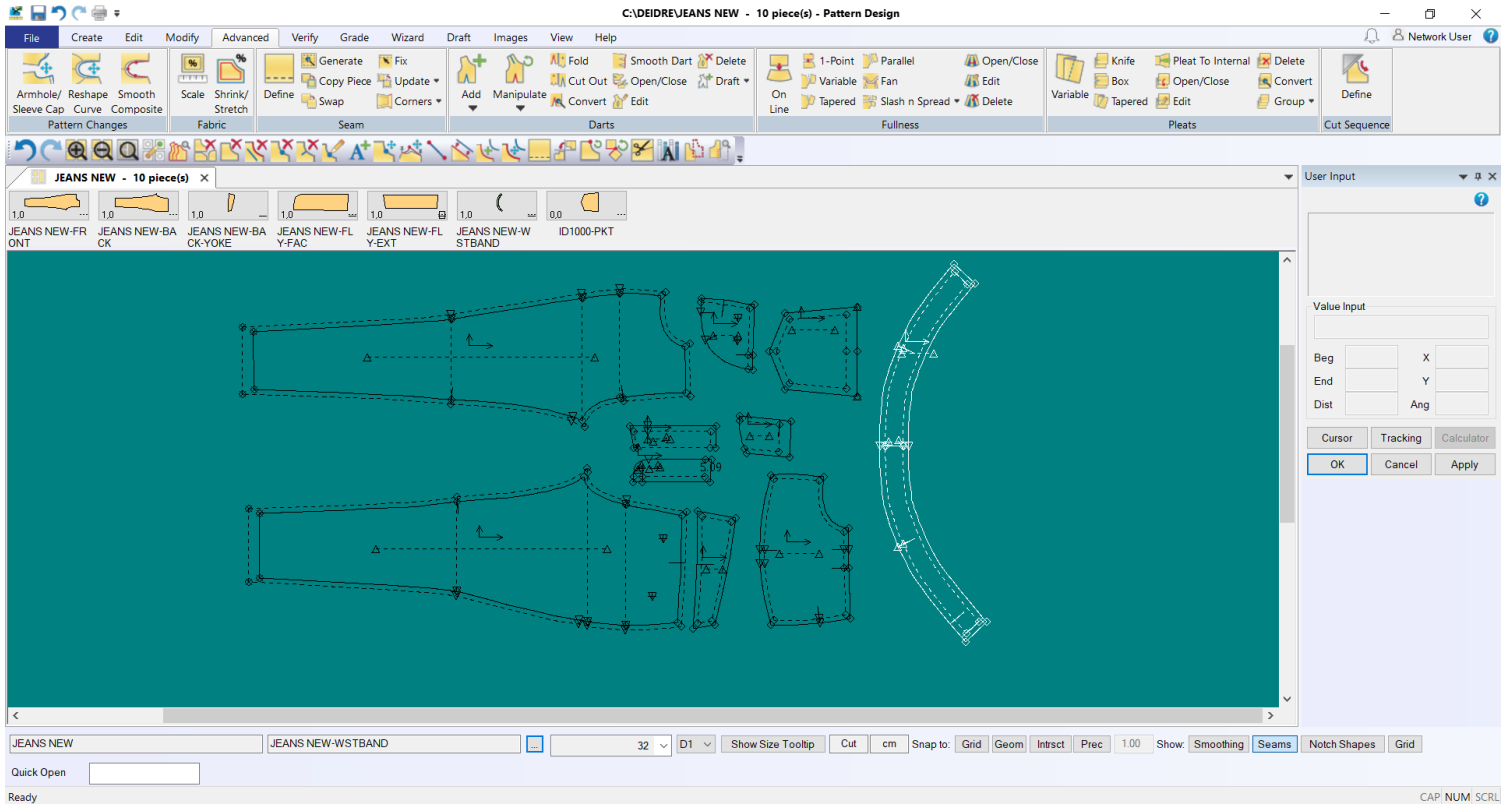


Figure 4.13: 2D CAD pattern of the 5-pocket high-waisted jeans block

Source: Windvogel (2022)

4.7.3 Pattern Grading

After the prototype was fitted and approved, the pattern was ready to be graded into the required sizes. This was also done using the Gerber Accumark (www.lectra.com) software and required very little time. The pattern was first graded using the traditional increments which was normally used to grade patterns. It was also graded using the new grading increments as calculated by the new sizing system. Both patterns were graded to have 9 sizes each as can be seen in the nested patterns in Figure 4.14.

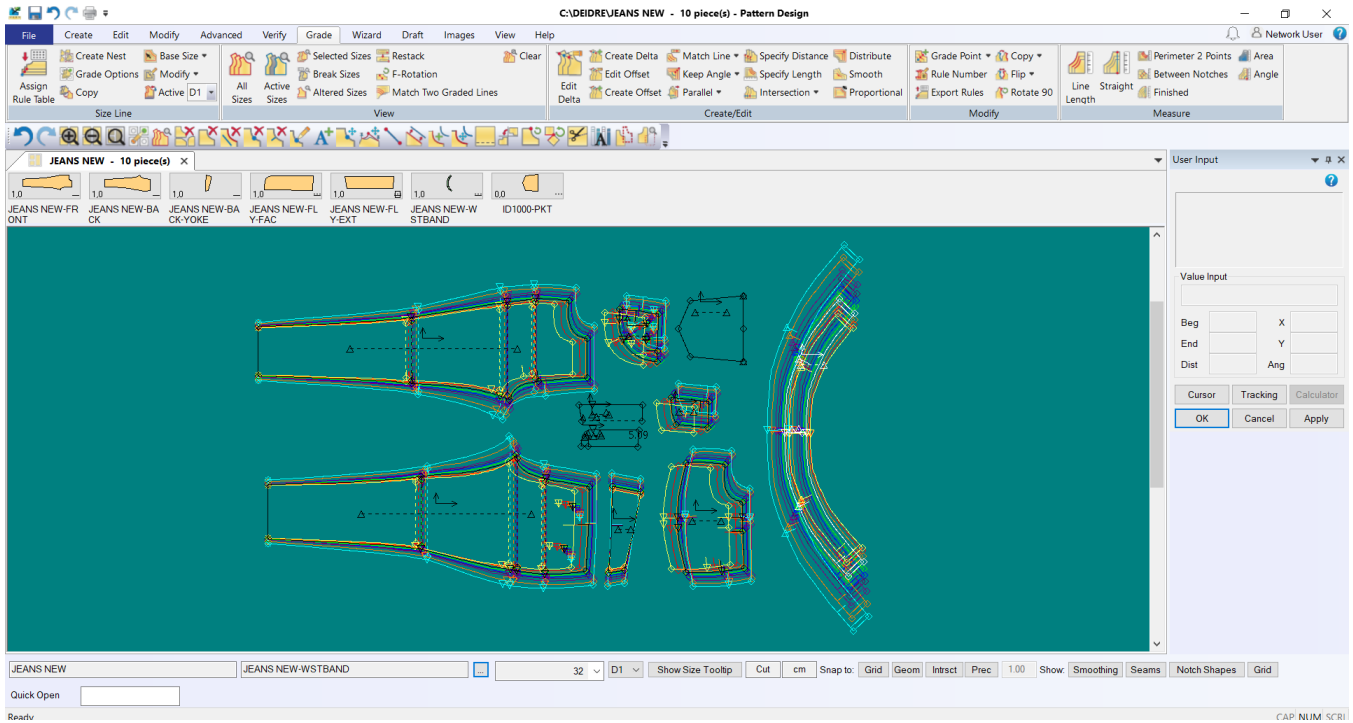


Figure 4.14: Graded nests of patterns in Accumark PDS

Source: Windvogel (2022)

4.7.4 Marker making

The ten (10) graded patterns on both sets of patterns were then transferred to a digital marker-making system for placement. For the computer to generate the markers, it requires information such as the width of the fabric, and the number of sizes needed from the set. The purpose of using this system is to ensure waste minimisation as the computer allows the operator to place the pattern pieces strategically within the width of the specified fabric. The marker for the patterns can be seen in Figure 4.15.

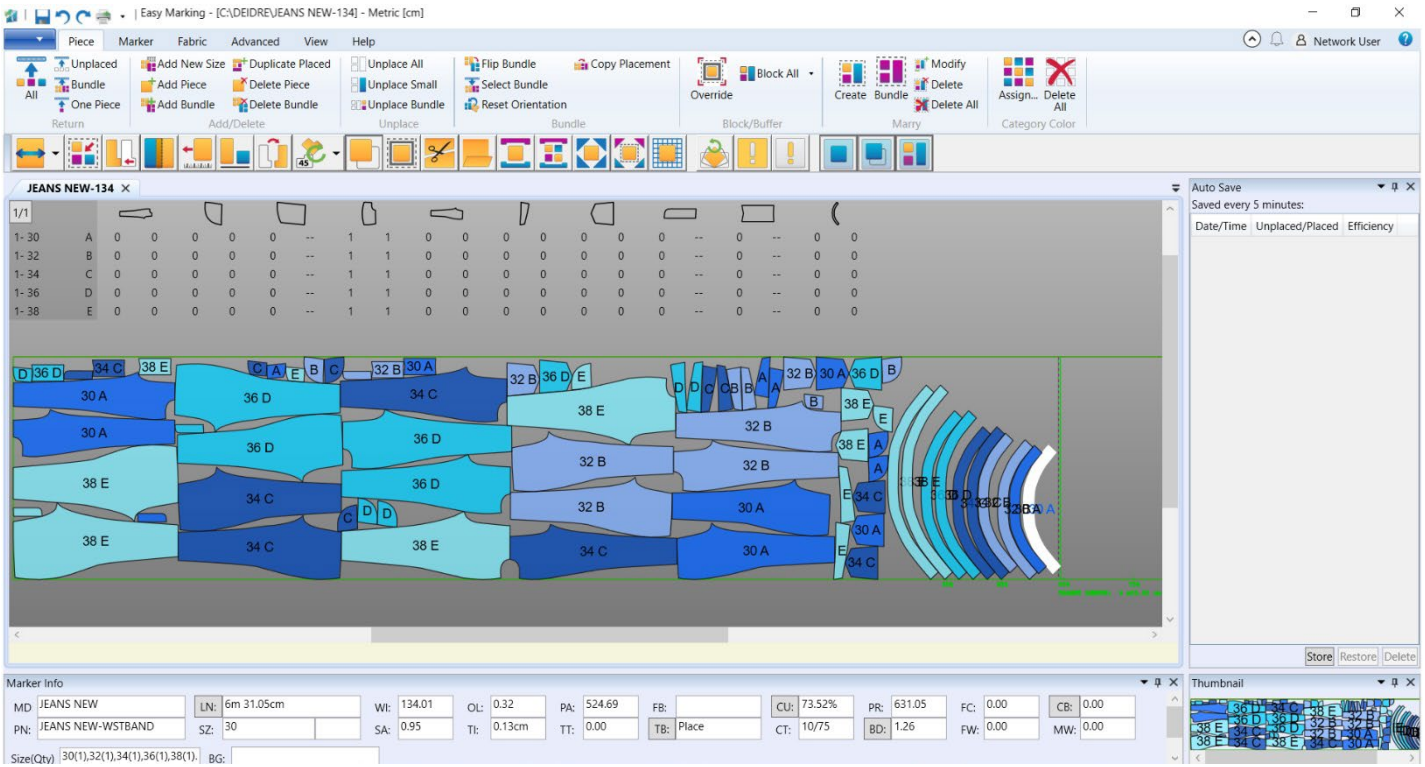


Figure 4.15: The marker with all sizes included

Source: Windvogel (2022)

4.7.5 Virtual prototyping

In response to sub-objective 6, to streamline the product development process and minimise waste, the basic jean block was sewn virtually to test the fit before grading it to the other required sizes. For this purpose, a virtual avatar was created as described in Chapter 3, in CLO3D based on the body measurements for a size 32 body. This enabled the fitting process of the basic block and the evaluation in terms of fit, thereof. Below is a screenshot of the avatar representing this study's sample population.

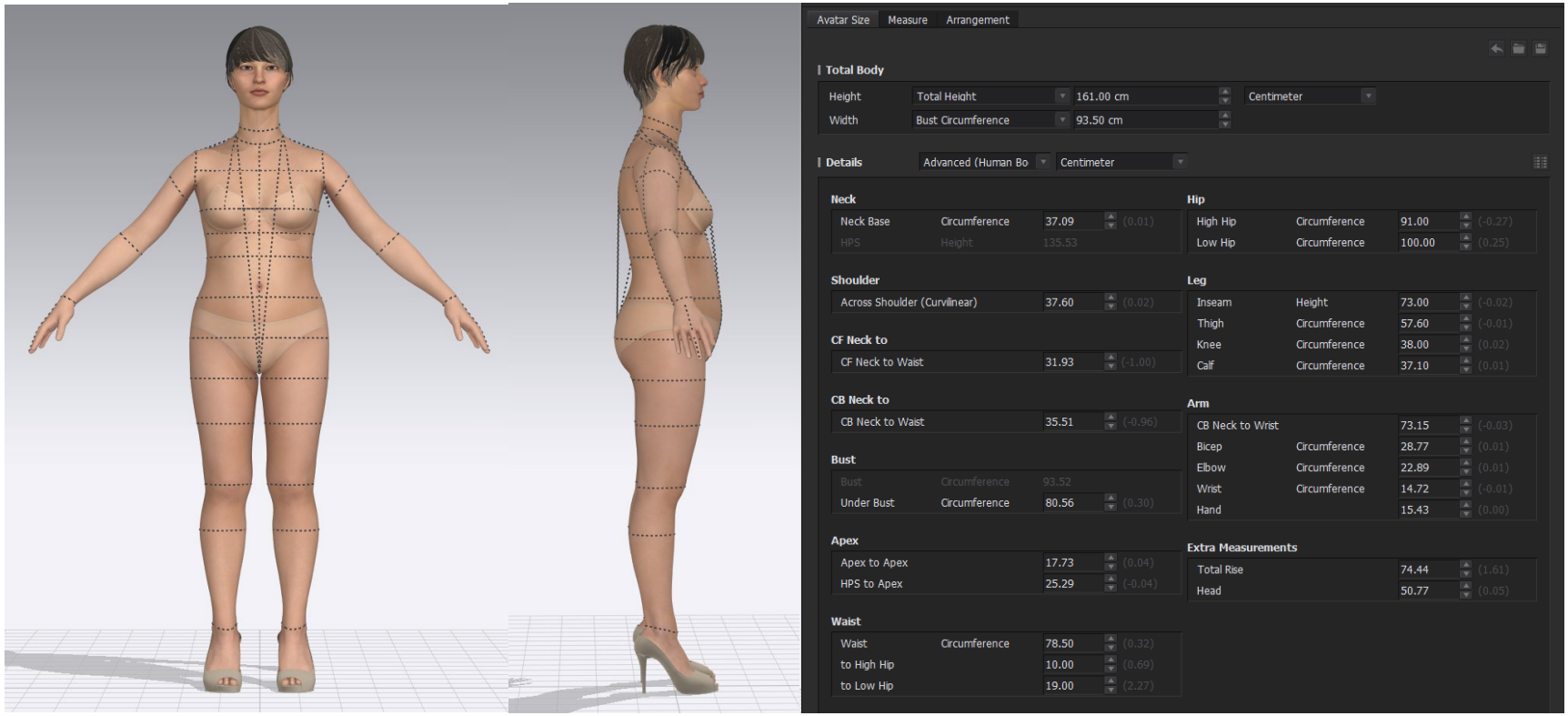


Figure 4.16: Front and lateral view images of the created avatar in CLO3D
Source: Windvogel (2022)

4.7.6 Physical sample making

It was decided by the researcher that both sets of test garments will be manufactured in sizes 30, 32, 34, 36, and 38. One copy of each selected size of the 10 patterns (both graded sets), was printed onto pattern paper for sample garments to be manufactured for fitting purposes. The fabric was laid up onto a cutting table based on the length of the digitally printed markers. The samples were cut and sewn by two (2) student assistants according to the standard construction methods of denim jeans. The samples created utilizing the traditional sizing were labelled A and the new proposed sizing was labelled B samples.

4.8 Evaluation of fit

Sub-objective 5 seeks to evaluate the fit of the denim jeans over various sizes by using both the traditional sizing systems and the newly developed system. The purpose of this is to do a comparative scale with the participants to answer sub-question 4, which is to investigate whether a more accurate body measurement size chart can enhance the fit and appearance of denim jeans.

Considering the complexity of evaluating fit on a body, two experts and colleagues from the Clothing and Textiles Technology Department were asked to assist the researcher in evaluating the visual fit of the jeans on the selected participants.

4.8.1 Feedback survey

A total of ten (10) student volunteers were selected randomly from the total pool of participants for fitting the manufactured prototypes. This was a convenience sample of participants that were on campus for practical subject classes. The purpose of this was to have one participant per size manufactured to be scrutinised and test their fit satisfaction. However, in some instances, more than one body was fitted per size to ascertain the fit of different body shapes. A questionnaire was issued to the participants to give their opinion on the fit of both pairs of jeans fitted.

4.8.2 Paired comparison scale

A paired comparison scale was used to ascertain the differences between the two pairs of jeans that each participant needed to fit. The survey consisted of nine (9) questions to gain feedback on the size, comfort, and fit of the jeans. The questionnaire can be seen in Appendix H. Below is a table with the results of the fitting session.

Table 4.5: The results of the fitting session

Participants	Current size	"Sample A" size (traditional sizing)	"Sample B" size (new proposed sizing)
Participant 1	30	30	30
Participant 2	30	30	30
Participant 3	32	32	32
Participant 4	34	34	32
Participant 5	34	34	32
Participant 6	36	36	34
Participant 7	36	38	36
Participant 8	38	38	36
Participant 9	40/42	None	36
Participant 10	40/42	None	38

Table 4.5 is a representation of the actual sizes of young women in South Africa. The newly developed size chart is based on a database of local females and gives a contrasting view on the current sizing system being utilised for RTW apparel. The table indicates the current size the participant wears when purchasing in local retail stores. The second column is the current sizing being used and is close to the current sizes being worn. The third column indicates the size worn within the new proposed sizing system. It can be seen that as the sizes grow bigger, the women cannot fit into the sizes or there are no sizes available for them to fit.

4.9 Concluding summary

Chapter 4 discussed the three stages of this research project as planned in the methodology in Chapter 3. The first part was the analysis of the gathered survey data from the participants and the statistical and visual analysis of the collected body scanning data. This was crucial information to assess whether it was possible to develop the body measurement size charts as discussed in sub-objective 4.

The second part was the product development of denim jeans with the use of CAD technologies to streamline the process, and part three was to review the fit of the newly developed jeans based on the collected data from the participants. This chapter concluded with the evaluation of fit based on objective expert opinions and important feedback from the participants and further developments will be discussed in Chapter 5.

CHAPTER 5

Data findings and interpretation

5.1 Introduction

This study's primary purpose was to generate suitable, authentic size charts for young South African women as a basis to improve the overall fit of garments, especially denim jeans. In Chapter 4 the sub-objectives were analysed, and the collected data results were presented. The process as set out in the methodology (see Chapter 3) section was followed to obtain the required relevant information. This data was analysed accordingly to confirm the research problem of this study.

The purpose of this chapter is to discuss and interpret the results obtained in the previous chapter in more detail. This chapter is also dedicated to forming a generalised picture and understanding of the raw research data. The feedback from the survey results is explored and the researcher clarifies how the information was used to improve the denim jeans development process. The statistical analysis results and their implications are described. The final section relates to the fitting of the newly developed patterns and samples and the feedback gained from the participants during a fitting of the newly proposed sizes and their brand of choice.

5.2 Survey feedback from participants

As stated in the previous chapter, the purpose of the survey was to understand the women's perspectives on the currently available jeans and whether their needs are being met in terms of the functional and aesthetic fit. This is in response to the second secondary question (see Chapter 1.5) which seeks to understand how local women feel about the availability and fit of denim jeans across the various brands and the aspects they experience as problematic.

5.2.1 User needs analysis

As discussed in Chapters 3 and 4, it was important to understand why women would want or need to use a specific product or service to be able to design a product that would leave them satisfied. This section sought to explore and respond to these needs.

Question 1: How do denim jeans fit into your wardrobe?

The results obtained in the survey, confirm that denim jeans are an everyday item for young females as an easy and comfortable staple. 51% of the participants reported that it is a staple in their wardrobe and 39% said that it fits perfectly well with the rest of the other items in their wardrobe.

Question 2: Please give your opinion on the following in terms of your current denim jeans.

i) **Comfort**

44% of the participants said that their jeans fit comfortably, but it is conditional on the fabric used and the brand they selected. From their answers, it is also clear that comfort is subjective and based on personal preference because some feel comfortable in jeans that fit tightly on their bodies, while some seek an easier and looser fit. This proves that Shin and Damhorst (2018) are correct when they state that fit assessment controlled by individuals wearing the pieces of clothing will in general be subjective, because two women with the same body measurements may have separate perspectives of how a garment fits their bodies.

ii) **Durability**

The durability of jeans is dependent on many factors: some of them refer to how often the jeans are worn, the quality of the fabric, how often it is washed, etc. In hindsight, the question was intended to investigate what the participants perceived as durable jeans, whether it was referring to the fabric or the garment itself, and the responses indicate that they perceived the fabric to be the main contributor to the durability of jeans. Most of the responses said that the durability is dependent on the fabric or that the jeans fade too quickly, or that the colour washes out too soon and all of these involve the denim fabric used for manufacturing.

iii) **Style**

As mentioned in Chapter 4.7.2, the style chosen for the prototypes is high-waisted skinny jeans. This is in response to the 68% of responses that stated they preferred this specific style of jeans. Some of the feedback was that this style is usually classic, easy-to-style jeans.

Question 3: Are the design details suitable for your style?

The responses to this question were diverse in the sense that there were many different opinions. Some students feel that the fit of the garment is more important than the design

details; others responded that they are satisfied with the options available. This section confirms that this specific age group focuses more on aesthetic fit rather than functional fit and that women with figure variations are excluded from many styles or designs and struggle to find RTW garments that fit properly (as stated in Chapter 2.4). This also answers the secondary question of how South African women feel about the currently available denim jeans.

Question 5: Is there a local denim/jeans brand that you would recommend to a friend or relative?

34% of the women feel that they would (or could) not recommend any brand to their friends or relatives. Levi's jeans are leading the pack with 11% of women saying that they would recommend the brand. As mentioned in Chapter 1, Levi's caters to different body shapes, and this has been confirmed by the feedback gained from the women.

Question 6: How would you describe your last shopping experience for a pair of jeans?

Since denim jeans are a staple in most young females' wardrobes, it is a garment that should be easy and comfortable to wear, without concerns about how others perceive them or their bodies (Rahman, 2015). The variety of denim jeans available to women has become so wide, however, that it is challenging to determine which style is most flattering for the individual body- and this is evident in the feedback received based on Question 6.

52% of the women in this study found it very stressful and frustrating to go jean-shopping due to several factors but the prevalent one was sizing issues. The fit was the dominant factor for the women when going shopping for jeans and many commented on the gaping waist, fabric that is not stretchy enough, and the high fashion jeans that were not available for their specific body shape.

5.3 Statistical analysis of anthropometric data

In response to Sub-question 3 in Chapter 1.5.2, which seeks to know how 3D technology can be utilised to generate/develop an improved measurement size chart, the gathered body scanning data were analysed statistically using various statistical methods (see Chapter 4.4). This part of the study had the intention to confirm whether the use of technology can be utilised in various stages of anthropometric studies to develop body measurement size charts. Microsoft Excel was used to analyse the correlation between variables, summarise the descriptive statistics, and develop the ridge regression model. The correlation results and the ridge regression model are discussed below in further detail.

5.3.1 Correlation results

In this quantitative section of the study, the researcher used correlation to denote linear associations between variables. As discussed in the previous chapter, this is useful to check whether the primary dimensions correlate well with the secondary dimensions. For this purpose, only the body dimensions relevant to this study were checked for correlation. The following were confirmed:

Key for the correlation results table

A:	Current jeans size	J:	High hip girth
B:	Body height	K:	Buttock girth
C:	Waist height	L:	Side seam at waist R
D:	Crotch height	M:	Thigh girth R horizontal
E:	Knee height	N:	Knee girth R
F:	Bust chest girth horizontal	O:	Upper knee girth R
G:	Crotch length	P:	Lower knee girth R
H:	Waist girth	Q:	Calf girth R
I:	Waist to buttock height R	R:	Min leg girth R

Table 5.1: The correlation status between various body parts

Body Part	Correlation status
1. Waist (H)	Has a strong correlation with the high hip girth (J) and the buttock girth (K) Has a mild correlation with the thigh girth (M), the knee girth (N), and the upper knee girth (O)
2. High Hip (J)	Has a strong correlation with the waist girth (H), the buttock girth (K), and the thigh girth (M) Has a mild correlation with the knee girth (N), the upper knee girth (O), the lower knee girth (P), and the calf girth (Q).
3. Buttock girth (K)	Has a strong correlation with the waist girth (H), the high hip girth (J), the thigh girth (M), the knee girth (N), the upper knee girth (O), the lower knee girth (P), and the calf girth (Q). Has a mild correlation with the crotch length (G), and the ankle girth (R)
4. Body Height (B)	Has a strong correlation with the waist height (C), the knee height (E), and the side seam length (L). Has a mild correlation with the crotch height (G), and the waist-to-buttock height (I)

Source: Windvogel (2022)

The table shows that these results from previous studies are correct in saying that both the girth measurements and the height measurements correlate well with each other.

5.4 Body measurement size chart development

The primary question of this study explored how a scientific body measurement size chart that uses 3D technology, can be developed for young South African women. A body measurement size chart was designed, using the processes as set out in the preceding chapter. The following headings constitute the interpretation of those processes and results in detail.

5.4.1 Size Range

Once the size allocations were done and plotted, it was decided that the size chart will only focus on a size range of 9 sizes. This was based on the total number of sizes that were identified from the regression model after it was calculated and clustered. The below table (Table 5.2) is an extract of the identified sizes and the total number of participants within.

Table 5.2: The identified sizes and their quantities

Size	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Quantity	**1**	**3**	**14**	**28**	**37**	**36**	**28**	**23**	**16**	**13**	**4**	**2**	**1**	**1**	**2**	**1**

Source: Windvogel (2022)

Due to the low quantity numbers of sizes 27, 28, 39, 40, 41 and 42, it was decided to exclude those sizes from the range. Sizes 37 and 38 were combined to form one size, which formed size 38. Size 32 became the base size as it is one of the most common sizes for young students' intent on appearance, but also because the fit model available was that size. The next step in the process was to establish the size increments.

5.4.2 Size/grade increments

Some errors were recorded when the recorded measurements seemed to be incorrect, such as when measurements were too big or too small in comparison with those of their peers. The highlighted increments caused concern because it was out of sequence. This implied that the body measurements for each participant needed to be inspected again to check for outliers. After the size range was established, the mean for each size was calculated and entered in the size chart in Excel as seen in Table 5.3.

Table 5.3: The calculated grade increments

	Height Range		155	158	160	161	162	161	162	161	162
	Girth measurements	Tolerance									
1	**Full waist**		71.5	73	**75**	78.5	86.5	86	94	101	109
	Increments		1.5	2	**0**	3.5	8	-0.5	8	7	8
2	**High hip**		**83**	**85.5**	**88**	**92**	**99.1**	**100.3**	**107.3**	**114**	**121.7**
	Increments		2.5	2.5	**0**	4	7.1	1.2	7	6.7	7.7
3	**Buttocks**		**91**	**93.5**	**96**	**100**	**105.2**	**108.3**	**112.5**	**118.8**	**126**
	Increments		2.5	2.5	**0**	4	5.2	3.1	4.2	6.3	7.2
4	**Thigh**		**51.2**	**54.2**	**55**	**57.6**	**60.6**	**63.6**	**65.8**	**70**	**75**
	Increments		3	0.8	**0**	2.6	3	3	2.2	4.2	5
5	**Knee**		**35**	**36.5**	**37**	**38**	**39.8**	**41.2**	**42.5**	**43.7**	**47.1**
	Increments		1.5	0.5	**0**	1	1.8	1.4	1.3	1.2	3.4
6	**Upper knee**		**37**	**39.4**	**39.6**	**41.4**	**43.6**	**45.6**	**47.1**	**49.5**	**53.5**
	Increments		2.4	0.2	**0**	1.8	2.2	2	1.5	2.4	4
7	**Lower knee**		**32**	**33.4**	**33.7**	**35**	**36.6**	**38**	**39**	**40.3**	**43.4**
	Increments		1.4	0.3	**0**	1.3	1.6	1.4	1	1.3	3.1
8	**Calf**		**33.7**	**35.5**	**35.8**	**37.1**	**38.8**	**40.4**	**41.2**	**43.1**	**45.7**
	Increments		1.8	0.3	**0**	1.3	1.7	1.6	0.8	1.9	2.6
9	**Ankle**		**21**	**21.7**	**22**	**22.5**	**23.2**	**24**	**24.3**	**24.7**	**26.3**
	Increments		0.7	0.3	**0**	0.5	0.7	0.8	0.3	0.4	1.6
	Vertical measurements		**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**38**
10	**Waist height**		**95.9**	**97.6**	**99.7**	**100.4**	**101.1**	**100.4**	**100.9**	**99.2**	**100.7**
	Increments		1.7	2.1	**0**	0.7	0.7	-0.7	0.5	-1.7	1.5
11	**Crotch height**		**70.5**	**71.6**	**73.2**	**73**	**73.5**	**72.7**	**72.3**	**70.5**	**70.5**
	Increments		1.1	1.6	**0**	-0.2	0.5	-0.8	-0.4	-1.8	0
12	**Knee height**		**42.3**	**43**	**44**	**44**	**44.7**	**44.3**	**44.6**	**43.7**	**44.7**
	Increments		0.7	1	**0**	0	0.7	-0.4	0.3	-0.9	1
13	**Waist to hip**		**18**	**18.4**	**18.8**	**19**	**18.8**	**19**	**19**	**19**	**18.6**
	Increments		0.4	0.4	0	0.2	-0.2	0.2	0	0	-0.4
14	**Side seam @ waist**		**96.6**	**98.3**	**100.5**	**100.9**	**102**	**101.4**	**101.8**	**100.5**	**101.5**
	Increments		1.7	2.2	0	0.4	1.1	-0.6	0.4	-1.3	1

Source: Windvogel (2022)

5.4.3 Outliers

The recorded errors were due to outliers that were detected in the data set. Outliers are data points that deviate abnormally from other values in a dataset (Hernández *et al.*, 2018). This was detected during the analysis stage and with the plotting of the data in the size chart when the growth patterns were not consistent on certain parts of the body.

5.4.3.1 Weighted regression diagnostics plots

To ascertain that linear regression assumptions are met and to explore if the model could be improved, the values were plotted diagnostically as seen in Figure 5.1 below.

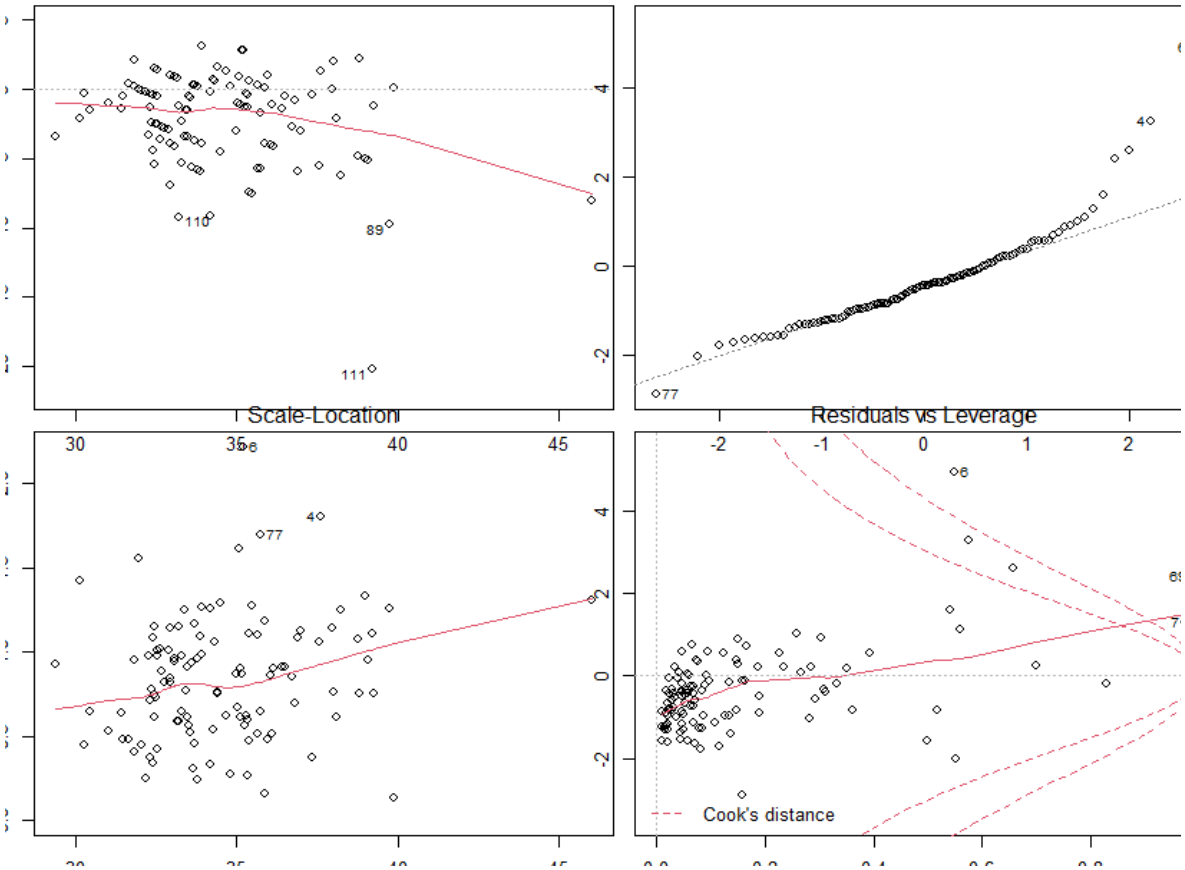


Figure 5.6: Weighted regression diagnostic plots

Source: Windvogel (2022)

The fitted values vs residuals plot appeared correct with a seemingly random spread but from the QQ-plot look like the plotted values do not follow the normal line in the tails. A normality hypothesis test should be done to test normality (Lekata, 2022).

The Scale-Location plot shows whether residuals are spread equally along the ranges of predictors. This is a check for the assumption of equal variance (homoscedasticity). It is constructive when you see a horizontal line with equally (randomly) spread points. But it is not the case with this plot. Points with high leverage were influential, hence deleting them would change the model significantly. Cook's distance became relevant, which measures the effect of deleting a point on the combined parameter vector. Cook's distance is here presented by the dotted red line, and points outside the dotted line have a high influence. Furthermore, outlier detection techniques indicated that there are plenty of outliers in the dataset, and case

deletion diagnostics should be employed in future research. According to the plots below in Figure 5.2, observations 6,4, 110, and 111 are outliers (Windvogel, 2022).

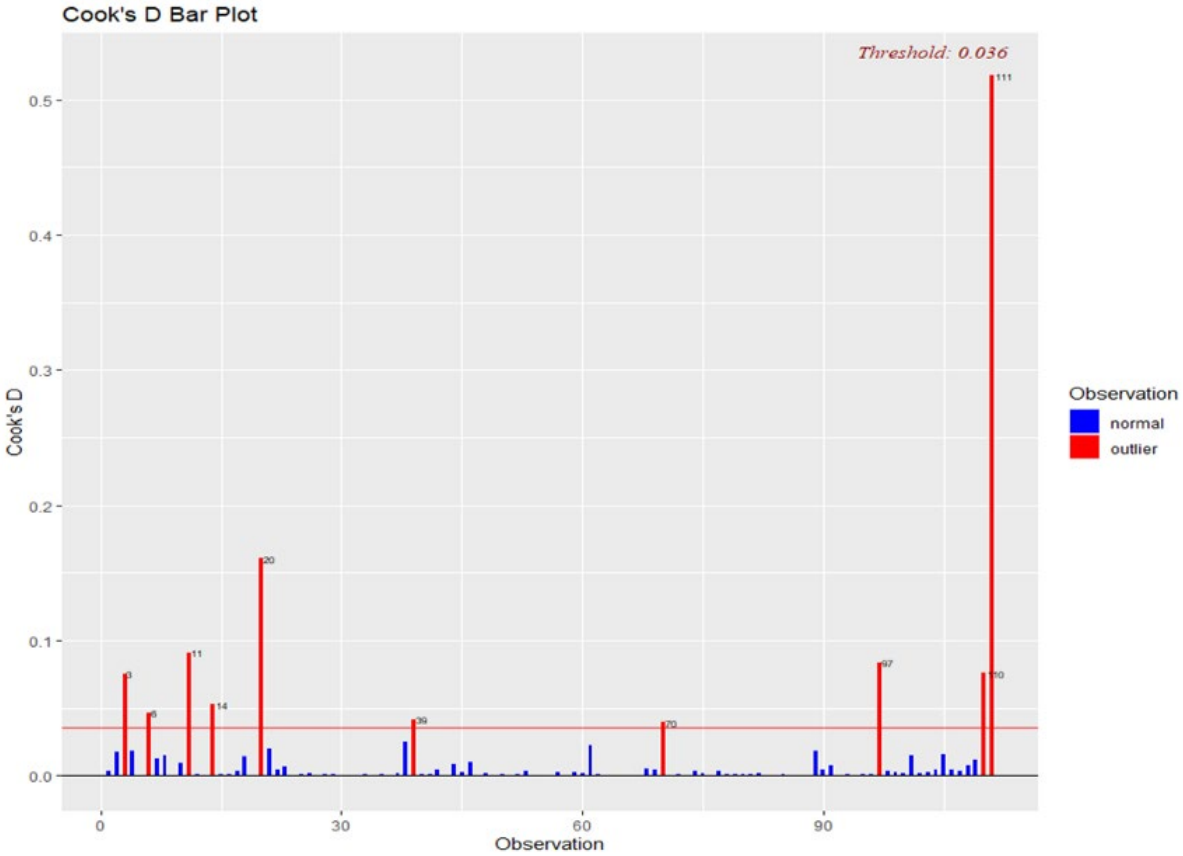


Figure 5.2: Outliers in the regression results

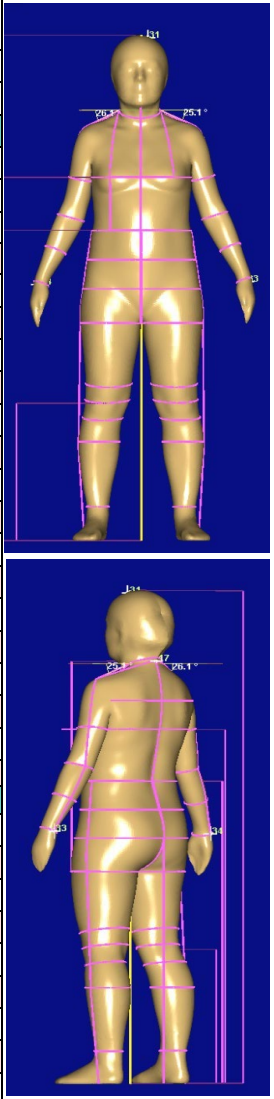
Source: Lekata (2022)

Once the outliers were identified, they were removed from the dataset. This delivered another size chart that can be seen in Table 5.4. Initially, it was assumed that there would be more than one size chart or a size chart for each body shape, but this assumption has not been realised.

Statistical methods confirm that the variables in this study prove to be the significant dimensions for the creation of a working size chart. From other studies (Chan, 2014; Zakaria, 2014; Gupta & Zakaria, 2014; Xia & Istook, 2017), the key dimensions acknowledged were also found to be significant in this study. This is discussed in more detail in Chapter 2.3.1.2.

Table 5.4: Body measurement size chart (n=210)

Body measurement chart											
	Measurements	Grade	Size Range								
			29	30	31	32	33	34	35	36	38
	Quantity		14	28	37	36	27	23	16	13	6
	Height Range		154.5	158	160	161	161	161	161	162.5	163
	Girth measurements	Tolerance									
1	Full waist		69.8	71.7	75	78.5	82.7	86.3	90.3	96	103.7
			1.9	3.3	3.5	0	4.2	3.6	4	5.7	7.7
2	High hip		81.5	84	88	91	96.1	100.5	104.3	110.3	121
			2.5	4	3	3	5.1	4.4	3.8	6	10.7
3	Buttocks		89	92.6	96	100	104	108.2	111	116.6	125.8
			3.6	3.4	4	4	4	4.2	2.8	5.6	9.2
4	Thigh		50.2	52.7	55	57.6	60.3	63.4	65.1	69	75
			2.5	2.3	2.6	2.6	2.7	3.1	1.7	3.9	6
5	Knee		35	35.7	37	38	39.4	41.2	42.1	43	47.1
			0.7	1.3	1	1	1.4	1.8	0.9	0.9	4.1
6	Upper knee		37	38.2	39.6	41.4	43.2	45.4	46.5	48.5	53.5
			1.2	1.4	1.8	1.8	1.8	2.2	1.1	2	5
7	Lower knee		32.2	32.8	33.7	35	36.2	38	38.7	39.7	43.4
			0.6	0.9	1.3	1.3	1.2	1.8	0.7	1	3.7
8	Calf		34.1	34.8	35.8	37.1	38.4	40.3	41	42.3	45.7
			0.7	1	1.3	1.3	1.3	1.9	0.7	1.3	3.4
9	Ankle		21.5	21.5	22	22.5	23	24	24.1	24.3	26.3
			0	0.5	0.5	0.5	0.5	1	0.1	0.2	2
	Vertical measurements		29	30	31	32	33	34	35	36	38
10	Waist height		95.9	98	99.7	100.4	100.7	100.7	101	101.8	102
			2.1	1.7	0.7	0.7	0.3	0	0.3	0.8	0.2
11	Crotch height		70.5	72	73	73	73	73	72.7	73.2	72
			1.5	1	0	0	0	0	-0.3	0.5	-1.2
12	Knee height		42.3	43.2	44	44	44.4	44.5	44.5	44.8	45.4
			0.9	0.8	0	0	0.4	0.1	0	0.3	0.6
13	Waist to hip		18	18.5	18.8	19	19	19	19.4	19.5	19
			0.5	0.3	0.2	0.2	0	0	0.4	0.1	-0.5
14	Side seam @ waist		96.5	98.7	100.5	100.9	101.8	101.8	102	103.2	102.6



Source: Windvogel (2022)

5.5 Body shape analysis

Previous South African studies (Makhanya, 2012; Muthambi, 2012; Makhanya *et al.*, 2014; Sekhotye, 2016; Ola-Afolayan *et al*., 2021) focused specifically on the pear-shaped body as they state that more than 60% of South African women have triangular-shaped bodies. In this study, using the waist-to-hip ratio calculation for the body shape analysis, it has been found that 71% of the participants' body shape is rectangular, 27% pear/triangular shape, and only 2% hourglass shape. Participant's bust, waist, high hip, and buttock measurements were considered to achieve these results. This is also evident in the visual analysis of the body shapes of the 210 scanned body images. Therefore, the most meaningful approach was to design only one generic pattern that could fit a variety of body shapes.

5.6 Product development

After the size chart was constructed, the jeans themselves could be developed for fit testing and analysis. It was not only critical to have the measurements for development but also the knowledge of ergonomics relating to the fit of jeans. In the pattern book that was used to create the jeans block pattern, Helen Joseph-Armstrong (2014) explains the range of functions and movements that the legs of individuals execute, such as walking, sitting, bending and squatting. She also gives instructions on the adjustment of patterns to create a comfortable garment.

In the illustration below Joseph-Armstrong (2014:660) demonstrates how the pattern can be adapted for this purpose as seen in Figure 5.3 below. This knowledge, together with the correct fabric, the feedback from the experts' visual analysis, and the feedback from the participants would determine whether the study answers the research questions and achieves the objectives.

Figure 5.7: The leg relative to the pant

Source: Joseph-Armstrong (2014: 660)

5.6.1 The connection between fit and design

Survey question no. 4 asked the participants whether they thought that the fit, appearance and sizing of their currently available jeans (the personal brand that they wear) could be enhanced, and if so, what their suggestions were to materialise this ideal. Most of the women wanted a better-quality fit in terms of aesthetics. Taking their opinions into consideration, the following was decided with regard to the creation of the ideal pair of jeans:

Table 5.5: Design considerations for the creation of the denim jean samples

Participants' complaints	Changes and fit considerations
1. Waist gaping	High-rise waisted style Curved waistband
2. A curvier fit around the buttock and thigh areas	Sculpting the pattern in those areas according to the size chart measurements
3. More durable fabric	The fabric should have minimal stretch and recovery loss to reduce sagging over time.

4. Leg length	Different leg lengths within the same fit of jeans .
5. Aesthetically flattering fit	Pockets: Back pockets must be the correct size and placed correctly for a more flattering appeal. Front pockets must not gape and be too bulky The front pocket lining must not be visible

Source: Windvogel (2022)

5.6.2 Fabric testing

As discussed in Chapter 4, various tests were conducted on the denim fabric to ensure that the properties were adequate for the intended end use. The same selected denim fabric was used for both sets of jean prototypes that needed to be made up. The clarification of the test results is as follows:

i) **The elasticity of the fabric (26.89%).** Elasticity or stretch is the material's ability to return to its original state – size and shape – after being exposed to a forced load (Newton Force). One of the most crucial aspects of body movement comfort is how a fabric stretches, and the stretch behaviour is tested in the weft direction (Akter *et al.*, 2021). Bedez Ute (2018), advises that the elasticity should be between 10-35% for denim fabric.

ii) **The modulus of the weft yarns only (0.297N/mm)**. Elastic modulus is the measurement of a material's elasticity i.e., a fabric or garment's resistance to deformation. Modulus is defined by Young's Modulus (Britannica, 2006), which is the slope of the linear part of the stress-strain curve for material under tension or compression. The higher the elastic modulus, the more resistant the composite material is to deformation within the elastic range (Bantom, 2022).

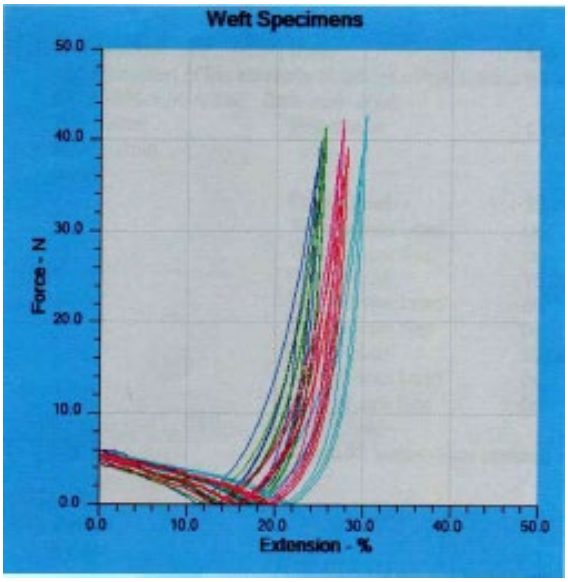


Figure 5.8: The results of the modulus of the weft yarns

Source: Bantom (2022)

iii) **A solubility test to check the fabric composition (6% spandex, 72% cotton, and 22% polyester).** Fibre composition is the weight of each fibre by percentage making up the fabric i.e., 60% polyester and 40% cotton. This is determined by quantitative chemical analysis to establish the fabric or garment's behaviour and suitability for product end-use (Bantom, 2022).

iv) **Dimensional stability to test the shrinkage of the fabric (warp = -0.5% and weft = 2%).** Dimensional stability is a linear measurement (warp and weft direction) to determine the stretch and shrinkage of a fabric or garment (Bantom, 2022).

v) **Seam slippage to determine the resistance to slippage of weft yarns over warp yarns, or warp yarns over weft yarns.** Seam slippage is a condition where the seam of a sewn garment or fabric opens under force. The seam opening may close when the force is removed or the fabric could break at the seam due to yarn breakage in the fabric and yarns slipping through the seam, or when the sewing thread breaks due to the force applied (Bantom, 2022).

During the mass manufacturing of garments, shrinkage allowance will be added to the pattern, and the manufactured garments are then sent to the laundry for washing. It was decided that the fabric required for the ten (10) samples was sent to the laundry for a quick rinse wash to allow for shrinkage before the physical samples could be sewn.

5.6.3 Virtual prototype

A virtual prototype was developed to test the initial fit of the basic jean block pattern to verify the newly developed body measurement chart on the virtual avatar that represents the study population's body and to save time and resources ahead of the actual fitting process. The entire manual process of cutting, sewing and fitting a prototype garment normally takes a full working day to complete and the virtual process took less than an hour.

The virtual fitting process was successful and minor adjustments could be made to the pattern before the grading into various sizes. As discussed in Chapter 2.6.1., the red areas indicate where it cannot be worn and needs to be adjusted and the yellow areas indicate where it feels tight in proportion to the body. The jeans block prototype can be seen in Figure 5.5 below.

Figure 5.9: The jeans prototype fitted on the developed virtual avatar

Source: Windvogel (2022)

5.6.4 Physical prototypes

During the development of the pattern blocks, the pattern book (Joseph-Armstrong, 2014) instructed that wearing ease must be added, but it was decided to only add ease allowance to the waist area as this is normally restricted with interlining. Due to the amount of stretch in the fabric, the rest of the garment did not require ease.

Initially, the researcher wanted to produce both virtual and physical samples for fit testing in various sizes, but after some consideration, it was determined that only physical prototypes would be manufactured to gain verbal feedback from the participants about their comfort levels. This could only be done by giving them a tactile experience of the product to test.

5.7 Fit analysis

It is advised by Hernández *et al.* (2018) that different sizes should be tested during live fit evaluation sessions to ensure uniform fit on more bodies. A convenience sampling method was employed to ensure that each size of the manufactured prototypes had a body on which to fit. Sample A was the size they wear in the RTW apparel in retail stores and sample B is from the new proposed size chart. The participants were asked to walk, sit, bend and squat in the jeans to measure the level of movement comfort. The visual fit analysis was conducted during the live fitting sessions, and consequently by reviewing the photographs taken during this session. A feedback survey was conducted after the fit sessions and the results are summarised below the images, while the **expert opinion** (EO) (the researcher and two academics) is below that in italics.

Participant 1

Sample A (size 30) Sample B (size 30)

Figure 5.10: Fit session for Participant 1

Source: Windvogel (2022)

The feedback from participant 1 indicated that both samples fitted very comfortably overall; however, she prefers the traditional sizing sample as it fitted her body more snuggly, and the leg length was ideal.

EO: Both samples fit the student well except the leg length on Sample B is too short for her height and as proved below, the waistline is slightly too big.

Participant 2

Sample A (size 30) Sample B (size 30)

Figure 5.11: Fit session for Participant 2

Source: Windvogel (2022)

Participant 2 commented that Sample A is a bit tighter and the waistline on Sample B is too big. She prefers Sample A as it provides a snug fit in comparison to Sample B which has more ease on the body.

EO: Sample A was too tight on the waistline as indicated by the visibility of the zipper in front, and the leg length is too long. Sample B looks more comfortable, except for the waistband on the back area which is too big.

Participant 3

Sample A (size 32) Sample B (size 32)

Figure 5.12: Fit session for Participant 3

Source: WIndvogel (2022)

Participant 3 responded that the leg shape was too tight on Sample A which restricted her movements. She preferred Sample B because “it felt more comfortable and gave her the allowance to move around freely”.

EO: The two pairs of jeans fit similarly on her body, except for the too-big waistline on Sample B. The student is pear-shaped with the weight distribution to the back of her body. The pattern would need to be altered to eliminate this issue. The leg length on Sample B fits her body height better.

Participant 4

Sample A (size 34) Sample B (size 32)

Figure 5.9: Fit session for Participant 4

Source: Windvogel (2022)

The feedback from participant 4 was that Sample B was more comfortable in comparison to Sample A because it fitted well in all areas. She preferred Sample A as it felt more "figure hugging".

EO: Both jeans fit the student's body well, but visually Sample B appears better fitting on her body. The leg length on Sample B is more suitable for her height as well.

Participant 5

Sample A (size 34) Sample B (size 32)

Figure 5.10: Fit session for Participant 5

Source: Windvogel (2022)

The feedback from participant 5 was that Sample B was more comfortable in all areas. She was able to move around freely and would recommend these jeans to friends. The waistline on Sample B was specifically too big.

EO: Sample B was slightly too big for the student and can be seen by the drag lines on the back area below the buttocks. Visually, Sample B fitted better, except for the waistline which is visibly too big.

Participant 6

Sample A (size 36) Sample B (size 34)

Figure 5.11: Fit session for Participant 6

Source: Windvogel (2022)

Participant 6 simply responded that Sample B felt tighter on the leg and buttock area, but she could move comfortably in it. Sample A felt more comfortable in those areas, but she prefers Sample B overall.

EO: Sample B fits her body more comfortably as there is room to move. The waistline is too low in the CB area. The leg length on Sample B is ideal for her body height.

Participant 7

Sample A (size 38)

Sample B (size 36)

Figure 5.12: Fit session for Participant 7

Source: Windvogel (2022)

Participant 7 commented that Sample A was too tight, and she felt very uncomfortable. Sample B was found to be comfortable in all areas of the garment and would be recommended to others by her.

EO: Sample A is too small for the respondent as the garment is meant to fit around the high waist area. Sample B provides a better quality of fit overall. The waistline is in the correct position and the leg shape looks better-fitting.

Participant 8

Sample A (size 38)

Sample B (size 36)

Figure 5.13: Fit session for Participant 8

Source: WIndvogel (2022)

The feedback from participant 8 was that Sample A was constricting and felt very uncomfortable. Sample B was a more comfortable fit overall and allowed freedom of movement. She would recommend Sample B to friends and family.

EO: Sample A is too tight for the participant as indicated by the drag lines on the front crotch area. However, visually the back fits very well on her body. In Sample B the back area has too much ease and can also be seen from the lateral view where the lines are pulling. A size 35 in the new proposed sizing would fit her body well.

Participant 9

Sample B (size 36)

Figure 5.14: Fit session for Participant 9

Source: Windvogel (2022)

There was no available sample in the traditional sizing (Sample B) for the participant to fit. She could only wear and provide feedback on Sample B. The participant commented that she felt very comfortable in the jean in all areas. It was difficult to ascertain the level of comfort as there was nothing to compare it to; however, the fact that a size 36 fit her, was a phenomenon that caused great excitement for her.

EO: The front waistline is not in the correct position and therefore the jeans are creating drag lines on the front area. Overall, the sample fit the participant's body very well and she appeared very comfortable when wearing the jeans.

Participant 10

Sample B (size 38)

Figure 5.15: Fit session for Participant 10

Source: Windvogel (2022)

This participant wears a size 40 or 42 in the RTW apparel in retail stores and hence there was no available sample in the traditional sizing for the participant to fit. Once again, she could only wear and provide feedback on Sample B. The sample was slightly too tight and was uncomfortable when performing certain tasks like bending and squatting. She was elated about the idea of wearing a size 38 versus a size 42.

EO: The size 38 is visibly tight on the participant's body, especially the leg area, and a size 39 would provide a better fit and more wearing ease. The back rise can also be raised to provide more ease on the centre back seam.

It was clear from the fitting sessions and the feedback from the participants that the current sizing systems being used for local women's bodies are indeed outdated as the jeans created from the traditional sizing were all too tight/small. The emotional responses from the women when fitting on a smaller size than what they normally wear in the RTW environment, and it fits their bodies, left them elated and satisfied. Additionally, their fit preferences when compared to the experts' opinion, relate more to the comfort of the jeans rather than the aesthetics. Many of the participants enquired whether the jeans were for sale and if more sizes will be produced.

5.8 Concluding summary

Chapter 5 extrapolated from Chapter 4 and gave more insight into the entire methodological process. The qualitative components of the survey were clarified with the intent to answer some of the research questions. Furthermore, the size chart development process was meticulously explicated and implemented for the development of denim jeans in various sizes. The chapter concludes with the results of the feedback survey with visual aids to present the final products on the participants' bodies.

The following Chapter 6 will conclude this empirical study and present the findings and recommendations.

CHAPTER 6

Conclusion and recommendations

6.1 Introduction

The driving motivation of this study was to answer the main research question about the absence of an accurate size chart for young South African women that can be used as a foundation for the improvement of clothing grading systems, and consequently improve the fit of denim jeans and pants for young women.

It was vital to explore the user needs, statistically analyse the gathered anthropometric data, develop an authentic size chart, and design a pair of denim jeans that fit the young South African female body well. The aforementioned was pivotal in achieving the objectives of this study. Chapter 5 interpreted the research data obtained in Chapter 4 which sought to comprehensively answer these objectives as set out in Chapter 1 (See section 1.4).

This chapter concludes the study by abridging the key research findings about the research questions and aims and reviewing the value thereof. Additionally, the limitations or weaknesses of the study will be discussed and recommendations for future research suggested.

6.2 Key findings

Based on the quantitative analysis of anthropometric data and qualitative investigation into participants' views, it can be concluded that these methodologies used have demonstrated to be effective for this particular study. Furthermore, the results indicate that the primary objective of developing a size chart by employing statistical analysis provides new insights into the field of size prediction. This denotes that a retailer or manufacturer in possession of the size chart and the model formula can employ the system for successful consumer sizing, especially when selling garments online to reduce their return rate and customer fit satisfaction. This is key as the garment can only be fitted once delivered to the consumer whereas they can fit various sizes in stores.

The main findings of this study, following the objectives and research questions formulated in Chapter 1, are resolved in the secondary questions and broad answers as follows:

6.2.1 Why is there no South African body measurement sizing system and can this be developed?

Initially, the assumption was that South Africa does not possess body measurement size charts and that the clothing industry utilises a British sizing system which is based on the Western ideal body shape (Muthambi *et al.*, 2015). Being employed at the Technology Station in the Clothing and Textiles Technology Department at CPUT from 2010 until 2020, the researcher worked closely with clothing industry experts and was exposed to many "trade secrets" that were kept in-house by these companies.

As this study progressed, more literature searches were done towards an improved contribution to the literature review. It became clear that there have been many attempts by local researchers and academics to address this problem but none of these has been either successful or implemented for use in the industry therefore the existing literature pointed to the necessity of further development of local sizing systems for young South African women. This has been discussed in sections 1.5.1 and 2.2.2, supporting the arguments that some of the biggest challenges for the industry are the time and cost involved in such studies. A flaw in the previous studies is that it has been limited to specific demographic groups only. Some countries such as America, Germany, Sweden and France, have conducted anthropometric studies of their population. Subsequently, they have made the information available to their various industries for use.

This study has demonstrated that a South African sizing system can certainly be developed with the guidelines for improved measurements herein. The mixed-method research design and methodologies applied, successfully guided the primary research and found practical guidelines for the design and development of better-fitting denim jeans for young women. By implementing the use of a linear regression model to predict sizes, the developed size chart has succeeded in developing the required patterns and the grading application.

6.2.2 How do young South African women feel about the current availability and fit of denim jeans across various brands and what aspects regarding fit and appearance do they experience as problematic?

The qualitative feedback (the survey discussed in section 5.2.1 and section 3.3.4.2 respectively) comprehensively explored the participants' thoughts on their current denim jeans acquired from various local retailers. The results showed that Levi's branded jeans are the preferred jeans for many women. Levi's jeans have managed to create jeans for a curvier shape with 40-50% stretch in the fabric (Levi's.co.za:2022). However, a third of the total population of women in the study felt that they would not recommend any jeans brands to their friends or relatives. These are brands both from local manufacturers and international brands.

Fit was the dominant requirement for the women when they go shopping for jeans and many respondents commented on problem areas on the body such as the gaping waist, fabric that is not stretchy enough, the leg length and high fashion – in other words, aesthetically flattering fitting jeans – that were not available for their specific body shape. The theory of body cathexis, as discussed in Chapter 2, is of critical importance during this discussion, as it is one of the primary motivators to try and establish a sizing system that is valid, which does not promote women feeling ashamed of themselves because of amongst other reasons, poorly fitting garments. All these remarks and input were considered when designing the new jeans samples for fitting purposes and were addressed accordingly as can be seen in Table 5.5 of the preceding chapter. The gaping waist problem still occurred with women who have an extreme pear shape, as the size chart does not accommodate one specific body shape only.

Most of the women in this study (52%) found the shopping experience for jeans in the local RTW clothing environment very stressful due to sizing and fit issues. Regarding comfort, durability and style, the views of the women were subjective and based on their personal fit preferences and their understanding of durability and comfort. This confirms the results of the study conducted by Kasambala (2016), which states that fit and sizing are the most important evaluative criteria that women consider when purchasing casual clothing.

6.2.3 How can 3D technology be utilised in this study of young South African female jean wearers to generate/develop an improved measurement size chart?

Accurate body measurements are needed to integrate with the pattern-making process for well-fitting garments (Strydom & de Klerk, 2010); this was achieved in this study with the use of a 3D body scanner. However, some of the limitations were that the manual process of taking body measurements was time-consuming and, in some cases, inaccurate due to the different views of where the landmarks are positioned on the bodies. Therefore, recommendations have been made by other local researchers that an anthropometric study is undertaken for

the South African population with the use of available technologies (Mac Duff & Smith, 2014; Makhanya, 2015; Muthambi *et al.*, 2016; Sokhetye, 2017).

Two 3D technologies were used and integrated at different stages of this research project namely:

1. 3D Body scanning technology – This was a valuable tool for collecting anthropometric data as it was a quick process, no physical contact was needed with the participants and thus the process was non-invasive, and the data was stored on the computer for later inspection. All the body measurements needed for both the primary and secondary dimensions were extracted from the machine and this also included the height measurements which would generally be taken manually when using the TC² body scanner. The collected data can now also be added to a local database for other researchers to utilise as secondary data.
2. 3D Visualisation technology – The CLO3D virtual stitching software was used during the prototyping stage of the project. This enabled the researcher to test the first pattern block prototype on a virtual avatar that was created to represent the sample body measurements. This streamlined the product development process and saved a lot of time and resources. These technologies have shown that limited time and space need not be a challenge when conducting such a study and that the creation of size charts can be completed in the minimum time required.

6.2.4 How could a more accurate body measurement chart enhance denim jeans' fit and appearance and consequently the user experience/satisfaction?

The results of the fit sessions indicate that the apparel industry is trying to compare two completely different variables by using data from another population and trying to fit local women's bodies into that system. The new proposed sizing system or charts demonstrate that the local female bodies are not obese, and we do not have a need to produce bigger sizes, but that we should use an authentic database of South African female bodies to create size charts.

The developed size chart consisted of all the primary and secondary dimensions needed to create the block patterns. There is a visible improvement in the jeans' physical, aesthetic, and functional fit. Fit is successful when the wearer's needs are achieved together with the garment's functionality and characteristics, and this confirms the expectancy disconfirmation

paradigm which suggests that consumers are satisfied when the product performs better than expected (positive disconfirmation). In addition, the participants have indicated that they would definitely recommend these jeans to friends and family, which corroborates that when consumers are satisfied with the product/brand, they are more likely to recommend the product to others, less likely to switch to other alternative brands, and more likely to repeat purchases (Iazzi *et al.*, 2016).

This study has endorsed the guiding theory behind the study (as discussed in Chapter 1) that the socio-psychological benefits of clothing are indeed endogenous (such as functional benefits, or intrinsic), experiential (what it felt like), and symbolic benefits (the need for social approval or personal expression) as discussed in section 1.6.

During the fit sessions, some of the participants were elated that they could fit into a smaller size than they would under normal circumstances in stores. This left them ecstatic, and it was not due to vanity sizing (where a smaller size label is added to a garment with bigger size measurements). In addition to this, the responses recorded on the feedback surveys, the participant's view of the jeans on their bodies and the expert's visual analysis differ significantly and this confirms that customer satisfaction is based on consumer preferences.

6.3 Contributions to the field

The desired outcome of this study was to collect body measurement data to develop size charts for use in the product development of pants or jeans and to create a model that would be able to predict jeans size with these improved measurements. All the sizes created on this new size chart were developed by utilising this prediction model and the results show that the body measurement charts that are in use in our industry, do not align with the bodies of the local South African women. Therefore, this prediction model can now be employed for online and real shopping sales but also in the manufacturing process of jeans or pants.

This research challenges other local studies that have assumed that most South African women have pear-shaped bodies, and that shape has the biggest challenges with RTW apparel (Makhanya, 2014; Muthambi *et al.*, 2016; Sokhetye, 2017; Ola-Afolayan *et al.*, 2021). The results of this study show that only 21% of the participants have pear-shaped bodies and that 71% have triangular-shaped bodies. Naturally, this severely affects the design and manufacturing of clothes for South African women.

6.4 Limitations

Due to the nature of the body scanning process, people are generally very reluctant to have their bodies scanned. The process was explained to them, and the confidentiality of their body information was ensured; however, some students still declined to partake in the study. The body scanner is the property of the Technology Station in the Clothing and Textiles department on the CPUT Bellville campus and since they only operate during business hours, which is when students have classes, it was difficult to obtain more information during these operating times. This restricted the data collection process to obtain a bigger sample size for this study.

Outliers were detected during the average calculation stage of the size chart as discussed in section 5.4.3 and could not be part of the study since they deviate radically from the existing dataset. They changed the grading increments significantly and created abnormal patterns and size breaks.

Initially, **virtual prototypes** were to be sewn virtually in all sizes and the fit sessions were going to be conducted in the virtual environment. The researcher decided against this decision due to the restrictions on the experiential benefits of fit. The fit map, strain map, and pressure maps can indicate where the garment is tight on the body, but an avatar cannot communicate how comfortable the garment feels or whether, due to personal preferences, changes are required. In addition, the software systems are costly, and it is not feasible for all companies to access them.

Additional fit models would have been ideal in the selected sizes to fit the physical samples, but due to the Covid-19 health restrictions, only a certain number of students were available on campus for the allocated times and not all of them were part of the initial scanning process.

6.5 Recommendations for future research

This study has demonstrated that a South African body measurement sizing system can be developed in collaboration with industry experts, local academics, or researchers, despite the limited number of participants. A bigger pool of anthropometric data would make it possible to create size charts for the various identified body shapes and not just one generic size chart for all. The challenge with a study such as this is that the topic is dynamic and body data

evolves as the population's lifestyles changes. Anthropometric research should be conducted regularly for the information to remain up to date.

The outliers or bodies that varied significantly from the others in the datasets should also be addressed in future research studies. For example, they could either be clustered and dealt with as a niche market, if the sample size is adequate, or they could be addressed with customised or tailored garments.

The traditional size charts that are used do not accommodate in-between sizes such as sizes 31, 33, 35, etc. The results of the fitting sessions have unveiled that those sizes should also be manufactured to accommodate more bodies and provide better-fitting garments.

Costly sample-making and fitting processes can be reduced in the prototyping stage of product development with 3D visualising technologies. This is a beneficial, sustainable tool to reduce the time to market of RTW apparel.

This study could also be useful to other researchers who are interested in the topic and can hopefully find the technology an easier and more accurate tool for gathering and analysing empirical data.

6.6 Concluding summary

This research clearly illustrates that it is feasible to conduct a sizing study, but it also raises the question of why local companies are not investing in this knowledge if it means better-fitting garments for their target consumer, which in turn leads to lower return rates. Based on these findings, actionable recommendations were made. While there have been many limitations to this study, this approach provides new insights into this field of research, from which future research recommendations have emerged.

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Appendix A

Cape Peninsula University of Technology
Clothing and Textile Technology
PO Box 1234 Bellville 7530
Tel: 021 959 6821

CPUT Indemnity Form

Research title: **A standard sizing system for younger South African women, using innovative technology.**

Project leader: Deidre Windvogel

Contact details: windvogeld@cput.ac.za (021) 959 6821 (Office hours)

The project leader will contact you to arrange a time for a session for the scanning to take place.

- Your involvement in this study is voluntary, you are not obliged to disclose information you would prefer to remain private, and you may withdraw from the study at any time.
- The information you provide will be treated as confidential. You will not be identified in any document, including the questionnaire and the research report, by your surname, first name, or by any other information. You will be referred to in the documents under a reference number. No one other than the project team will be informed that you participated in this research.
- The research may include risks to you, but these will be minimal and no different to those encountered by people on a daily basis. Every effort will be made to minimise possible risks.
- The research findings will be made available to you should you request it.
- Should you have any queries about the research, now or in the future, you are welcome to contact the project leader at the above email address.
- We appreciate your willingness to be involved in this research project.

I .....understand the contents of this document and agree to participate in this research.

..../...../2018
Signature Date

....
Witness 1 Witness 2

The project leader appreciates your willingness to participate in this research study.

Cape Peninsula University of Technology
Clothing and Textile Technology
PO Box 1234 Bellville 7530
Tel: 021 959 6821
E-mail: windvogeld@cput.ac.za

CPUT Indemnity Form

Consent to participate in the CPUT and Technology Station Clothing and Textiles department's research study:

A standard sizing system for younger South African women, using innovative technology.

I.....hereby acknowledge and declare that I agree to participate in all activities related thereto at my own risk and on the expressed condition that neither CPUT, nor their employees, shall be liable to me for any damage arising out of loss of life or bodily injuries suffered, or for any loss of or damage to my property or estate arising out of any accident or cause which may occur during such trip, or whilst in transit, whether or not such accident or other cause arises out of negligence , failure, incompetence or any act whatsoever, on the part of such employees, and on behalf of myself, I hereby indemnify, hold harmless and absolve CPUT and their employees from any damages whatsoever and legal expenses or costs, which may arise out of my participation in said activities.

Signed at.....on this the.....day of 2018

Signature

.....

Witnesses:

1.....

2.....

Members of the CPUT Ethics Board:

Appendix B

Cape Peninsula University of Technology

Office of the Deputy Vice Chancellor:
Research, Technology Innovation & Partnerships
Bellville Campus
P O Box 1906
Bellville 7535
Tel: 021-9596242
Email: NhlapoC@cput.ac.za

13 March 2018

Ms Diedre Luzina Windvogel
Department of Clothing & Textile Technology
Faculty of Engineering
Bellville
7535

Email: WindvogelD@cput.ac.za

Dear Ms Windvogel

RE: PERMISSION TO CONDUCT RESEARCH AT CPUT

The Institutional Ethics Committee received your application entitled: "Development of standard sizing system for younger South African women with the use of innovative technology" together with the dossier of supporting documents.

Permission is herewith granted for you to do research at the Cape Peninsula University of Technology.

Wishing you the best in your study.

Sincerely

APPROVED
Chair Senate Ethics Committee
13 MAR 2018
Cape Peninsula University of Technology
Sign: .....

PO Box 1906 Bellville 7535 South Africa
086 123 2788

Appendix C

P.O. Box 652 • Cape Town 8000 South Africa •Tel: +27 21 469 1012 • Fax +27 21 469 1002
80 Roeland Street, Vredehoek, Cape Town 8001

Office of the Research Ethics Committee	Faculty of Informatics and Design

Ethics approval was granted to Ms Deidre Luzina Windvogel, student number 199093121, for research activities related to the MTech: Design degree at the Faculty of Informatics and Design, Cape Peninsula University of Technology (CPUT).

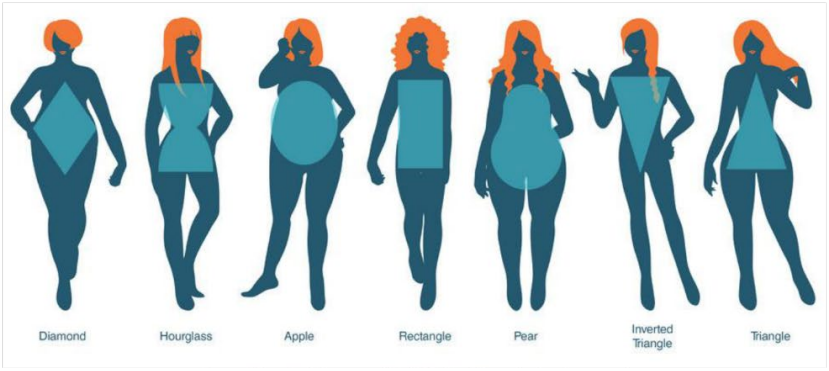
Title of dissertation/thesis:	The development of standard sizing system for younger South African women with the use of innovative technology

Comments

Research activities are restricted to those detailed in the research proposal. Permission from CPUT is required since students will be used as subjects in the research.

Signed: Faculty Research Ethics Committee	Date 15/11/2017

Appendix D: A poster designed to attract the target group



https://augfashion.com/2015/08/01/female-body-types/

FEMALE STUDENTS 18-35

VOLUNTEERS NEEDED

FOR BODY SCANNING!

MON - FRI

TIME : 9AM – 5PM

LOCATION:

TECHNOLOGY STATION: CLOTHING AND TEXTILES

This research responds to the challenges that local retailers and manufacturers are having when needed to provide their defined target markets with well-fitting clothing. The focus of this study is mainly on collecting measurements of female students and consequently analysing it, both statistically and visually.

FREE GOODIE BAG!

FOR QUESTIONS OR MORE INFORMATION CONTACT:

DEIDRE WINDVOGEL: 076 740 5968 / WINDVOGELD@CPUT.AC.ZA

Appendix E

Cape Peninsula University of Technology
Clothing and Textile Technology
PO Box 1234 Bellville 7530
Tel: 021 959 6821
E-mail: windvogeld@cput.ac.za

Research title: **The development of a standard sizing system for younger South African women, with the use of innovative technology.**

Researcher: Deidre Windvogel

Contact details: windvogeld@cput.ac.za (021) 959 6821 (Office hours)

Questionnaire

Thank you for agreeing to be part of this study. Please take a few minutes to answer the following questions related to the clothing products/services that you have experienced so far.

- How does denim jeans fit into your wardrobe?

_____

_____

- Please give your opinion on the following in terms of your current denim jeans:
    - Comfort
    - Size _____
    - Durability
    - Style _____

- Is the design details of available denim jeans suitable for your style? Please explain.

_____

_____

- Could the currently available denim jeans be improved and how would you suggest it?

_____

_____

- Is there a local denim/jeans brand that you would recommend to a friend or relative?

_____

_____

- How would you describe your last shopping experience for the right pair of jeans?

_____

_____

..../...../2018
Signature Date

The researcher appreciates your time and willingness to participate in this research study.

Appendix F: Excel template created to capture the 52 key body measurements from the scanning process.

3D BodyScanning Anthroscan					
Date	29 March 2017				
Name/Code	Salmi				
Age					
Gender	Female				
Province	Western Cape				
	Measurement Names	M		Measurement Names	M
No	Overview	[cm] [degree]	No	Overview	[cm] [degree]
1	Body height	166.6	27	Arm length left	53.4
2	Cervical height	144.8	28	Arm length right	54.1
3	Waist height	103.8	29	Upper arm length left	29.9
4	Crotch height	74	30	Upper arm length right	30.5
5	Knee height	45.7	31	Upper arm girth left	26.8
6	Breast height	119.9	32	Upper arm girth right	27.1
7	Trunk length	68.6	33	Elbow girth left	23.5
8	Mid neck girth	34.1	34	Elbow girth right	23.4
9	Shoulder width left	12.2	35	Forearm girth left	20.5
10	Shoulder width right	12	36	Forearm girth right	20.7
11	Shoulder angle left	26	37	Wrist girth left	16.3
12	Shoulder angle right	27.5	38	Wrist girth right	16.3
13	Bust points width	17.5	39	Sideseam at waist left	104.7
14	Neck right to waist over bust	44.1	40	Sideseam at waist right	104.8
15	Bust point to neck left	27	41	Thigh girth left (horizontal)	56.9
16	Bust point to neck right	27.1	42	Thigh girth right (horizontal)	57.4
17	Bust/chest girth (horizontal)	84.7	43	Knee girth left	36.6
18	Across Back Width	33.4	44	Knee girth right	36.6
19	Neck to waist center back	39.7	45	Upper knee girth left	39.1
20	Crotch length	78.6	46	Upper knee right	39.1
21	Waist girth	69.4	47	Lower knee girth left	33.6
22	Waist to buttock height right	19.2	48	Lower knee girth right	33.8
23	High hip girth	85.3	49	calf girth left	35
24	Buttock girth	95.2	50	calf girth right	35.1
25	Arm length to neck back left	71.7	51	min. leg girth left	22.6
26	Arm length to neck back right	72.4	52	min. leg girth right	22.4

Appendix G: Test certificate

WARNING: The sample(s) to which findings recorded herein (the "Findings") relate, was drawn and / or provided by the customer. The findings constitute no warranty of the sample's representativeness of any goods and strictly relate to the sample(s). The TSCT – Textile Testing Laboratory, accepts no liability with regard to the origin or source from which the sample(s) where said to be extracted.

TEST CERTIFICATE

Customer Details:	**DEIDRE WINDVOGEL** (Post Graduate Masters)	**Report No.:** **No. of Pages** **No. of Attachments:**	LU032-TC01-22 1 2
Contact Person:	Deidre Windvogel	**Test Report Issue Date:**	31 August 2022
Sample Description **Laboratory Sample Reference:**	Stretch Denim – Dark Blue LU032-010822/01		
Testing Location: **Atmospheric Conditions:** **Deviations:**	TSCT – TEXTILE TESTING LABORATORY Temperature: 20°C No Deviations	Humidity: 65% RH	

Test Description	UOM	Test Method	Performance Specification		Results
			Min.	Max.	
2. Elasticity of Fabric a. Extension at Force of 30N - Weft Only	%	EN 14704-1 [Knitted Fabric - Method A: Extension at Load]	-	-	26.88
3. Modulus a. Weft Only	N/mm		-	-	0.297
4. Seam Slippage a. Warp Direction b. Weft Direction	N	ISO 13937-3	-	-	≥200 ≥200
5. Solubility (Fibre Composition)	%	ISO 1833-11	-	-	6% Spandex 72% Cotton 22% Polyester
6. Dimensional Stability a. Warp Direction b. Weft Direction	%	ISO 6330:2012 [4N]: Procedure-Flat Dry			-0.5 2.0

TECHNICIAN

AUTHORISED SIGNATORY

31/09/2022
Date (dd/mm/yyyy)

01 /09 /2022
Date (dd/mm/yyyy)

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Appendix H: Feedback Questionnaire

Cape Peninsula University of Technology
Clothing and Textile Technology
PO Box 1234
Bellville
7530

Research title: **The development of an Afrocentric apparel measurement size chart for young women's jeans through the use of 3D technology.**

Researcher: **Deidre Windvogel**

Contact details: windvogeld@cput.ac.za (021) 959 6177 (Office hours)

Feedback Questionnaire

Thank you for agreeing to be part of this study. Please take a few minutes to answer the following questions related to the 2 pairs of jeans handed to you.

Instructions:

- You are presented with 2 coded samples (Sample A and B)
- Fit one sample at a time and wear it for a few minutes.
- You are required to walk, squat, bend, and sit with the jeans.
- Both samples must be fitted before completing the questionnaire.
- Tick where appropriate or expand on your answer where needed.

1. What jeans size do you normally buy?

2. What size did you fit today?

Sample A	Sample B

3. Which leg shape feels more comfortable?

Sample A		Sample B	
Comments:		Comments:	

4. Which waistline fits better/is more comfortable?

Sample A		Sample B	
Comments:		Comments:	

5. Which buttock area fits better/ is more comfortable?

Sample A		Sample B	
Comments:		Comments:	

6. How does it feel when you do the following? Please state whether it is comfortable or uncomfortable

	Sample A	Sample B
Walk		
Sit		
Bend		
Squat		

7. What do you “feel” when wearing jeans? Please tick.

	Sample A	Sample B
Uncomfortable		
Comfortable		
Other		

8. Which jeans do you prefer overall? Please explain why.

Sample A		Sample B	
Comments:		Comments:	

9. Which jeans would you recommend to a friend/relative?

Sample A		Sample B	

Name: ..... Date: ..... September 2022

…….
Signature

The researcher appreciates your time and willingness to participate in this research study.

Appendix I: Editor's Certificate

Gerald T du Preez

PhD

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THE DEVELOPMENT OF AN AFROCENTRIC APPAREL MEASUREMENT SIZE CHART FOR YOUNG WOMEN'S JEANS THROUGH THE USE OF 3D TECHNOLOGY.
BY
DEIDRE WINDVOGEL

with a final word count of 41 872 on 1 December 2022

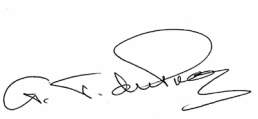
I am a member of the Professional Editors' Guild (member number DUP015) and commit to the following codes of practice (among others):

- *I have completed the work independently and did not sub-contract it out*
- *I kept to the agreed deadlines and communicated changes within reasonable time frames*
- *I treated all work as confidential and maintained objectivity in editing*
- *I did not accept work that could be considered unlawful, dishonest or contrary to public interest*

I uphold the following editing standards:

- *proofreading for mechanical errors such as spelling, punctuation, grammar*
- *copy-editing that includes commenting on, but not correcting, structure, organisation and logical flow of content, formatting (headings, page numbers, table of contents, etc.), eliminating unnecessary repetition*
- *checking citation style is correct, punctuating as needed and flagging missing or incorrect references*
- *commenting on suspected plagiarism and missing sources*
- *returning the document with track changes for the author to accept*

I confirm I have met the above editing standards and professional, ethical practice. The content of the work edited remains that of the student.



Gerald T du Preez, PhD