SIZE PREDICTION FOR PLUS-SIZE WOMEN'S INTIMATE APPAREL USING A 3D BODY SCANNER

BY

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In fulfillment of the requirements for the Master of Science Degree in the Department of Textile Science at the Nelson Mandela Metropolitan University, Port Elizabeth.

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September 2009

The researcher wishes to inform the reader that this dissertation contains illustrations of nude breasts, taken from the different sources and used with the permission of the subjects involved in this study and the different referenced sources. The Memorandum of Understanding signed between the CSIR and Playtex (Pty) Ltd is bound by a confidentiality agreement.

DECLARATION

I, Krishnavellie Pandarum hereby declare that:

The work in this dissertation is my own original work; and all sources used are acknowledged and referred to appropriately; and this dissertation has not been previously submitted in full or partial fulfillment of the requirements for an equivalent or higher qualification at any other recognized tertiary institution.

Krishnavellie Pandarum
September 2009

ACKNOWLEDGEMENTS

The researcher wishes to thank the following individuals who directly or indirectly contributed to this study:

- Mr. Abisha Tembo, of the Fibres & Textiles Competence Area of the CSIR Materials Science and Manufacturing Unit, for making funds available to conduct the study.
- Professor Lawrence Hunter and Professor Winnie Yu, for their invaluable guidance and advice during the course of this study.
- Mrs. Jenny Wooldridge from the CSIR Information Services.
- Mr. Ian Braum from DBApparel (Playtex Pty Ltd.)
- Mrs. Ros Allan from DBApparel (Playtex Pty Ltd.)
- Mrs. Comien Kleynhans from DBApparel (Playtex Pty Ltd.)
- Dr. David Bruner, Vice President Technology Development [TC] 2 – United States of America.
- Mr. Coos Bosma – InnoVenton – Nelson Mandela Metropolitan University.
- Mr. Steve Chapple from the Fibres & Textile Competence Area, CSIR.
- Dr. Asis Patnaik from the Fibres & Textile Competence Area, CSIR.
- Mr. Roger Metelerkamp from the Fibres & Textile Competence Area, CSIR.

- Unamalay and Logan Pandarum, my mum and late dad, for their unwavering support and belief in me.

ABSTRACT

Garment “fitting” from tailor-made to ready-to-wear clothing, has evolved over time. Ready-to-wear and standardized sizes appeared in the middle 19th century. Today garment fitting is one of the most important criteria in the consumer buying decision making process. This is particularly so with “body hugging” garments, such as intimate apparel; or the bra that moulds the form of the wearer to produce “smooth” outer garment silhouettes. The South African bra retailer and manufacturers sizing charts are generally based upon body dimension data collected using traditional anthropometric methods. Professional measurers are not able to capture the hidden areas of the breast such as the inframmatory fold line, the volume, shape and contour of the breast using tape measures, calipers and other measuring devices. Traditional anthropometry also does not have the ability to systemically observe the bottom line of the breast base and extract accurate data on breast volume which are key factors in designing underwire bras and in the pattern making of the bra cup panels. Exploratory retail and consumer studies have indicated that consumers, notably plus size women, experience considerable problems and dissatisfaction with poorly fitting bras. There is therefore clearly a need in South Africa to conduct a 3D anthropometric study, focusing especially on the plus-sized women’s bra market segment, as there is very little or limited studies, to date, conduct for this market segment of the population.

This pilot study collected 3D torso body measurement data from a convenient sample of 176 plus sized women, recruited from Playtex (Pty) Ltd. situated in Durban, KwaZulu Natal, South Africa. The study evaluates the 3D breast volume measurement data extraction process, using an expert system developed by [TC]2 integrated into the propriety NX12-3D full body scanner software and that taken using the traditional dress-makers tape-measure. The objective is to establish the relationship between the 3D torso and breast volume data measurement output as extracted by the expert system when compared to the South African bra manufacturers sizing chart, for use in pattern making for bra cup panel designs and in the designing of underwire bras for large breasted or plus size women.

The results contained in this dissertation cannot be extrapolated to the larger population of South Africa and is limited to the 176 plus size women selected by Body Mass Index; recruited from KwaZulu Natal, South Africa.

KEY WORDS: plus-sized women, 3D scanner, breast shape, breast volume, bra size, fit.

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3. To compare the volume measurement data collected using the volume extraction programme that is integrated into the [TC]2 software with that indicated by the Playtex Sizing Chart; and also with that reported by the subject as their claimed bra size.

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A convenient sample of ten women was chosen from the 176 plus-size women to take part in this exercise. The women will try on two set of bra sizes i.e.

1. one recommended by the bust full and the underbust body measurements as taken using a tape measure and;
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Digital images of the same subjects wearing the different bra sizes will be taken for further evaluation of the fit between the two different data extraction methods and also for reporting purposes.

The "fit" comparison will also be rated against questionnaire designed for this exercise to determine which of the bra sizes extracted by the two different methods is closer to the actual bra size that the subjects is comfortable in and for any further input from the subject as to improvements on the "fit"

CHAPTER 6

The final chapter will discuss the outcomes of the study, propose possible solutions and make recommendations for future 3D body scanning intimate apparel projects.

INTRODUCTION

An ill-fitting garment represent a worldwide issue and is a major concern for retailers and shoppers alike.[1] The challenge for the clothing manufacturing industry is not only to produce better fitting garments for outerwear apparel but also to do so for intimate apparel as the population slowly but continuously changes in size and shape. An emerging international trend that can be applied with the South African context as well, is the growth in obesity and therefore in the consumer plus-sized market. The freedictationary.com[2] defines plus-size as "an extra large or oversize clothing size, especially for women's or children's clothing". The average American women is now said to weigh +/-65kgs or more which mostly represent the plus size category and plus-sizes account for 75% of the US clothing sales. Casselman[3] reported that an average American women's bra size has increased in the past 15 years from a bra size 34B to 36C and that a size D bra cup breasts could weigh between 7kg and 10kg. This trend is also being observed in South African by retail and garment manufacturers. According to just-style.com, [4] more than 50% of the adult western population are obese in countries such as South Africa, Mexico and in the Caribbean. This is supported by a survey conducted by a Weekend Argus reporter which indicated that 30% of South African women are size 16+[5] i.e. plus- size. The plus-sized clothing market is seen to be a financially lucrative and growing sector of the consumer market, with huge spending potential.

Extensive research is currently being conducted on the plus-size women outer and intimate apparel consumer markets. In the intimate apparel, more specifically in the bra retail and manufacturing industries, human anthropometry and sizing are key issues in understanding the technical aspects of sizing since the bra is designed to mould the form of the torso. Bra size, like pants size and dress size, affects a woman's body image and self-esteem. According to O magazine,[6] 85% of women wear the incorrect bra size. Factors such as life-style changes, age, illness, weight gain and weight loss, affect the sizing and fit of the bra. Ennis[7] also found that bra sizing was of particular concern; "since bra sizes is comparable to clothing size in its ideological significance," with the clothing industry free to exploit bra size as a form of control for profit. Bras are foundation garments that cover, support and elevate the breasts into a particular position on the chest wall.[8] Evolving fashion dictates that these under-garments should not only be functional but also aesthetically pleasing and comfortable as well. Today, bras are not only seen as support garments but also as functional garments; for shaping the wearer's figure, manufactured in many sizes and shapes to meet the modern women's needs. There is no "one size or design that fits all"; neither is there a "multi-purpose bra".

Measurement of the torso is an important parameter when it comes to the fit of a bra; although the definition of "fit" has varied over time and is dictated by fashion trends, industry norms and an individual's perception of fit.[9] Studies conducted by Keiser *et al.*[1] indicate that the current methods of creating sizes and analyzing garment fit are:

1) based on measurements of "one ideal customer embodied in a single fit model";
2) adjusted for additional sizes by using "grade rule from the base pattern"; and
3) visually evaluated on the fit model and in "two dimensions" by comparing linear garment measurements to linear body measurements.

Brown & Rice[10] went further stating that the fit of the garment is dependent on five elements, namely the (1) Grain, (2) Set, (3) Line, (4) Balance and (5) Ease. With Shin[11] reporting that in the evaluation of the proper fit of a bra, "tension", is replaced by "ease". The stretch material of the wing of the bra accommodates the "negative ease" estimated to be between 10 to 15 centimetres from the actual ribcage circumference. Hence the fabric properties and selection are also important criteria in the proper fitting of a bra.

In South Africa, the intimate apparel manufacturer's current bra sizing charts were developed using manual measurements. Since the 1950s a dressmaker's tape measure or other measuring devices were used to obtain body measurements, this being commonly known as traditional anthropometry. Lui *et al*.[12] define traditional anthropometry as "a set of body measurements corresponding to linear distances between anatomical landmarks and circumference values at predefined locations" on the body. The current method used in the intimate apparel industry to determine the breast volume or bra cup size has been established by taking the difference between the under-bust and over-bust torso horizontal linear measurements which is converted into a bra cup size. The torso measurements are taken from a standard fit model for band and bra cup size, comfort, support, appearance and "fit" for the different bra size notations and styles. This method of calculating the over-bust and under-bust measurements is said to be inaccurate, more especially in large or plus size woman, as the “tape slides easily into the flesh” and is also very time consuming.

Numerous studies have been conducted in the intimate and the reconstructive medical fields[13, 14, 15, 16] on breast volume measurement using various methods and techniques to extract the breast surface data. Nevertheless, there still appears to be no reported standard method for breast volume extraction. Previous studies on breast volume reported by, Lee[17], using the mould technique and by Loughry *et al*.[18], using stereo cameras, did not fully consider the breast base as it was assumed that the breast base is a circle and the “bulk” of the breast was cone shaped. More recent studies[19, 20, 21,22,23,24], aimed at developing better fitting bras and prosthesis for the intimate apparel and the medical breast reconstructive fields, focused on developing methods and techniques to better understand breast volume and the curve of the breast base. Some of the reported studies were conducted by Zheng *et al*[13], on breast depth, using a 3D body scanner for establishing a new bra sizing system for Chinese woman using the underbust girth and breast depth width ratio; Wright's[25] study on the development of a widely used graphical analysis of bra size calculation procedures, from body measurements and; Sun *et al*.[26] used the analogy method of observation on the female breast parameters that defined the contour of the female breast form from varied reference points. The breast base line and breast volume were calculated using software, with a view to integrating the information gathered by 3D scanning into CAD systems for use in breast implant surgery, as the surgeons judge the female breast according to the size, shape and breast position on the chest wall. These 3D scans were extracted with the subjects in a “normal seated position” on a standard measuring chair and not with the subject in the natural upright anatomical position commonly used in the bra manufacturing and retail industries.

Lee *et al.*[27] cite the volume of a woman's breast as being one of the most difficult parameters to measure. This study also refers to factors such as the inherent ambiguity existing in defining the outline of the breast as it is difficult to select reliably anthropometric breast points. The hidden areas such as the inframmary fold line prevent the collection of optical data of “sagged breasts”, hence the bottom line of the breasts are not clearly defined for designing under-wire and the front panels of the bra cup, more especially in plus-sized women. This indicates, that as breasts are 3D in nature, it is understandable that many women are uncomfortable wearing a bra as their “true” breast size and shape characteristics are either not known or there are existing ambiguity in bra sizing and fit from one style to another, even within the same manufacturer or retailer and also from one bra manufacturer or retailer to another. Other reported causes of discomfort are the inaccurate measurement of the breast volume which forms the basis for the pattern making of the bra cup panels and underwire bras. Lifestyle changes, such as individuals gaining or losing weight, childbearing, hormones and menopause, pose further challenges to bra manufacturers and retailers. All these factors change the breast mass at any given time, thereby affecting the breast volume or bra cup size. As breasts become larger, the tissue distribution changes to bulbous. Furthermore, Losken *et al.*[28] state that the degree of breast asymmetry is significantly higher in women with larger BMI, relative to cup size and chest wall circumference, with 62% of the women with the left breast larger than the right breast, this is more especially so when the breasts are large.

Therefore, to achieve better bra cup size notations and collect more reliable breast volume data for manufacturing intimate apparel; the measurement extraction process has to be very accurate and provide sufficient information on the 3D geometric female torso for the designing and manufacturing of better fitting bras, on a significantly large and representative population sample. The traditional tape measuring technique of collecting body measurement data on the female torso is extremely time consuming and costly, but with the advent of 3D body scanners it is now possible to collect large amounts of body measurement data on a statistically significant sample size in a relatively short space of time.

3D body scanning is a technology that is rapidly replacing traditional anthropometry and is seen to have significant potential for use in the design, sizing and manufacture of apparel, particularly for the South African bra manufacturing industry. 3D scanning technology is seen as an effective tool that can rapidly, accurately and quantitatively measure and compare three-dimensional objects, such as female breasts. 3D scanning of the female torso has the potential to extract torso body measurements with greater accuracy, repeatability and non-intrusively. This is supported by Rudolph *et al*.[29] study aimed at 3D breast imaging reproducibility. More 3D surface torso data measurement points can be extracted and the data collection process has the ability to extract the traditional breast body points of measure, such as breast slope, angle, depth, cup length, bust prominence, volume and circumference of torso, for the construction of better fitting bras. The 3D cloud form of the scans can be captured and stored for the evaluation of critical visual fit information, that is said to be far more effective than photographic or videotaping that were used for body shape and apparel fit analysis prior to the use of 3D body scanners.[30.] This is supported by other studies conducted by Loken *et al.*[28] that 3-dimensional imaging of the breast has the ability to extract accurate data which will improve the ability to quantatively determine differences in shape, size and contour of the breasts.

This pilot study on size prediction for women's plus-sized intimate apparel seeks to explore and collect torso body measurement data on plus-sized South African women using a 3D body scanner. The 3D extracted torso body measurement data is for use in the bra manufacturing and retail industries, focusing particularly on breast volume or bra cup size, for pattern making of the bra cup panels and in the designing of better fitting underwire bras for plus-size women. This data is currently not available to bra manufacturers and retailers in South Africa, since breast volume and measuring of the inframmary fold lines of the breasts are difficult or almost impossible to obtain on very large women, when using the traditional method of a tape measure. The process is not only embarrassing to the women involved but is also very invasive and unreliable. The 3D scan and the tape-measure extracted torso body measurement data once analysed for similarities and anomalies in the different data extraction methods used in this dissertation, will enable the South African intimate apparel manufacturers and retailers to make informed decisions, when manufacturing bras for plus-sized women, focusing particularly on the pattern pieces for bra cup panel design or breast volume and underwire bra designs.

1.1 PROBLEM STATEMENT

Discussions with intimate apparel manufacturers and retailers have clearly indicated a need for more accurate and relevant bra torso measurement data, notably breast volume or bra cup size, for plus-size South African women. The 3D scan technology lends itself admirably for this purpose as it has the ability to extract traditionally difficult -measure breast areas. This study is therefore aimed at applying the 3D scanning technology to extract more accurate and reproducible torso measurement data on the breast surface dimensional parameters, such as breast volume, contour and size and depth that could be used for manufacturing better fitting bras and in the optimization of bra sizing systems. Essentially this study will investigate the correlation and agreement between the 3D scan torso body measurement data and the traditional tape-measurement methods of data extraction and relate the results to the current bra sizing systems in use by using an expert system developed by [TC]2 for extracting breast volume data for plus size women.

1.2 OBJECTIVES AND SCOPE

The objective of this research is to collect surface breast body measurement data for plus-sized women using a 3D body scanner. This study, with a target sample of 176 plus-sized women aged between 23 to 60 years old, covering various ethnic groups, employed by Playtex (Pty) Ltd. Durban, South Africa, aims to:

1. Compare the upper torso measurement data collected using the traditional tape-measurements with that extracted by a 3D body scanner.
2. Convert the data extracted into a bra size for every subject scanned using the Playtex's-Measurement- Bra sizing chart, then compare this against the bra sizes suggested by the two systems i.e. tape-measure system and 3D body scanner expert system to determine which is closer to the size that the subject should be wearing.
3. Determine whether the breast quadrant data will provide the bra manufacturers with sufficient data for the designing of bra cup panels and underwire bras for plus-sized women.

1.3 DELIMITATIONS OF THE RESEARCH

The size prediction research for intimate apparel using the 3D body scanner is limited to:

1. A target population of approximately 176 plus-sized women aged 23 to 60 year old, covering the ethnic groups employed by Playtex (Pty) Ltd situated Durban, South Africa, that have no history of breast cancer or breast surgery and are not pregnant nor breastfeeding.
2. 3D scanning which will be conducted on the subject wearing a controlled styled, soft bra that is comfortable and slight under-wired.
3. Providing analyzed data on torso body measurement points extracted from the 3D scans. The data collected using both the manual and the 3D scan methods can be used to optimize the intimate wear manufacturer's current size chart, by providing the manufacturer with updated 3D scan body measurement data to enable the manufacturer to make informed adjustments to the current bra sizing chart.
4. Providing the manufacturer with surface breast volume data for plus-sized woman for designing of bra cup panel pattern pieces for better "fitting" bra cup panels and underwire bras for plus sized woman.

This study will not:

1. Examine the commercial viability of bras.
2. Investigate the cloth construction, finish, and price of the fabric currently used in manufacturing bras by Playtex (Pty) Ltd.
3. Design bras from the 3D scan data collected, but will merely provide the manufacturer with sufficient information to establish whether the current size chart in use has sufficient plus-sizes on the range to accommodate the South African plus-sized women.

1.4 SIGNIFICANCE OF THE STUDY

The breast volume measurement data collected in this study using a 3D body scanner is not currently available to the South African intimate apparel manufacturers and retailers. A study of this nature has not been conducted in South Africa before. There is no available 3D body measurement data on the female torso that can be accessed by bra manufacturers for manufacturing better fitting bra for plus-sized women. 3D body scanning is a technology aimed at reducing the problems of incorrect sizing of apparel through its ability to extract body measurement data that can be used to make custom fitting garments for both outer-wear and intimate apparel. The 3D measurement and collection process is quick, non-intrusive, uses white light and has the ability to scan large numbers of subjects. The 3D data collected can be stored indefinitely for future use and the data base can be continuously added to as new 3D scan measurement data becomes available, and which can be used for statistical analysis and monitoring changes in overall body profiles and body shapes of the saved 3D body scans, as and when required. The study measurement data set so generated is a dynamic set of information, which, when captured, can be re-analysed once new needs or information arise; making 3D body scanning the sizing survey technique of the future. This study is not only beneficial to the large to medium scale retailer or manufacturer but also to the brand owner. Once the data collected for this study is analysed, the 3D scan measurement data on plus-sized women, will become available for use by students, manufacturers and retailers in South Africa.

1.5 METHODOLOGY USED IN THE STUDY

1.5.1 Introduction

This study will involve a comprehensive literature research of anthropometric body measurement and 3D body scanning techniques used in bra manufacturing internationally and in South Africa. The experimental data will be collected using an American manufactured 3D full body scanner the [TC]2 -NX12, which is available for use at the Fibres and Textile Competence Area of the CSIR based in Port Elizabeth, South Africa. Demographic questionnaires will be used to collect data and gauge the views of approximately 176 plus-sized women aged 23 to 60years, comprising of the different ethnic groups enabling the researcher to collect information on consumer views and behaviour when purchasing intimate apparel, concerning body sizing, bra fit, shopping habits, current bra sizes, bra comfort and general perceptions of the women when purchasing bras. The same subjects will be scanned using the 3D full body scanner and their torso measurements will also be taken manually using a tape-measure. The body measurement data will be saved for further statistical analysis. The data will be input into software designed to extract torso measurement for manufacturing better fitting bras; bra cup size panel designs and underwire bras for plus sized woman. The bra cup size notations extracted by the 3D scanning will be correlated with the subjects claimed bra size for the 176 plus-sized woman selected by BMI as reported in Chapter 5 of this dissertation

1.5.2 The Preparatory work will focus on:

a) Reviewing research literature extracted from books, the internet, newspaper articles, research journals, conference papers, newsletters and private communications.
b) Determining the population sample size and strata.
c) Designing a demographic questionnaire for additional information, to be used in the data analysis.
d) Designing a flyer on the significance of the study to facilitate recruitment of the subjects.
e) Designing a consent form for the subjects to complete prior to the study, thus ensuring that anonymity of the scanned subjects is maintained.
f) Conducting trials on the best design, style and colour of bra for the subjects to wear when collecting measurement data on the breast of plus-sized woman using a 3D body scanner.
g) Conducting an informal survey on the current measuring techniques used by the South African retailers that provide bra measuring services in-stores to the general public.
h) Designing a company questionnaire on current bra manufacturing practices within Playtex, Durban, South Africa.

i) Designing a bra fitting questionnaire for a convenient sample “fit trials” of ten plus-sized individuals used in this dissertation when trying on the manufacturer recommended bra size against that recommended by the scanner software.

j) PowerPoint presentation on the significance of the study, to the management, employees and the shop-stewards of Playtex.

k) Verifying that the manual measurements are taken at the same body points of measure as that extracted on the 3D scanner extraction programme to standardize the measurement data collection process. The changes were programmed into the scanner software and a new mep. folder created,named Playtex Bust Extraction mep, which will be used for the extraction of the 3D scan measurement data of the 176 plus-sized for comparative analysis in Chapter 5.

l) Ensuring that every subject to be scanned receive an envelope with the required paperwork that had to be completed prior to scanning taking place, namely the demographic form, consent form and a flyer on the study. The demographic forms will be numbered consecutively with the same number being duplicated on the monitor of the computer attached to the Playtex Bust Extraction software programme for that subject.

m) Ensure that a team is available from Playtex to assist every subject with completing the paperwork, given a comfortable scanning garment and is manually measured, prior to scanning.

1.5.3 The Practical component of the study will involve:

a) Logistics and cost involved in moving the scanner from Port Elizabeth to Durban, South Africa.

b) Recruitment of 176 plus-sized women.

c) 3D scanning of 176 plus-sized women.

d) Taking manual body measurements, using a dressmaker’s tape measure, of the torso breast points used for manufacturing bras.

e) Comparing the current bra sizes as extracted by (d) above against those of the manufacturer’s size chart and the subjects predicted bra size using the Playtex Bust Extraction mep. This programme is Integrated into the [TC]2 software to extract between 20 to 25 upper torso bust measurements. Use will also be made of an “open source” expert system “New Bust Measurement” software that was created by [TC]2 to extract bust volume measurement data and recommended bra cup size. The programme divides the volume of the left and right breasts into four quadrants. The sum of the four left and right breast quadrants are equal to the total volume of the breast, or bra cup size.

f) Extracting breast volume measurement data for the 176 plus-sized women and comparing the 3D breast volume against that taken from the demographic forms as the subject’s claimed bra size.

1.6 DEFINITION OF CONCEPTS

Following is a list of abbreviations and specific terminology used in this dissertation:-

- **CSIR** – Council for Scientific and Industrial Research.

- **Fit** – be of the right size or shape.

- **Size** – measurements, dimensions, largeness, a class unto which clothes are grouped according to size.

- **3D Body Scanner –** the three dimensional body scanner (3D) is a tool that captures information about the surface of the body using multiple white light and charged couple cameras. This three-dimensional image is an accurate replica of the scanned object, viewed, rotated and measured on a computer screen using white light and charged coupled cameras [30]

- **Notation -** bra cup size expressed as an alphabetical number i.e. A,B,C.

- **Ease –** The amount of fabric in a garment beyond what is required to fit the body exactly.[30]

- **mep. –** measurement extraction programme.

- **Bust Girth –** circumference around the torso taken under the breast.

- **Under-wire –** the wire used at the bottom of the bra cup at the inframmatory fold line.

- **kg.** – kilograms.

- **cm** – centimetres.

- **US –** United States.

- **Utilitian** – clothing that meet many practical and protective purposes.

- **Scan Data** – The information captured by the body scanner in the form of XYZ coordinate points. The resolution of accuracy of the data is 1mm in the horizontal and 2mm in the vertical plane.[30]

- **Bra** – is an article of clothing that covers and elevates the breasts.[31.]

- **Sizing Systems** – The method or system used to create a set of clothing for a variety of people in the target market. The most common sizing systems in use today utilizes a base size designed for a fit model and a graded set of proportionally similar sizes derived from this base size.[30]

- **Anatomical position-** standing upright; relaxed.

- **Inframmatory fold line –** found at the base of the breasts.

- **Statistically Significant Difference –** the difference is unlikely due to chance.

- **Target Market** – a set of people from the population to which the company wishes to sell, defined by demographic information, such as age, income level, ethnicity, or interests and not by body shape or size.[30]

- **Fit Model -** a person hired by an apparel company to assist with the development of base size patterns by trying on a sample for every style. The fit model is chosen on her body size and proportions with the goal of representing all of the people in the target market.[30]

- **Virtual Bra** – the method of testing fit by putting on a virtual body or "dressing" a scanned body image with a bra on the computer screen, this enables the assessor to evaluate the fit of the garment without actually trying it on. [30]

- **CCD** – charge couple device (camera)

- **CAD** – computer aided design.

- **Of-the-Rack** or (Ready-to-Wear) - clothing manufactured in size sets, designed to be purchased in an appropriate size and worn without alterations. The great majority of clothing made today is ready-to-wear.[30]

- **Bust Full –** the over-bust measurement.

- **"Shelf bra" -** A shelf bra is an open bust bra that allows the breasts to show at the top of the bra whilst maintaining the support needed underneath the breast area.[32]

CHAPTER 2 – THE BRA

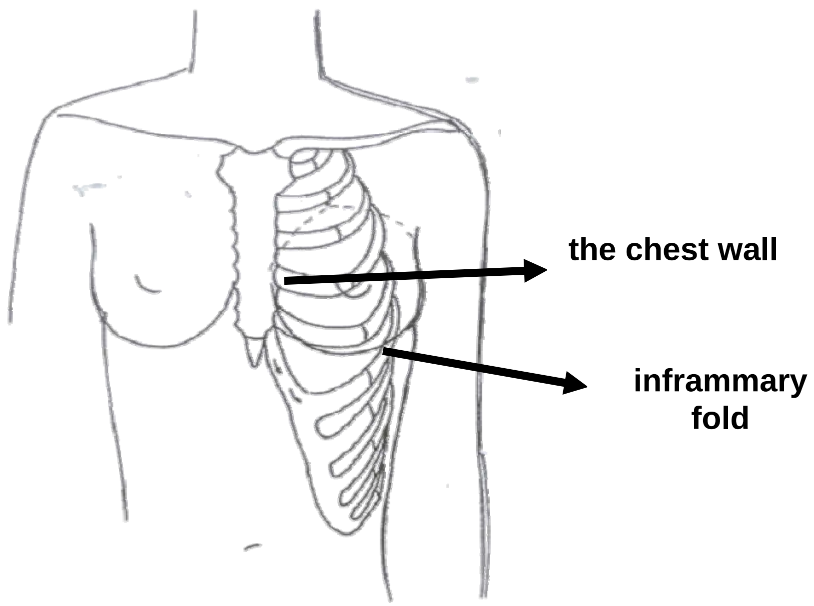
To provide a better understanding of the complex nature of fit and comfort of bras and the objectives to be achieved in Chapter 1.2, this chapter explores; the shapes and sizes of breasts; the different types of bras available to the plus-size consumer today and the current measuring techniques and the common problems that the plus-size woman experiences wearing a bra of the incorrect size.

2.1 A BRIEF ANATOMY OF THE BREASTS

Breasts are modified soporiferous (sweat) glands, producing milk[33]. Breasts are composed of fatty tissues called adipose tissues, which are held in place by Cooper's ligaments bonded by a layer of skin.

FIGURE 2.1.

ANATOMY OF THE BREASTS

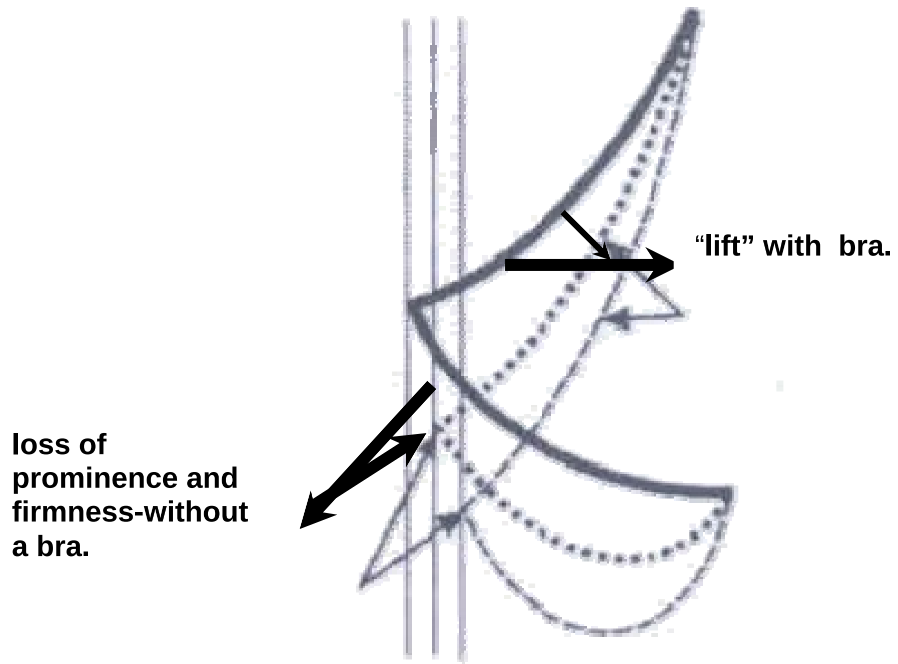


SOURCE: Adapted from Corsetry Presentation for Edcon.[34]

The size can change due to time and other factors, such as weight gain or loss, puberty, pregnancy or ageing. Each breast has a nipple surrounded by an areola. The larger mammary gland within the breast produces milk. The shape is largely dependent on the support from the skin and the ligaments of the breasts and the underlying chest. These ligaments and the overlying skin determine the breast shape. Breasts are found on the chest wall between the second and the sixth rib as illustrated in Figure 2.1.above. The exact mechanisms that determine breast shape and size are relatively unknown and it has been claimed that the normal anatomical support is inadequate in woman with large breasts or the elderly. Therefore, the bra is said to provide an artificial means of providing that support as it is assumed that the breast cannot support itself.[35] This concept is illustrated further in Figure 2.2 that shows the effect of "gravitational load" on the breast position of an unsupported breast (without a bra) and one that is supported by a proper fitting bra; resulting in loss of "breast prominence and firmness" as the bra is said to assist the postural muscles, in supporting the spinal alignment muscles thereby relieving "gravitational load" or stress on the body.

FIGURE 2.2

BREAST POSITION WITH AND WITHOUT A BRA



SOURCE: Adapted from http://www.thehealthybracompany.com[35]

Although breast symmetry is not uncommon, the left breast generally is larger than the right breast. This is especially so in heavier built women.[33]

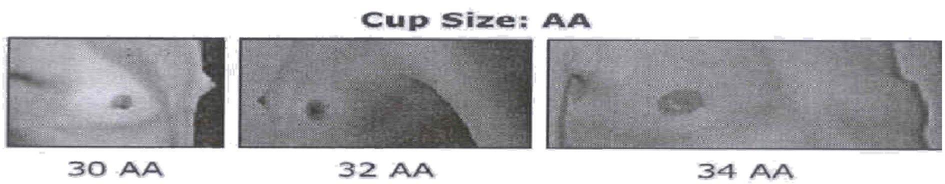
2.2 THE DIFFERENT BREAST SHAPES AND SIZES

The size and shape of the breasts are determined by the amount of fatty tissue that is contained within. Breasts are said to be asymmetrical where one breast, usually the left breast, is slightly larger than the other i.e. the right. The breast guide[36] recommends different cup bra size notation based on the different breast shapes as listed in Figure 2.3 below. These breast images illustrate the challenges faced not only by intimate apparel manufacturers and retailers but also by the consuming public; that bra sizing and fitting is a very complex issue and that there is no one size that fits all, although there has been considerable standardization of bra sizes and cross grading over the years.

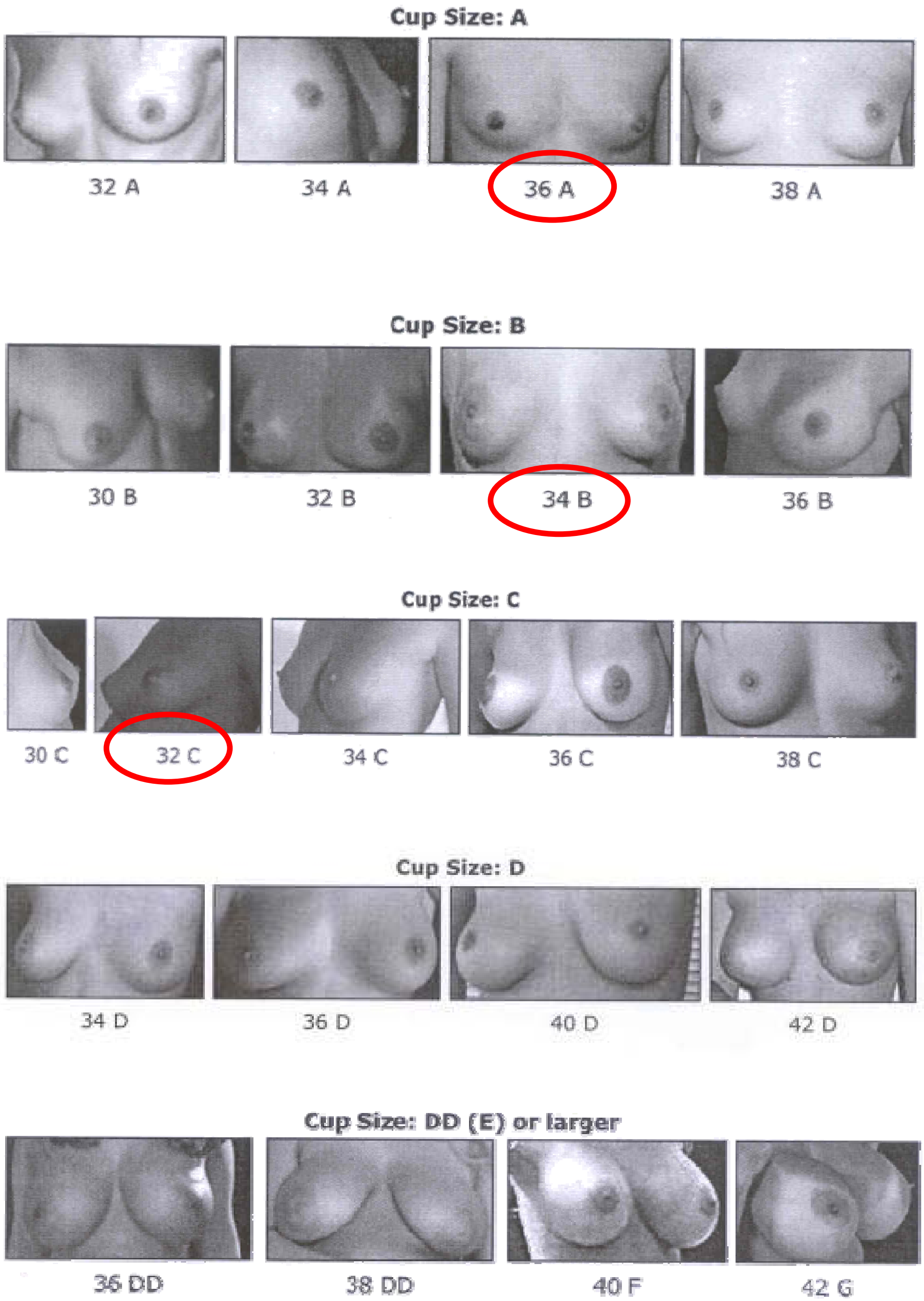
The illustrations below show the recommended bra cup sizes related to breast shapes and sizes classified from the smallest to the largest bra cup size. The largest bra cup sizes being D to DD and, although less common, the larger cup sizes of F,G, and H are also available to very large breasted woman. It is interesting to note that the bra notations circled in red represent a typical cross grading method used in the industry; although it varies from one manufacturer to another. Hardaker *et al.*[37] note that cross grading assumes that if one is a size 34B bra cup, then one can wear a size 36A bra cup or a 32C bra cup and that the band sizes are different.

FIGURE 2.3

BRA CUP SIZE EQUATED TO NUDE BREAST SHAPE AND SIZE



cont...



SOURCE: Taken from The Breast Guide[36]

Figure 2.3 shows the different bra cup sizes suggested as cross graded sizes. For example, women who claim to wear a bra size labeled 34B, can also fit into a bra size labeled 32C or a bra size labeled 36A. As noted from the illustrations above, the breast sizes and shapes for these bra size labels are visually very, very different.

Therein lies the challenge of obtaining the correct breast volumes or bra cup size for manufacturing better fitting bras especially for plus-size or large breasted woman. The breast volume in large breasted women is cited as being one of the most difficult parameters to measure because it is difficult to select the anthropometrical outline of the breast for the designing of under-wire and front panels of the bras. This concept will be explored further in the chapters to follow.

Tabulated in Table 2.1 below is a typical bra chart showing an example of cross-fitting in bold print.

TABLE 2.1

CROSS FITTING BRA CHART

Bra Cup Size Notation	**Bra Under-band**							
	32	**34**	**36**	**38**	**40**	**42**	**44**	**46**
A	32	34	**36**	38	40	42	44	46
B	32	**34**	36	38	40	42	44	46
C	**32**	34	36	38	40	42	44	46
D	32	34	36	38	40	42	44	46
DD	32	34	36	38	40	42	44	46
E	32	34	36	38	40	42	44	46

SOURCE: Adapted from Playtex (Pty) Ltd. (personal communication) [38]

2.3 EXPLANATION OF THE DIFFERENT BRA CUP SIZE NOTATIONS

According to the Bra Cup Size Facts[39,] the following are the functions of the different bra cup size notations:-

- **Small AA – A cups**: - Bras in this cup size provide light support. Contoured or push-up bras are said to emphasize the size of the bust.

- **Medium B-C cups**: - offer more support and are manufactured from either stretchy or rigid fabrics.

  B cups: - offer light, medium and firm support, both with under-wire and without.

  C cups: - offer more medium to firm support, wired and non-wired. The fabric chosen is usually made of supportive fabric and band.

- **Large D cups**: - these large cup sizes need to offer both comfort and support. Cup fabrics have limited stretch whilst the straps are thicker and fuller and the cups are structured, providing excellent support and coverage.

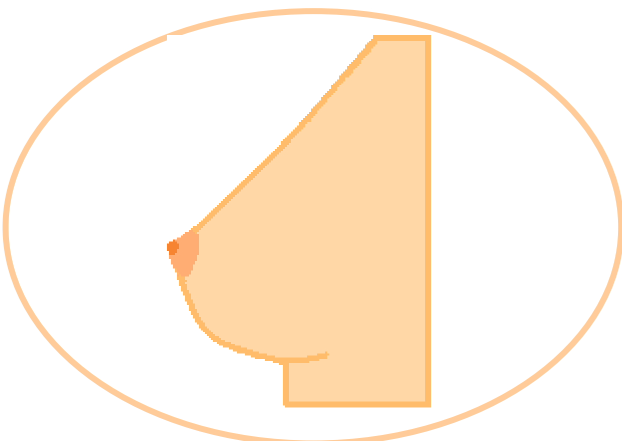
- **Extra Large DD – E cups**: - It is important that bras in these cup sizes offer maximum support and are functional and comfortable. The straps are usually wide and may be of the padded variety. Bras of this size are usually manufactured of supportive fabrics, with wide side and back panels.

2.4 THE DIFFERENT TYPES OF BREASTS

Research suggests that no two women are the same and that the size and shape of women's breasts vary depending on genetic factors, region, diet , climate and other factors.[40] Breasts are said to come in a large variety of shapes and types; but the different types can be broadly classified as illustrated in Figure 2.4 below.

FIGURE 2.4
DIFFERENT TYPES OF BREASTS

- **Perfect breasts**

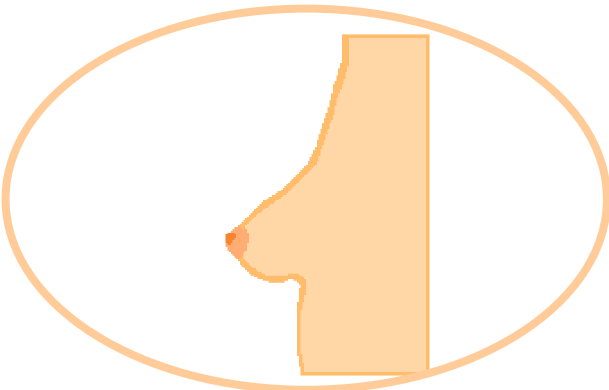


- **Swooping Breasts**

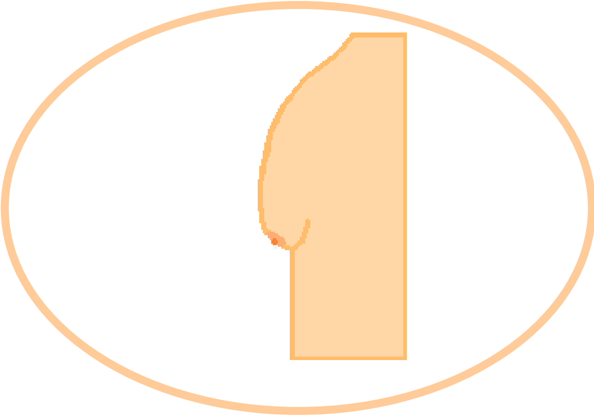
- **Saggy or Ptotic Breasts**

- **Small Breasts**

- **Tubular or Constricted Breasts**



- **Pectus Carinatum or Pigeon Breasts**



SOURCE: Adapted from Common Breast Abnormalities and Solutions[40]

2.5 THE DIFFERENT BRA STYLES CURRENTLY AVAILABLE FOR LARGE BREASTED WOMEN

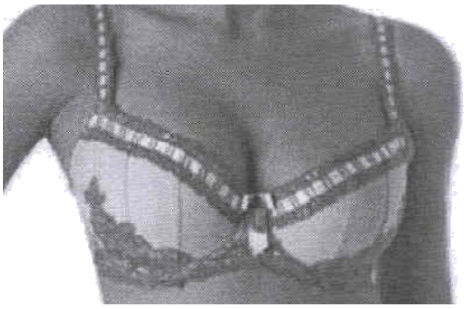
Today, due to the hi-tech science of bra design, women can chose a style to suit every occasion and outfit. The right bra can either, push breasts up, smooth them out, or squeeze them together. Figure 2.5 illustrates some of the different types of bra styles available to the modern woman today; the intended function of the bra style and the intended target market segment. The different bra styles are included into this dissertation to add value to the comments made by the plus-size women that took part in the "bra style trials" discussed in Chapter 5.

FIGURE 2.5

DIFFERENT BRA STYLES RECOMMEMDED FOR PLUS-SIZE WOMEN

2.5.1 - SOFT BRA

A soft cup is one with or without an under-wire. This design is better suited to maternity, sports bras and for young teenagers and for large breasted woman.

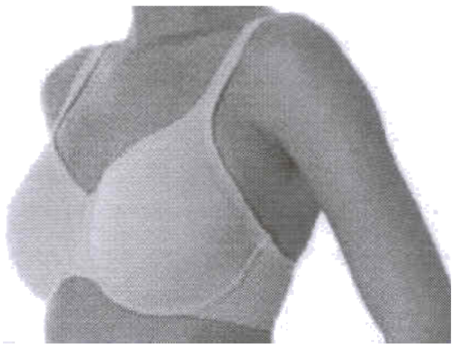


2.5.2 - BALCONETTE

This bra style is of a low neckline that goes straight across the breast, with wide straps for square necklines generally recommended for large breasted women.

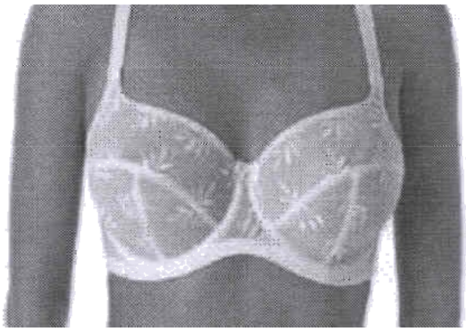
2.5.3 – SPORTS

A good sports bra is said to reduce breast movement by up to 50%. Some of the features are wide non-stretch straps, moisture wicking fabric, seamless cups and cushioned fastenings.



2.5.4 - MINIMISER

A minimiser bra is said to flatten the breast tissue so that the breast do not protrude as much, and one can do up one's shirt buttons, generally for large breasted women.



2.5.5 - FULL-CUP

This style usually covers the entire breast. Recommended for large breasted women.

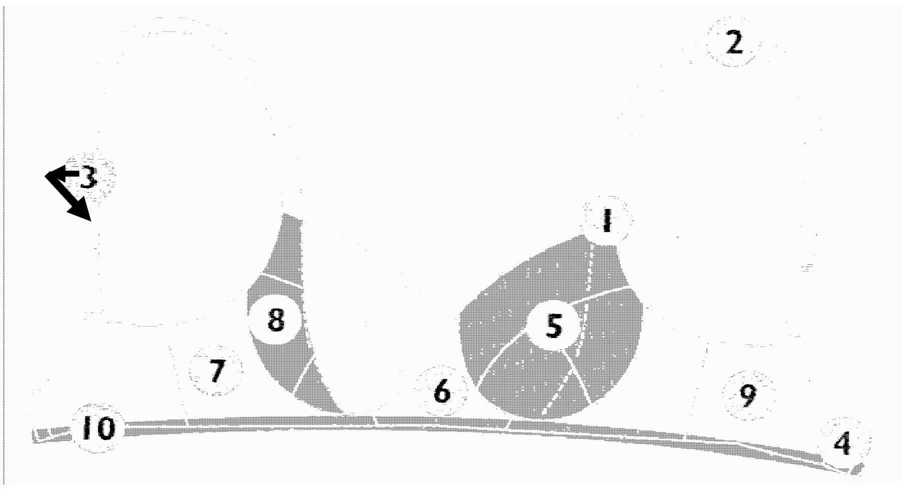
SOURCE: Taken from The Bra Book[41]

2.6 THE DIFFERENT COMPONENT PARTS OF THE BRA

Illustrated in Figure 2.6 are the various component parts that make up the bra and the functions of each piece. This is included into this Chapter and is referred to in the upcoming chapters of this dissertation. The numbers are explained on the next page.

FIGURE: 2.6

THE VARIOUS COMPONENTS MAKING UP A BRA



SOURCE: Adapted from The Bra Book[41]

2.6.1: APEX

The apex is that part of the bra where the strap joins the cup.

2.6.2: THE STRAPS

The strap keeps the cups in place.

2.6.3: ADJUSTER

The adjuster is used to tighten or loosen the straps. The design of the bra dictates its position as it varies from one style to another.

2.6.4: HOOK AND EYE

This is used to fasten the bra to the body.

2.6.5: CUP

The cups support the breasts, with the bottom half of the cup usually lined.

2.6.6: CENTRE FRONT

This is the piece that fits flat against the chest in between the breasts.

2.6.7: CRADLE

The cradle helps in positioning the cups and the wires securely against the chest.

2.6.8: SLING

This is popular in cups for larger breasted women. The sling is used in the infer cup (see illustrated numbered 8), to provide additional support to the side of the breasts.

2.6.9: WING

The wing fastens at the back, secures the bra to the body and also positions the wire around the breast.

2.6.10: UNDER-BAND

The under-band runs at the bottom of the bra and anchors the bra to the body.

2.7 THE DIFFERENT BRA MEASURING TECHIQUES

The first known record of bra cup size in the clothing manufacturing industry was in 1922 when a seamstress in a New York dress shop noticed that "a bra that fit one woman did not fit another woman"[42,] which led to the development of the bra cup size notations and bras for different ages. Today, a large range of bra sizes caters for a wide variety of women's body shapes and breast sizes. The volume or the bra cup that fits over the breasts and the back strap length that goes around the body are the basic measurements used in bra sizing. Sizing varies from country to country and from one manufacturer to another and from one brand and size to another, creating many problems and confusion to consumers in term of comfortable fitting bras. Researchers[12, 13, 14, 15] have demonstrated that the problems are largely related to the breast volume and not to the length around the body. Current bra sizing methods use the torso girth circumference to estimate the volume of the breast but this is unreliable.[6] It is unclear how the bra manufacturing industry establishes the volume of the actual breast, as the only recorded research studies on breast volumes are in medical journals using different techniques of mammography. Literature reviews on breast volume in medical journals are numerous and reach varied conclusions on how the data on breast volume is collected; from software that divide the breasts; to coefficient of variation and the use of X rays using curved epipolar lines for predicting the breast volumes; to MRI, thermoplastic casts, anthropometric methods and the Archimedes principle. Some such studies were conducted by Qiao[43] who found that breast volume correlates positively with weight, waist circumference, buttock circumference and chest circumference, but negatively with body height; and that the breast volume increased by 20ml for every kilogram over the women's ideal weight. Loughery *et al*[18] study of using a moulding based measurement method. The breast boundary was closed by the use of base measurement planes and the volume inside was measured. However the curvy nature of the breast boundary was not clearly defined, since the base plane for the measurement was lying in a single geometric plane or flat. This study found that the average breast volume when using stereo cameras was 437.5cm³. Although there is no reported bra cup size notation associated to the average breast volume. Lee *et al* [27] study using a 3D phase shift moiré found that the folding line method was useful in finding the continuous and natural boundary of the breast so that the breast volume could be measured more accurately for form fitting clothing items. Losken *et al*[28] validation of the three-dimensional imaging of the breasts found that when evaluating breast measurements, there will always be inherent subjectivity involved, although 3D technology does provide valuable information, more specially in the longitudinal evaluation of results. Kovacs *et al*[44] in their study on the comparisons between breast volumes measurement using 3D surface imaging and the classical techniques, found that there is no one acceptable method as the methods measure different breast volume areas and that the comparison was only possible at the measurement precision levels. Lee *et* al[27] found that by using the global average radius of the under breast curve in the design of the bra wire improved the shape satisfaction and wear sensation of the breast. This was more especially so for women with breast curves that were skewed along the torso. Westreich[45] study on aesthetically perfect breast found that there was statistical correlation between the parameters of the breast and the torso shape to the breast volume. Bras[46] reported that different people have different breast shapes and that the most common bra fitting problem was due to the incorrect bra cup size whilst Descamps et *tal*[47] study reported that one cannot use the bra cup size to predict breast volume, as this was an unreliable indicator of breast volume. Catanuto *et a*l[48] study focused on segmenting the breast using reproducible landmarks into four quadrants using a 3D laser scanner. The subjects were scanned thrice by rotating them into 45 degree angles. The computations generated were based on the total surface area and on the single subunit area of the breast. More importantly, the study found that breasts with identical volumes can result in two completely different breast shapes and that small physical deformity of the subject's chest wall or spinal column can prejudice the final results. Data collected by the 3D scanner is considered to be far more accurate, collected quickly and non-intrusively in the upright standing position resulting in the creation of reliable and more reproducible 3D virtual models of the torso, more especially the breast regions. The data output is analysed to quantitatively evaluate breast volume, shape, and contour, of surface and point to point breast measurements. Using 3D body scanners to collect breast measurement data is gaining popularity in the clothing and medical fields as scanners become more affordable and due to the ease with which the breast surface data can be collected, stored and analyzed.

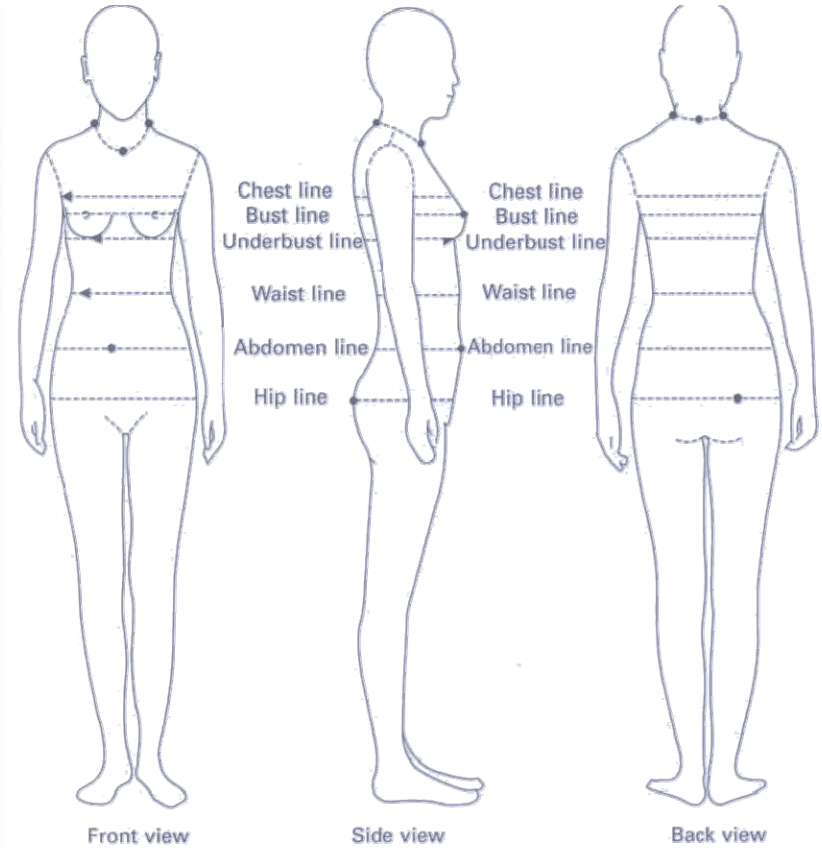
However, there is no one generally recognized method of breast volume extraction.

The Cornell Glossary[30], state that the traditional method of extracting body measurement data is commonly known as anthropometry. This is the study of measurements of humans for classification and comparison in apparel design and in equipment design for identifying how the population varies in shape and size. Anthropometrists measure the body surface landmarks using anthropometric tools, such as the tape measures and caliper even though the measurers are trained professionals, the manual process is very time consuming and fraught with difficulty. Jones and Rioux[49] mention that investigators have been attempting to measure the human body since the 17th century.

Figure 2.7 shows the body landmark measurement points as extracted by anthropometrists to determine breast shape and proportion.

FIGURE 2.7

ANTHROPOMETRIC BODY LANDMARKS

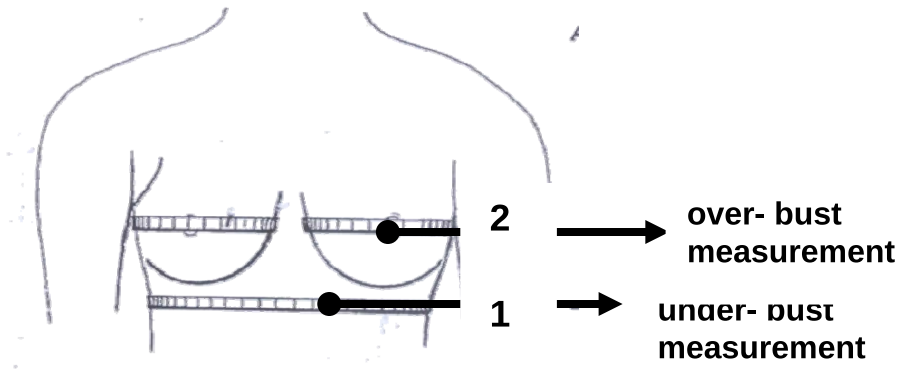


SOURCE: Taken from "Innovation and Technology of Woman's Intimate Apparel. p.33[50]

In the medical field, the horizontal method of extracting bra data is cited in a United States Patent by Petcher[51] as one of the methods of bra size determination by direct measurement of the breast, for use in breast surgery to determine breast volume (Figure 2.8). The difference between that reported for breast volume in the medical field and that used in the clothing industry is not in the method used for measuring the under-bust but in how the over-bust is measured and how the bust volume is calculated. According to the bra industry every inch increase in the difference in over-bust and under-bust equates to an increased alphabetically notated bra cup size, and the direct methods used in the medical field measure each breast separately using linear measurements, and seven inches is cited as a “A” cup equivalent and eight inches as a “B” cup.

FIGURE 2.8

EXAMPLE OF BRA SIZE DETERMINATION USING THE DIRECT METHOD IN THE MEDICAL FIELD

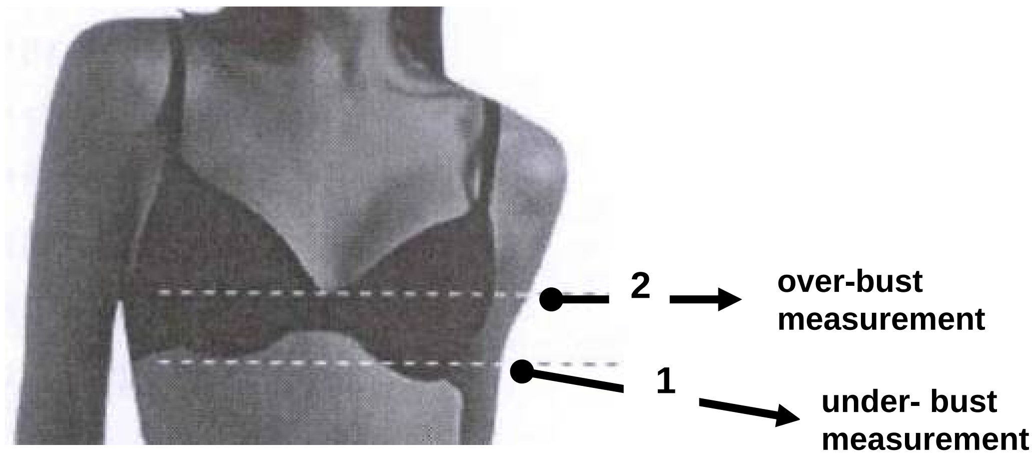


SOURCE: Adapted from United States Patent: nr. 5,965,809, 1999.[51]

It is interesting to note the differences in extracting and determining the bra cup size in these two fields, where breast volumes are used to determine the consumers’ bra cup size. In the clothing industry, bra size can be described by two values, as illustrated in Figure 2.9. The first value is the under-band which is a number based on the circumference of the chest under the breast. The second value is the bra cup size, calculated by subtracting the under-bust measurement from the over-bust measurement, which is then denoted by a letter of the alphabet. The current method of determining bra cup size in the bra manufacturing industry is therefore the difference in the horizontal linear measurements of the under-bust and over-bust measurements converted into a bra cup size. For example a difference of one inch corresponds to an "A" size cup and two inches corresponds to a "B" cup size with every inch increase corresponding to an increasing alphabetical notated bra cup size.

FIGURE 2.9

COMMON BODY LANDMARKS USED FOR BRA SIZING IN THE CLOTHING INDUSTRY



SOURCE: Adapted from http:playtex.co.za/aboutus.php [52]

A 34B bra size is for a 34 inch-size under-band and a B bra cup size[53]. Traditionally the measurement of the bra cup size is taken in centimetres and that of the under-band in inches. Research indicates that a pair of breasts weighs several kilograms. According to Wikipedia (2007) a pair of "D" breasts cup size can weigh as much 10kgs, depending on the bra cup and band size. The principle defining characteristic of the bra [35] is to support the weight from the back and shoulders and not from below. The back straps and bands should not support the breasts, as this could cause the weight to transfer from the breasts to the neck, shoulders and head, causing injury and pain, more especially so in large (plus-size) breasted woman. Therefore, it is important to understand that the principle mechanical function of the bra is to support and shape as opposed to lifting the breasts.

The shape and tissue distribution in larger breasted women are different to that of the smaller breasted women, being more ptotic and bulbous rather than conical. There are also problems associated with the accurate under-band measurement in larger (plus-size) woman, since the tape measure “sinks” into the flesh more easily.

Bra sizing and fit are inconsistent from one bra manufacturer and retailer to another and obtaining the correct fitting bra is further complicated by the size and shape of women’s breasts.

The researcher’s personal experience at the outset of this study in being measured for a bra by different retailers and lingerie stores in Port Elizabeth, South Africa, also highlighted that not all stores use a standard method for calculating the bra size with sizing also varying from one store to the next. Whilst some stores use a graduated bra tape measure that listed the under-band and the corresponding alphabetically notated bra cup size on the same tape-measure, others use a dress-makers tape measure and read the over-bust and under-bust measurements off a standard bra size chart in the store, irrespective of the brand. The recommended bra size was also not consistent from one retail store to the next.

2.8 HISTORY OF BRA SIZING SYSTEMS

Historically, the recorded sizing system used for current bra manufacturing was founded in the year 1926, a system that was originally intended to classify breast shapes into analogous types. Warner Brothers[54], in America, incorporated the volume size into the bra size specifications in 1935. This gave birth to the alphabetically notated sizing system for bras and the basic modern bra sizing charts in use today, although manufacturers and bra designers of the different brands use different sizing charts for specific target markets. Consumers find their sizes by trial and error, by trying on bras of different styles, models and brands, until they find a bra that fits well. This is still the most dependable method of finding a bra that fits well, because of the differences noted above, as well as the fact that body measurements used for manufacturing bras are taken manually and are prone to error. Today, many countries still use the metric system whilst others prefer the imperial system to determine the bra under-band size. There are various International Standards Organisations systems, including the European, Japanese and Chinese bra sizing standards, in use today for developing bra sizing charts. This dissertation will only make reference to the comparisons in the metric and imperial systems, as illustrated in Table 2.2 and the conclusions as drawn and reported by Zheng *et al.*[13] as these are the most popular bra sizing systems in use today.

TABLE 2.2

COMPARISON OF THE IMPERIAL AND METRIC BRA SIZING SYSTEMS

B cup with different Band Sizes								
1. **Imperial Size**	30	32	34	36	38	40	42	44
Corresponding full bust (cm)	78.7	83.8	88.9	94.0	99.1	104.1	109.2	114.3
2. **Metric Size**	65	70	75	80	85	90	95	100
Corresponding full bust (cm)	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5
Band Size 34 with different Cup Sizes								
1. **Imperial Size**	34AA	34A	34B	34C	34D	34DD	34E	34F
Corresponding full bust (cm)	83.8	86.4	88.9	91.4	94	96.5	99.1	101.6
2. **Metric Size**	75AA	75A	75B	75C	75D	75DD	75E	75F
Corresponding full bust (cm)	82.5	85	87.5	90	92.5	95	97.5	100

SOURCE: Adapted from Innovation and technology of woman's intimate apparel. p.49 [50]

Table 2.2 is based on a B bra cup size of different band sizes and a band size 34 with different cup sizes. The following conclusions were drawn after the equivalent centimetre values of the bust girth indicated in the imperial system were compared and plotted against those of the metric system for the bra sizes.

1. The size intervals are almost the same for both systems per one band- size difference. namely 5cm or 2”.
2. A similar bra cup grading was used in both the systems, namely 2.5cm or 1” per one cup size difference.
3. Using 75B as the base size; the bust girth of the sizes smaller and larger than 75B, of the metric system, is always smaller than that of the imperial system.
4. The linear regression relationship between the imperial and metric systems for the different band or bra cup sizes was found to be $y = 0.9843\ x$, where y denotes the metric bust girth and x is the imperial bust girth.

An article in Apparel Search[53], reports that a difference of one inch requires an “A” cup size and two inches a “B” bra cup size, and that it is far more difficult and confusing when calculating the larger cup sizes. A 5 inch difference can either represent a DD or E cup; 6 inch difference can be labeled as either DDD,EE or F. A 7 inch difference can be labeled as EEE, FF or G bra cup size, with an 8 inch difference is an H bra cup size. Manufacturers are said to use these different notations as marketing tools as there is “essentially no difference between them from the DD cup size upwards” and the size notation is used at the discretion of the manufacturer. This information on size notations, more especially for the “larger bra sizes”, is useful for comparison of the 3D scan volume data collected for the sample of 176 plus-sized-woman used is this study; reported in subsequent chapters and compared against the manufacturers current bra size chart. There are numerous articles published on the internet explorer in bra shopping websites that have built in bra size calculators [52] and instructions on how to measure the torso. Measurements are input into an on-line calculator, and the system recommends the bra size, for that individual. The output can be calculated using either the metric or the imperial bra sizing systems.

The researcher found that some of the on-line bra calculators published on the different bra websites are limited and could not calculate bra sizes for plus-sized or “large” women and that the bra sizing systems used in different countries are not the same. Tables 2.3 and Table 2.4 illustrate the different international and South African bra sizing systems that are available to the on-line shopper today.

TABLE 2.3

BRA BAND SIZE CONVERSION CHART

UK	USA	Europe	France	Italy	Australia	(Playtex) South Africa
28	28	-	-	-	-	28
30	30	-	-	-	-	30
32	32	70	85	1	10	32
34	34	75	90	2	12	34
36	36	80	95	3	14	36
38	38	85	100	4	16	38
40	40	90	105	5	18	40
42	42	-	-	-	-	42
44	44	-	-	-	-	44
46	46	-	-	-	-	46
48	48	-	-	-	-	48
50	50	-	-	-	-	50
52	52	-	-	-	-	-
54	54	-	-	-	-	-
56	56	-	-	-	-	-

SOURCES: Adapted from www. breasttalk.co.uk/size_charts.asp [56]
Adapted from the Playtex Measurement – Bra Sizing Chart [APPENDIX 1]

TABLE 2.4
BRA CUP SIZE CONVERSION CHART

UK	USA	Europe	France	Italy	Australia	(Playtex) South Africa
AA	AA	AA	AA	-	-	AA
A	A	A	A	A	A	A
B	B	B	B	B or Nothing	B	B
C	C	C	C	C	C	C
D	D	D	D	D	D	D
DD	DD or E	E	E	DD	DD	DD
E	DDD or F	F	F	E	E	E
F	G	-	-	F	F	F
G	I	-	-	-	G	-
GG	J	-	-	-	GG	-
H	K	-	-	-	H	-
HH	L	-	-	-	HH	-
J	M	-	-	-	J	-
JJ	N	-	-	-	JJ	-
K	-	-	-	-	-	-

SOURCES: Adapted from www. breasttalk.co.uk/size_charts.asp [56]
Adapted from the Playtex Measurement – Bra Sizing Chart [APPENDIX 1]

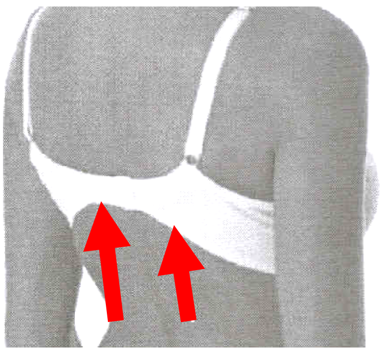
The UK and the USA use the Imperial sizing system with the alphabetical bra cup size notation, whilst most European countries use the Metric sizing system and the alphabetical bra cup size. Italy uses a sizing system that is based on numbers, with the bra cup size denoted by a letter of the alphabet, whilst in the Australian sizing system the band size is based on dress size and the bra cup size on the alphabet. The USA and the UK supply the smaller band sizes of 28 and 30cms, whilst the band size of the other countries begin at 70cm in Europe, 85cm in France, I in Italy and dress size 10 in Australia. The bra cup sizes show more consistency in the denomination used in the UK, USA, Europe and France, starting with the smallest bra cup size of AA whilst in Italy and Australia the smallest available bra cup size is an A. In South Africa, referring to the Playtex Measurement – Bra Sizing Chart (see Appendix 1), the band and cup size notations are the same as those of the UK, except that the Playtex chart lists the largest band size as 50cm and the largest bra cup size as an F.

2.9 SOME OF THE MOST COMMON BRA FITTING PROBLEMS

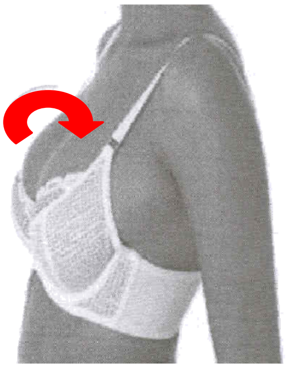
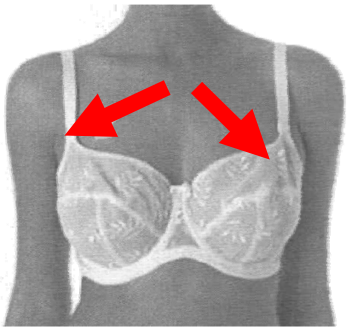
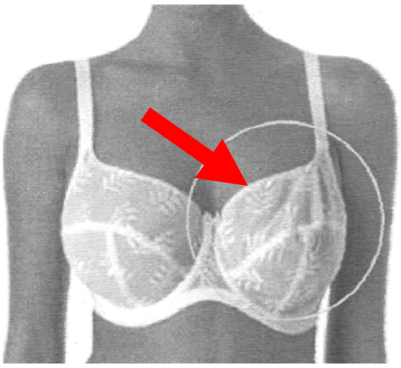
Back-bands that ride up the back, the band 'digging' into the flesh and slipping bra straps are some of the most common problems experienced by women worldwide. Shown below are some of the most common bra fitting problems and the possible solutions. The common bra fitting problems from Figure 2.10 to 2.16 was used as guidelines towards designing the bra fitting questionnaire as reported in Chapter 5 of this dissertation.

FIGURE 2.10 – 2.16

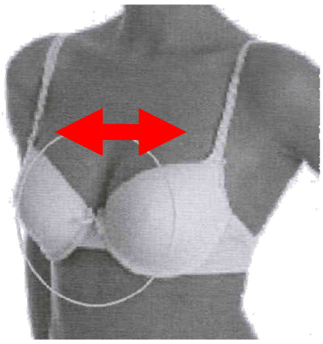
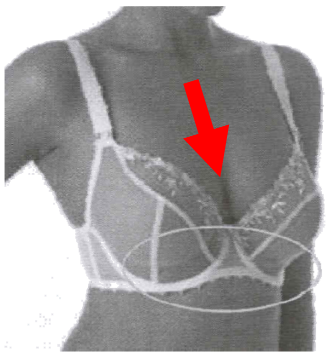
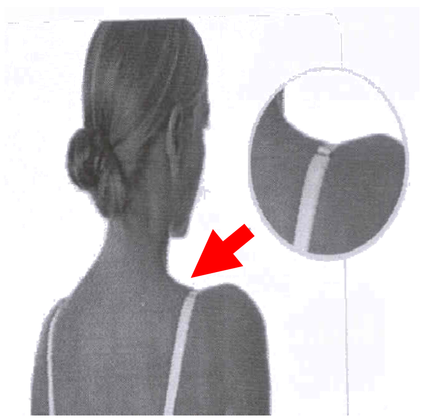
COMMON BRA FITTING PROBLEMS

FIGURE 2.10	PROBLEM	SOLUTION
	**Back of bra riding up.**	An under-band that is too large can cause this problem. The under-band should be in a straight horizontal line across the body.

cont…

FIGURE 2.11	PROBLEM	SOLUTION
	**Bust bulging over the bra cup.**	The bra cup is too small, use a larger bra cup.
FIGURE 2.12	**PROBLEM**	**SOLUTION**
	**Bra cup is too baggy.**	A smaller bra cup size or a balconette bra style is recommended.
FIGURE 2.13	**PROBLEM**	**SOLUTION**
	**Different size breasts.**	Possibly wearing a moulded bra.

cont…

FIGURE 2.14	PROBLEM	SOLUTION
	**Centre front lifting away from the body.**	The centre front should lie flat against the body. If it does not then the bra cups are too small, causing the breasts to push the centre front. Therefore, change to a larger cup size.
FIGURE 2.15	**PROBLEM**	**SOLUTION**
	**Front band pulling down**.	The under-band should lie just under the ribcage. If it pulls down lower then the band size is too small. Therefore, change to a larger band size.
FIGURE 2.16	**PROBLEM**	**SOLUTION**
	**Shoulder straps digging in**.	The under-band is too loose. Try a band of a smaller size or alternatively loosen the straps.

SOURCE: Adapted from The Bra Book [41]

2.10 BODY VOLUME INDEX

Body Volume Index[80] is the relationship between the distribution of body mass to volume and where on the body the mass is located and is suggested as an alternative tool to BMI. It is a computer based measurement of the body for obesity. BVI can differentiate between people who have the same BMI rating, but who have a different body shape and body mass distribution. The BMI of a person is measured manually by total weight and height, while the BVI is calculated by using 3D body data and the appropriate software to determine volume or weight distribution. BVI measures where the weight and the fat are located on the body rather than total weight or total fat content. The 3D body scanner determines the three-dimensional outline of a person's exterior surface, so that computation can be used to “calculate the part volumes and the part body composition of that person”.

BVI is not used as an analysis tool in this study on size prediction, but is worth noting for use in further studies conducted on plus-sized women. BMI was a conclusive indicator for use in this dissertation, as the subjects were initially recruited on visual observation of being “large breasted” and on dress size 36 or larger.

3. CHAPTER 3 – [TC]2- NX12 3D BODY SCANNER

This chapter will focus on the 3D body scanner and, where relevant, make reference to studies on the:-

1. Increased use of the scanner internationally to take body measurements that are more accurate and less-intrusive than those taken traditionally using a tape-measure.
2. The basic operating principle of the [TC]2-NX12 3D body scanner used in this study.
3. Brief explanation of the program used to extract the torso measurements for plus-sized woman used in this study; and
4. A brief overview of the operations of DBApparel ((Playtex (Pty. Ltd)).

3.1 THE [TC]2-NX12 3D FULL BODY SCANNER

3D body scanning has been quoted by Loker *et al*[57], from the Cornell University, as providing valuable 3-dimensional data of the human body surface which can be used to improve the fit of garments. Currently, 3D body scanning is increasingly being used by retailers and manufacturers to measure their customers and provide "made-to-measure" apparel. The Cornell University team pioneered studies on 3D body scanning and published amongst others, a paper on "size specific analysis of body scanned data to improve apparel fit". The first recorded study on breast measurements using a 3D scanner was conducted by Wacoal[58] to assess breast shape characteristics. The 3D system of data collection has the added advantage of being compatible with apparel CAD systems that can use the data to stitch a virtual bra. Lee *et al.*[27] used a folding line method to find the continuous and the natural boundary of the breast so as to measure the base and volume accurately. The Textile/Clothing Technology Corporation [TC]2 reported on a study[59] that was conducted for Victoria Secrets that collected scanned data of 1400 women resulting in the identification of four breast shapes regardless of the geographical location, age and ethnicity of the women. According to private communications from Dr. David Bruner, the CEO of [TC]2, the data collected is proprietary and the bra company used a [TC]2 scanner for collecting the 3D cloud forms and in analyzing the data. [60]

3D scanners have also been used extensively in the plastic reconstructive medical surgery field to conduct studies on breast volume for implants. There are numerous published papers on the different methods used to extract the breast volume data related to bra cup size. One such study was conducted by Descamps *et al*.[47] on South African women between January 1993 and January 1996 that established a formula for calculating the breast volume post-operatively correlated to the accuracy of the resection weight. Nevertheless, few such studies have been carried out using 3D body scanners with the subject in the upright anatomical position.

Worldwide there are thirteen different scanning systems available today, using light projection, laser projection or microwave technology to capture the 3D scans. The total 3D process and extraction times for the different scan generating systems are between 11 to 60 seconds.

One such 3D scanning system, namely the TC [2]-NX12, an American manufactured 3D full body scanner (see Figure 3.1) was used for collecting the 3D scanned body measurement data of size prediction for plus size women's intimate apparel.

FIGURE 3.1

[TC]2 - NX12 3D FULL BODY SCANNER

SOURCE: Taken from [TC]2 - 3D Body Scanner (http://www.tc2.com)[61]

The year 1985 heralded the production of the [[TC]2]] system that uses a horizontal sheet of light to completely surround the body, using projectors and cameras to scan the entire body[61.] The [TC]2 3D data capturing technology is based on the method used for measuring the three-dimensional surface of the earth, that was perfected in the 1900s, using the triangulation method. According to Simmons *et al*[62] this triangulation is the basis for measuring the human body, where the theodolites were replaced with light sensing devices. The triangulation data collected is a process of joining the point data from the body scan, creating a curved surface, enabling the scan data to be visualized as a solid object. Telmat, Hamamatsu, Wicks and Wilson and CogniTens represent other examples of commercially available 3D body scanners which use a light based scanning system similar to the [TC]2.

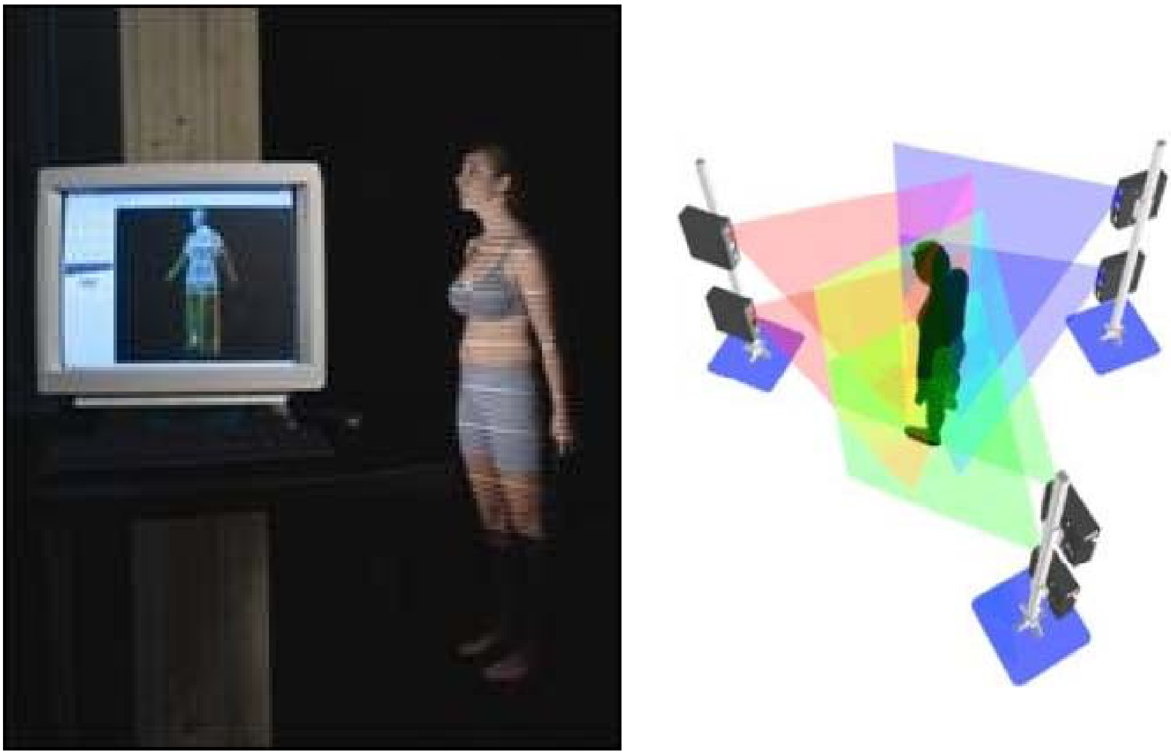
In the next section, the salient features of the TC[2]-NX12 3D body scanner and the 3D scan capturing and generating processes are discussed.

3.2 OPERATION OF THE [TC]2-NX12 3D BODY SCANNER

The NX12 is a custom apparel and design system that is used to capture critical body landmarks and anthropometric data that guide sizing of garments and for the generation of virtual models which use phase image profilometry, white light based projection, to capture the 3D cloud point form of the subject. White light is considered to be safer than laser based scanning technologies which have been rejected for perceived health risks. Simmons[63] reports that the profilometry method involves shifting the grating preset distances in the direction of the varying phase, thus capturing the subject's image in each position using structured white light as illustrated in Figure 3.2. The white light projects the image of a two dimensional sinusoidal patterned grating onto the surface of the body. The pattern projected is captured by CCD cameras, mounted at fixed positions on the front and back towers. A single sensor captures an area segment of the body surface. The data from all the sensors are combined to form an incorporated surface with critical area coverage of the body for use in the production of apparel. This information is used to calculate the 3D data cloud points as illustrated in Figure 3.3. The transitional yield of the pilometry method is a data cloud for all four views. The output is 400 000 processed points together with extracted body landmark measurements.[63]

FIGURE 3.2

PATTERN GRATING CONCEPT GENERATED BY THE [TC]2 SCANNER



SOURCES: Taken from www.tc2.com [61]

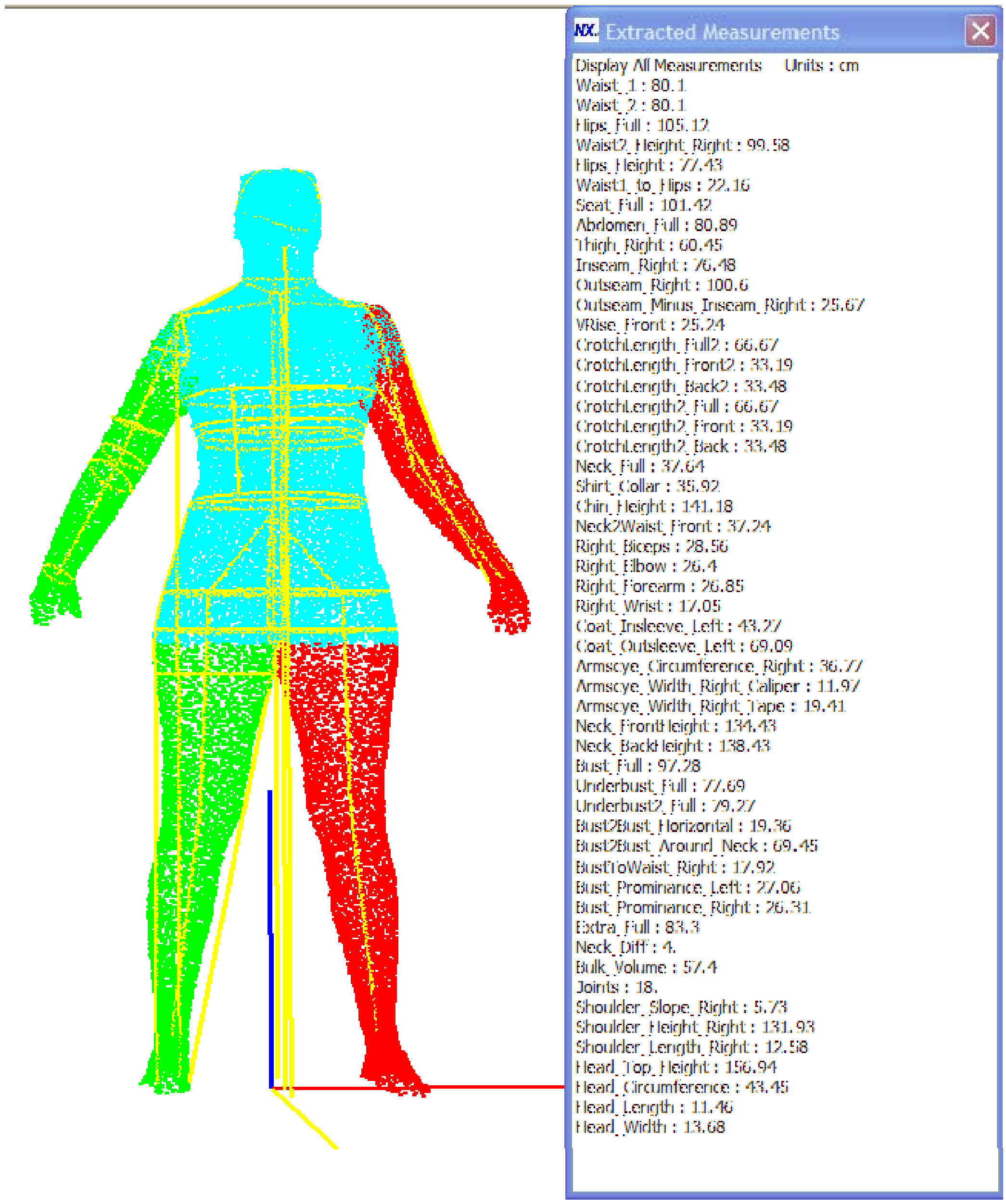
Taken from Three-Dimensional Body Scanners. Textile Magazine. [62]

The [TC]2-NX12 3D body scanner operates as a fully automated system that scans the entire body in six seconds generating approximately 100 to 176 body landmark measurement points. The 3D data is extracted in centimetres and inches, and produces a “true-to-scale” body model. The 3D scanner has the capacity to scan subjects up to 2.1 metres in height and 1.2 metres in width. The scanning process is quick and non-intrusive. The image output is in the form of 3D cloud point data. Because of the accuracy of the data generated, the [TC]2- NX12 was the 3D body scanner chosen in the 2000’s to conduct a comprehensive national sizing survey in the United Kingdom, *Size UK*[64] as well as the *Size USA* national survey in 2002, The

3D body scanner measurements can be easily customized for each end user to meet their different data application needs.

FIGURE 3.3

SCAN OUTPUT IN 3D CLOUD FORM WITH EXTRACTED BODY MEASUREMENTS



3.3 NEW BUST EXTRACTION SOFTWARE

Rasband[65] stated that bra fitting begins with "a fair assessment" of the body. Hence collecting body measurement data using a 3D body scanner and storage of the 3D cloud forms of subjects of different shapes and sizes represent a faster and the most effective means of developing a bra library that can be saved and used indefinitely as different needs arise in the bra manufacturing industry. The sophistication of the 3D scan technology and the ability to import scans directly into apparel CAD software that enables the user to design and assess fit prior to any pattern pieces are cut (in virtual fit), will help to improve the fit and comfort of bras and increase the competitiveness of the bra production process. One such software program that was developed by [TC]2 to address the problems of incorrect fitting bras is "The New Bust Cup Size Extraction" software program. This is an "open source" expert system developed in conjunction with bra and swimwear manufacturers and the reconstructive medical fields, based in the United states of America and is compatible with the NX12 software. The ISO 8559 Standard[66] was used as guidelines for body point of measure input into the default program, but more body points of measure were included into the extraction software. This dissertation used two different software programs to extract the breast data; namely, the New Bust Cup Size Extraction mep, and the [TC]2 user defined propriety Bust Specific Measurement Extraction Programme for surface breast measurement data extraction.

Figure 3.4 is an example of the output from the New Bust Cup Size Extraction program. The torso and bust volume measurements are extracted in cubic inches. The average breast volume is based on the empirical bust volume for bra cup size notation extraction. In this example, the subject's bra cup size is assumed to be 18.0 cubic inches. According to the CUP SIZE CHART marked (A), this subject represents a B bra cup size as her bust volume measurements lie between 5 to 30 cubic inches marked (B). The measurements at the bottom of the list represent all the bra extracted measurements of the subject including the right and left bust volumes. The sum of quadrant volumes at the end of the list marked (C); the sum quadrant volumes left and right are the 3D measured volumes, as illustrated in Figure 3.5, as extracted by the expert system software.

FIGURE 3.4

NEW BUST SIZE EXTRACTION SOFTWARE PROGRAM OUTPUT

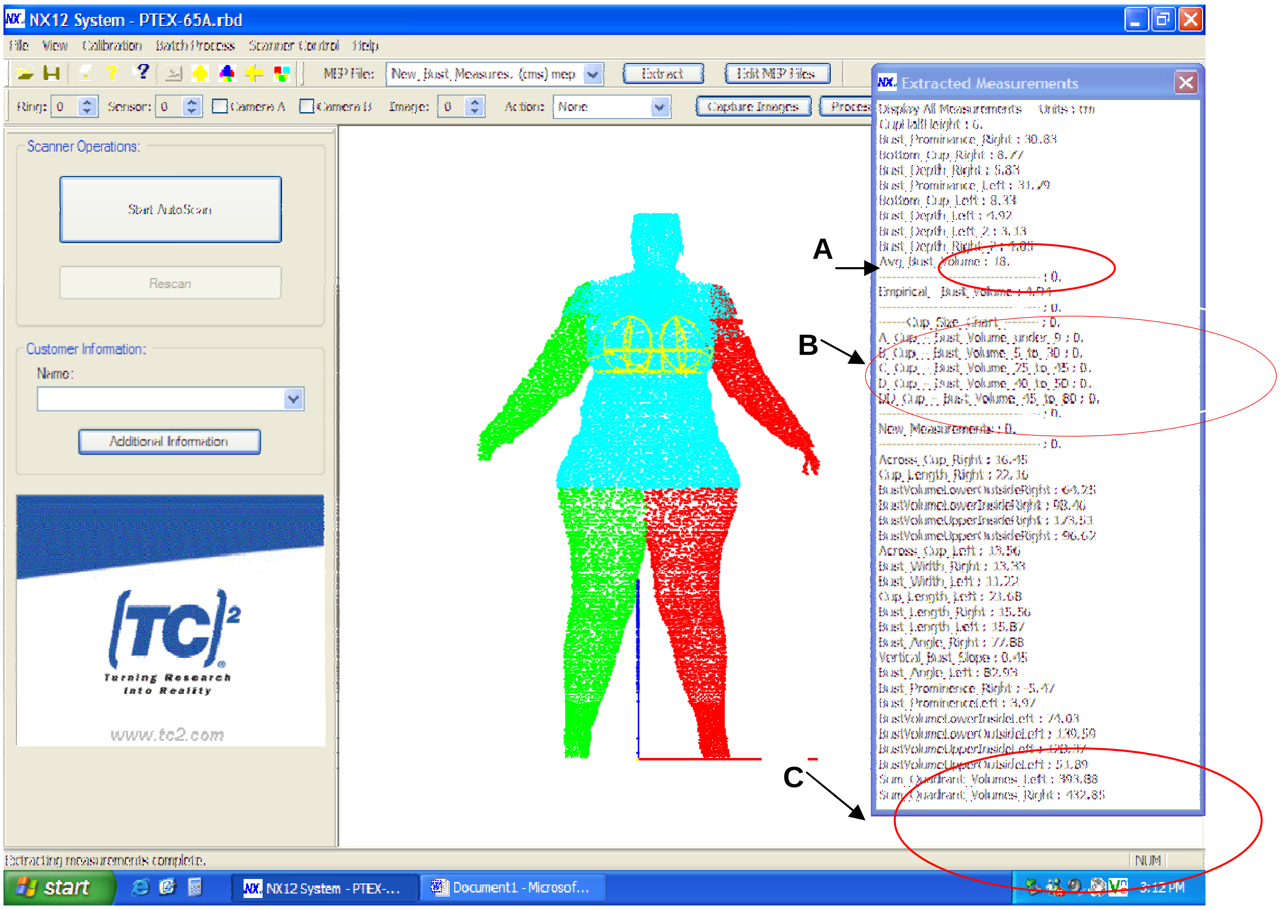
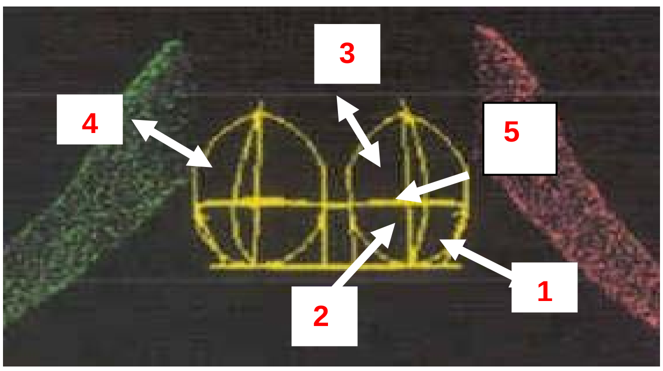


FIGURE 3.5

RIGHT AND LEFT BUST SUM OF QUADRANT VOLUMES



As noted, the sum of the Left and Right bust quadrants are calculated from the:-

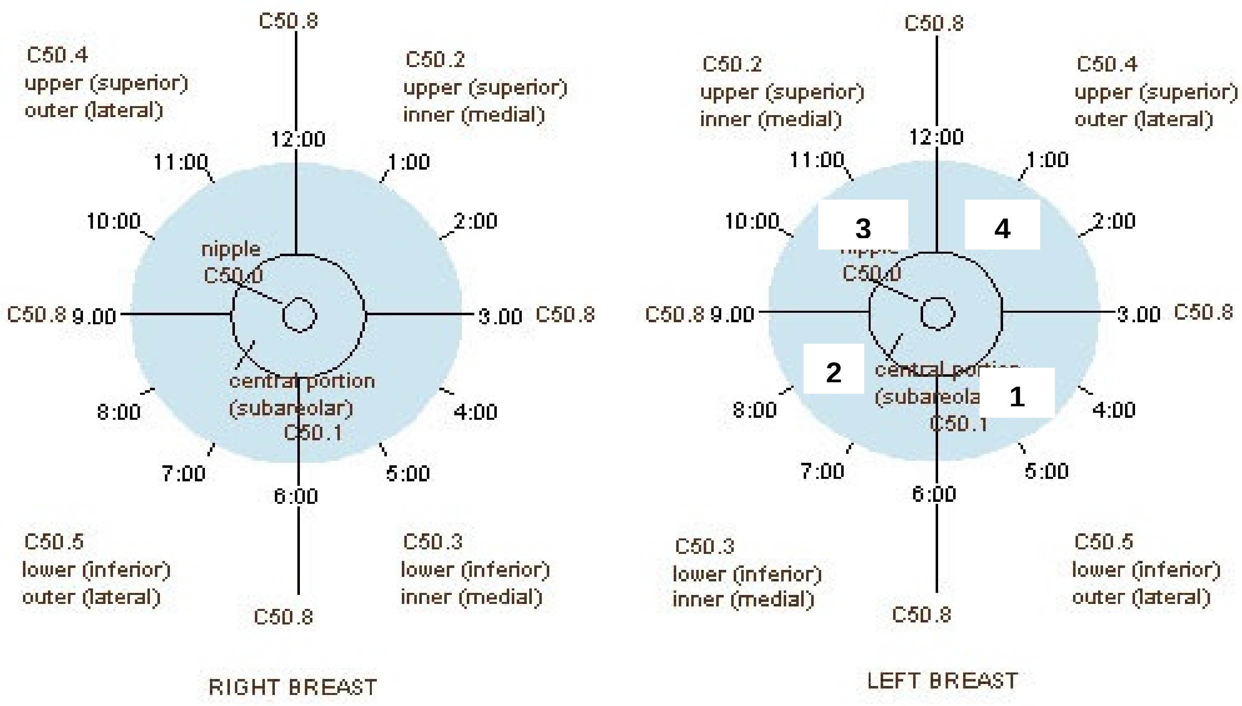
1. bust volume Lower Outside Right and Left

2. bust volume Lower Inside Right and Left
3. bust volume Upper Inside Right and Left
4. bust volume Upper Outside Right and Left
5. bust prominence Right or Left and Right

Illustrated in Figure 3.6 in “clockwise” positions are the 2 -dimensional views of the four quadrants as indicated in points 1 to 4 above.

FIGURE 3.6

2- DIMENSIONAL VIEW OF THE BUST QUADRANTS



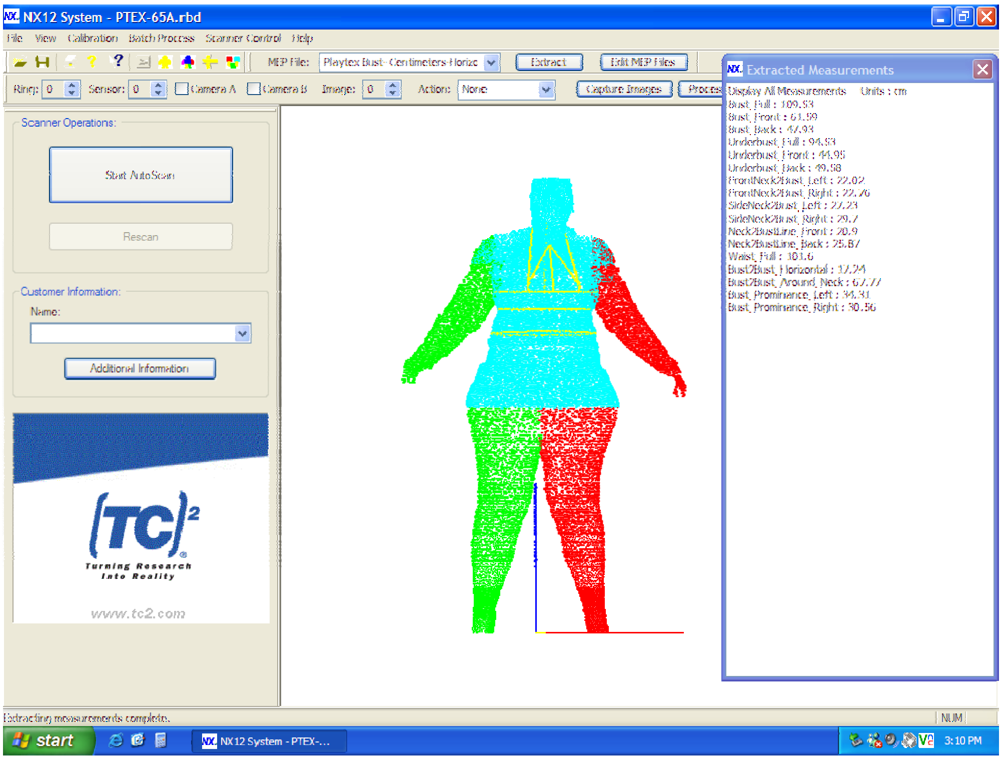
SOURCE: Adapted from Quadrants of the Breast [67]

3.4 THE 3D USER DEFINED BUST SPECIFIC MEASUREMENT SELECTION PROGRAM

The 3D User Defined Bust Specific Measurement program built into the [TC]2 default scanner program and is not a stand–alone software. This program allows the user to program a software extraction mep. specific to breast surface data, ensuring that the points are extracted as one would take manual tape-measurements of the selected body measurement points. This was programmed by the researcher and the body landmarks points to be extracted were verified by the technical team of Playtex (Pty) Ltd. and the program named Playtex - Horizontal Plane mep. This measurement extraction program was used for the extraction of 176 body landmark points during the data collection process (Figure 3.7) and in the statistical analysis. This program was used to compare the scan linear body measurements with the traditional tape measurements as extracted by the manufacturer reported in Chapter 5 of this dissertation.

FIGURE 3.7

BUST SPECIFIC MEASUREMENT SELECTION PROGRAM OUTPUT

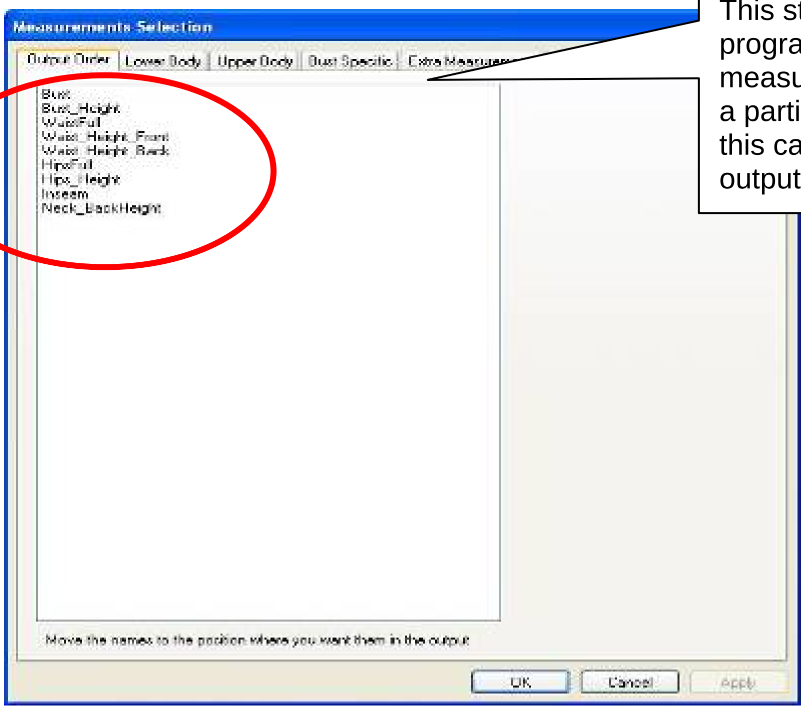


The program was developed using the "tool options" function built into the existing 3D scanners basic software as illustrated in the following steps:-

STEP 1

For this project, a new dialogue extraction program was opened and the measurements were saved in inches and centimetres.

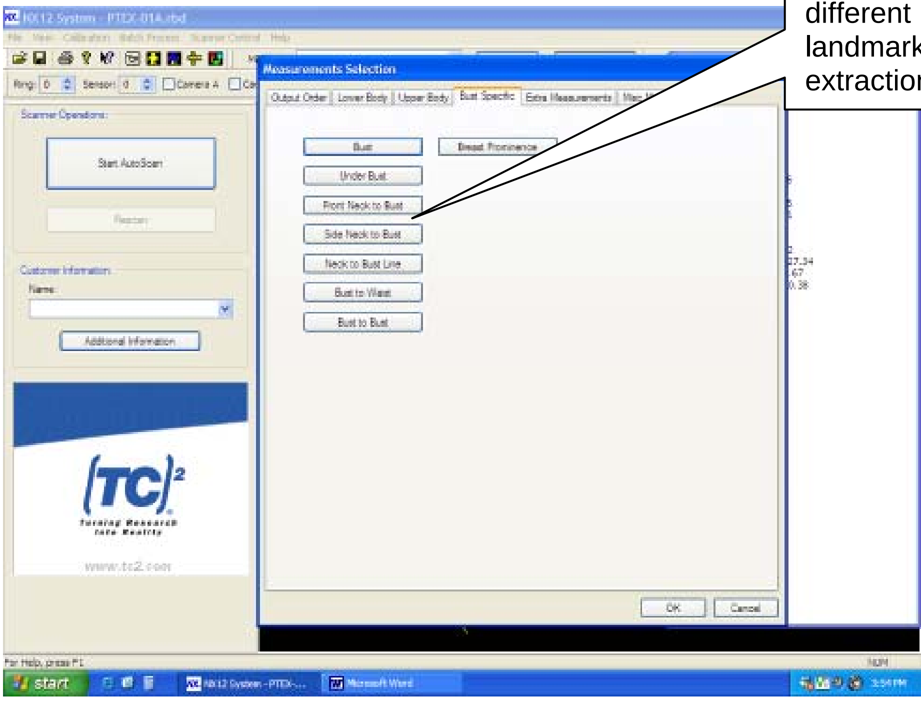
STEP 2



This step allows the programmer to choose the measurement selection for a particular body part; in this case the Bust Specific output was selected.

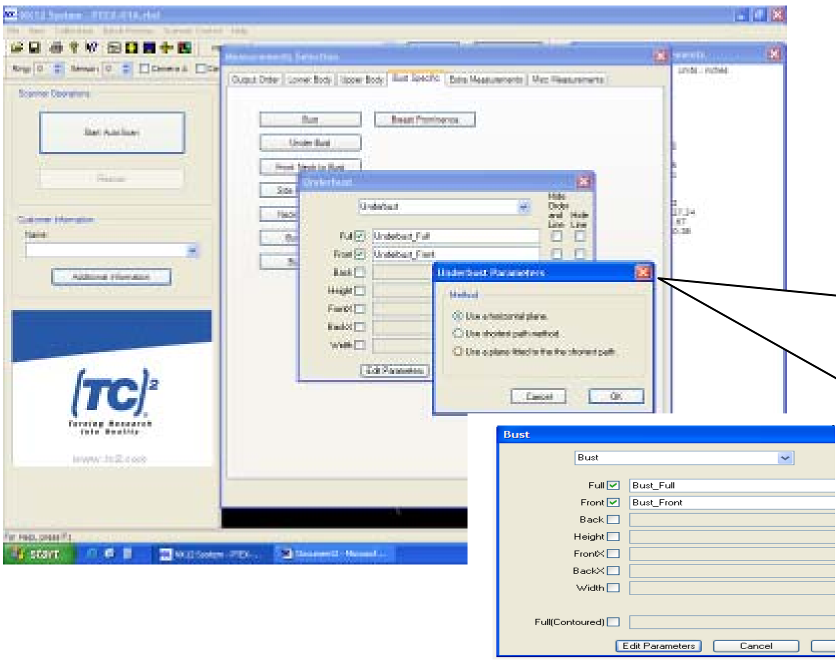
cont…

STEP 3



Step 3, provides the option to define the different bust body landmark points for extraction.

STEP 4



This dialogue box is a further illustration of the different parameters that can be chosen i.e. under-bust full, under-bust front etc. For this study, the under-bust points were chosen using the horizontal plane, as this is how the

All the body points of measure were verified and the extraction program was saved as Playtex Bust Extraction Horizontal Plane mep. This was used to extract the scanned data for the 176 plus-sized subjects.

To better understand the complexity of the nature of the extracted bra volume measurements, it was necessary to understand and view the operations at Playtex (Pty) Ltd., so that the current mode of determining the bra volume data can be explored further for comparative analysis.

3.5 A BRIEF OVERVIEW OF THE OPERATIONS OF DBApparel (Playtex)

Playtex (Pty) Ltd.[52] uses a metric bra sizing chart. The bra sizes range from 32A to 48E. The fabric used is imported and the range changes on a continuous basis. Different types of fabrics and fibres are used for manufacturing the bras, including polyamide, polyester, cotton, viscose and elastane, these being bought according to specifications, and tested in the in-house laboratory to ensure that the fabric meets the required end-product specifications. Live models are used in the new product development and the time taken from pattern grading to fitting is between four to a month. A typical wear trial can take between two and four weeks. Wear trials are conducted during the development stages of a new bra design, after the base sample size is approved and graded, before production commencing. Grading is conducted on an apparel CAD system. A designer is considered to be experienced after two to five years of employment. According to Ros Allan[38] Technical Manager at Playtex, the different styles are fashioned from basic pattern blocks. The measurements of these basic blocks have been verified for design, fabrication and fit. The styles are modified with trimmings and other bra cup, side panel and band strap details to develop different products. Once the samples are manufactured and fitted for size onto live fit models, the style is documented with a new style number and sent to the sample production floor.

After the different bra styles are graded and manufactured, the bras are fitted onto live fit models wearing the different grading styles to check for obvious distortions in styling, manufacturing and the positioning of the bra cup under-wire to obtain comments from the models. This information is then used to improve the fit of the samples. Pattern dimensions are adjusted; and the new samples are modified accordingly and sent to the sampling department until the “fit” is correct. The bra specification is dependent on the torso dimensions of the fit models and not on the actual garment specifications, although bras are manufactured according to specifications that are altered to fit the torso of a fit model with a given set of torso body dimensions.

The bra cup fabric is cut into a circular mould in the garment shape, and flattened into a 2D pattern piece. The top of the cone is used to design the bra cup notations that are graduated from a size 34 to 42C, as illustrated in Figure 3.8. The graduated cones are purchased from the an international company that produces the bra graduated moulds upon the specific request and specifications of Playtex (Pty) Ltd, and used as is for the different bra cup sizes. The bra sample is adjusted on the relevant fit model and the adjustments to the sample size are made accordingly.

FIGURE 3.8

PLAYTEX GRADUATED BRA CUP SIZE CONE

SOURCE: Adapted from Playtex (Pty) Ltd. (personal communication) 38

The company has a fully functional laboratory where the base fabrics and trimmings are quality tested to ensure that the product conforms to the fabric specifications. The finished product is tested for:

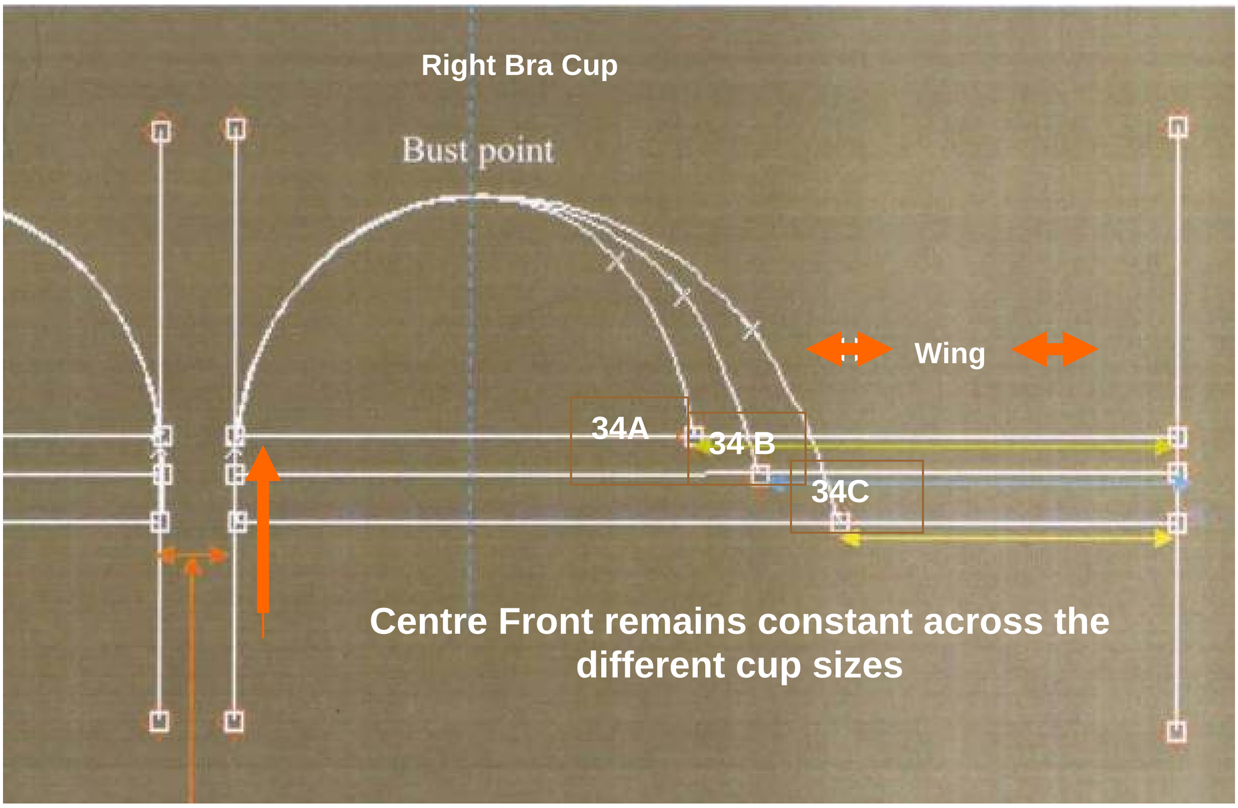
- Wash durability
- Colourfastness to perspiration
- Colourfastness to rubbing (dry)
- Colourfastness to light
- Colourfastness to sea water

- Shrinkage after washing and tumble drying.

Garment aftercare is recommended on the bra size label attached to every bra sold. Laboratory tests are not conducted on the cup sizes since the accuracy of the "fit" is conducted and verified on a live fit model with established body dimensions.

FIGURE 3.9

GROWTH OF THE BREAST ACROSS THE DIFFERENT BRA CUP SIZES



SOURCE: Adapted from Playtex (Pty) Ltd. (personal communication) 38

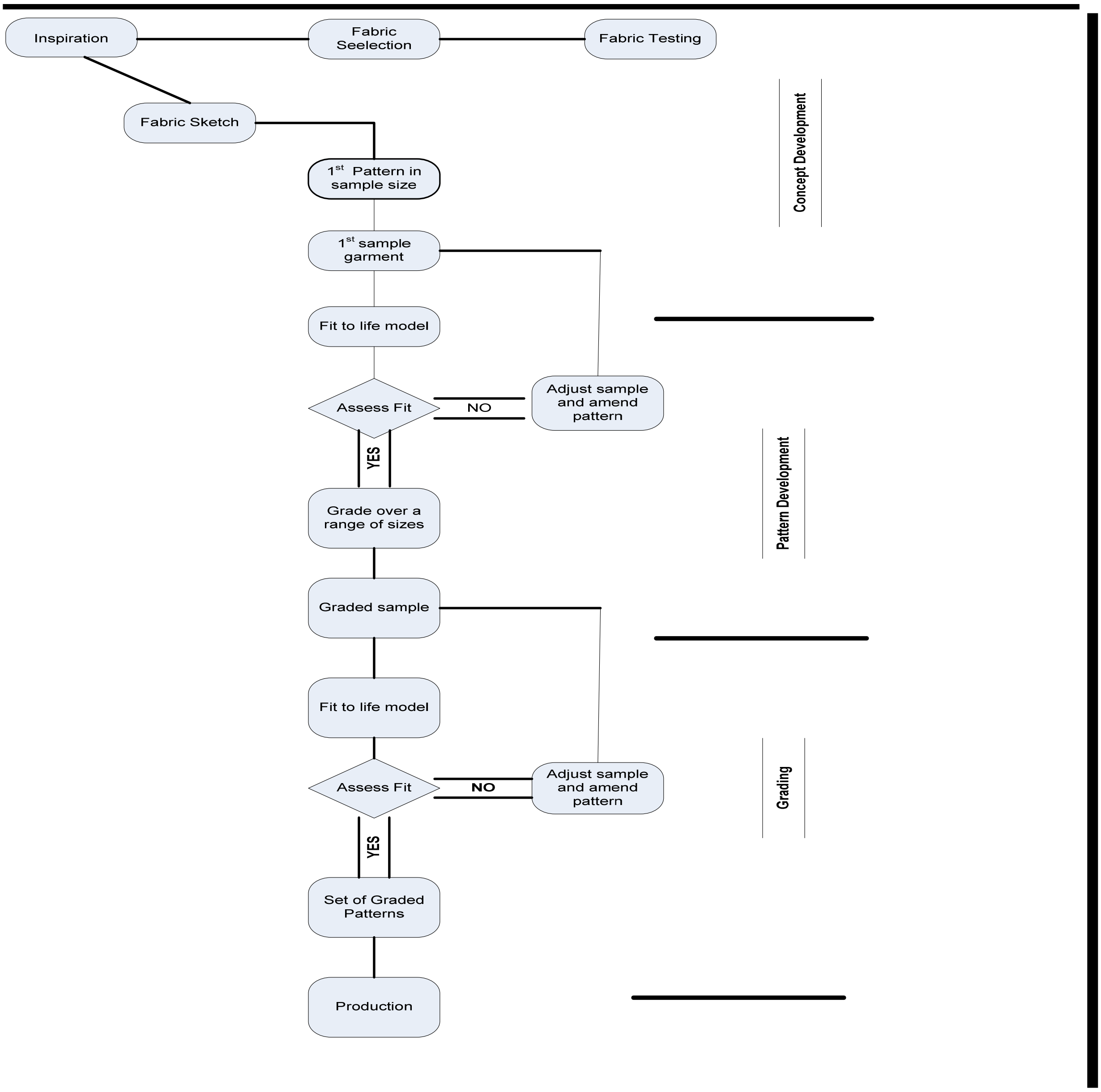
In theory, the cup size is based on the fitting chart, but in fitting, the placement of the bust on the chest wall affects the underbust girth shape as it is different in every woman, hence a 34A cup pattern piece may be closer to the 34B bra cup size pattern piece. The underwire shape may remain the same across grades, and the bra pattern may be close from one graded cup size to the next, but the length of the wing around the body will change as illustrated in Figure 3.9. Therefore, an individual will have to fit the bra for size prior to purchasing, as the ultimate choice of a bra is largely dependent on comfort.

Li[68] reports that the average absolute threshold for the breast region of the “female skin” is dependent on the fabric to skin contact and the mechanical interaction of the bra during wear. The process is explained as the application of pressure and mechanical stimulation of the skin, which triggers various mechanoreceptors resulting in an array of touch sensations. For this study it is also worth noting that the static pressure when wearing a bra, in the standing position, was at the back, in the side and at the shoulders, and that wearer preference in the choice of the bra size was related to pressure distribution.

Designing bras is not only a lengthy but a complicated process that requires various skills including design creativity, a detailed knowledge of fabric performance and precision pattern making. A typical bra design process involves three broad stages, namely; concept design, pattern development and grading as illustrated in Figure 3.10. This is a standard process flow diagram throughout the bra manufacturing industry.[37]

FIGURE 3.10

A TYPICAL BRA DESIGNING PROCESS FLOWCHART



SOURCE: Adapted from IJCST. Volume 9 No.4.p312 [37]

The initial sample bra design is sketched and fashioned mostly from stretch fabrics or combinations or blends thereof, cut from flat panels and accurately shaped to the nearest millimeter. The pieces are sewn or fused together into a three dimensional garment and fitted onto a "live model", to check the support of the torso without obvious distortions or discomfort to the wearer.

CHAPTER 4 – METHODOLOGY

This study on size prediction for plus-size women intimate apparel was initiated in September 2007, due to a complaint from the bra manufacturer on ill- fitting bras for the larger breasted (plus-size) women. The 3D body scanning methodology used in the study is based on ISO/DIS 20685 Standard.[69] The subjects recruited for this study were not pregnant nor did they have breast enlargement or reduction surgery.

This chapter will focus on the experimental design for the study which could also be used as a model for future scanning of women's intimate apparel.

4.1. DETERMINING THE CORRECT SCANNING BRA STYLE AND COLOUR

The researcher's personal experience of using the 3D body scanner, established that the colour of the scanning garments worn during the scanning process, on the different skin tones, had an effect on the 3D scan generating process, where certain coloured garments did not generate a 3D cloud form of the subject. The colour of the inside of the scanning booth is black; hence the scanning garments cannot be of a dark shade i.e. black or navy blue.

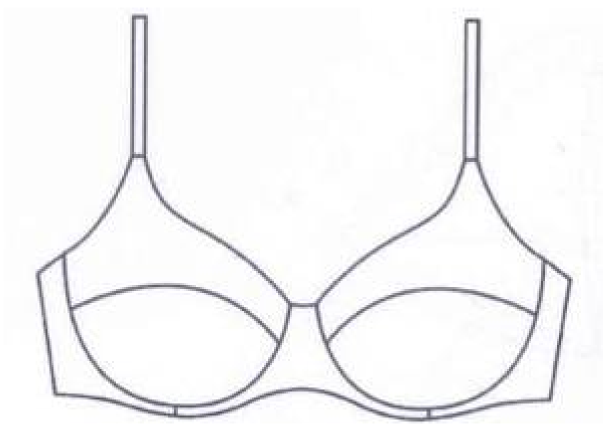
The optimal colour as recommend by [TC]2 is grey or heather grey.[61] Due to production constraints, the personnel on the planning team at Playtex, were not able to manufacture all of the 176 scanning garments in heather grey based on the subjects' "claimed" bra size. Therefore, a compromise had to be made to ensure that the information that was required for this study was determined by the bra style and colour worn during scanning. Accordingly the colours chosen were not black, navy blue, white on certain dark skin tones or beige made from fabric that was not lustred.

The bra style was initially determined by the researcher by conducting 3D body scan trials using different retail bought bra styles with a limited convenient sample, drawn from within the CSIR, of small, medium and large breasted women. The data obtained was verified against the New Bust programme's mep. recommended bra cup size for that particular subject. These scans were also batch processed into a Microsoft Excel spreadsheet for "errors" in the data set of the subjects wearing the different style trial samples. Batch processing allows the user to process multiple body data files without having to load and process each scan individually into a Microsoft Excel Spreadsheet.[70]

The chosen style was a soft cup slightly under-wired bra. This bra style gave the researcher the most realistic data output reading of all the bra styles available in retail stores. The soft cup moulded the form of the breasts even in the larger breasted women and the underwire defined the base line of the breasts for extracting the breast volume data without any "errors" in the data set. Dr. David Bruner from [TC] 2 later confirmed that this is the best style and choice of bra scanning garment for extracting reliable 3D bra scan data. Figure 4.1 is an example of the bra style chosen for the subjects used in this pilot study. Scanning of the plus-size women in such a scanning bra ensured consistency of the output measurement data, as the bras manufactured for every subject scanned, was the "best" fit for that particular subject, ensuring that there was no distortions in sizing and fit as indicated by the "common bra fitting problems" in Figures 2.12 to Figure 2.10 on page 35 to 37 of this dissertation.

FIGURE 4.1

SOFT CUP BRA - SCANNING GARMENT



BASIC FULL CUP BRA

4.2. THE DESIGN OF THE STUDY

This study formed the basis for developing a model or modus operandi for future scanning of intimate apparel for other women body types and shapes. The subjects in this study consisted of a convenient sample of 176 plus-size South African woman aged between 23 and 63 years, recruited from within Playtex (Pty) Ltd. based in Durban, KwaZulu Natal. Initially, the recruitment criterion was based on visual observation of the women being "large breasted" and on their retail dress being size

36 or larger. On this basis 263 subjects were selected thereafter, Body Mass Index (BMI) was used as the final selection tool. On this basis only subjects with a BMI of or greater than $25kg/m^2$ be included, a total of 176 plus- size women were selected out of the 263 plus-size women originally scanned.

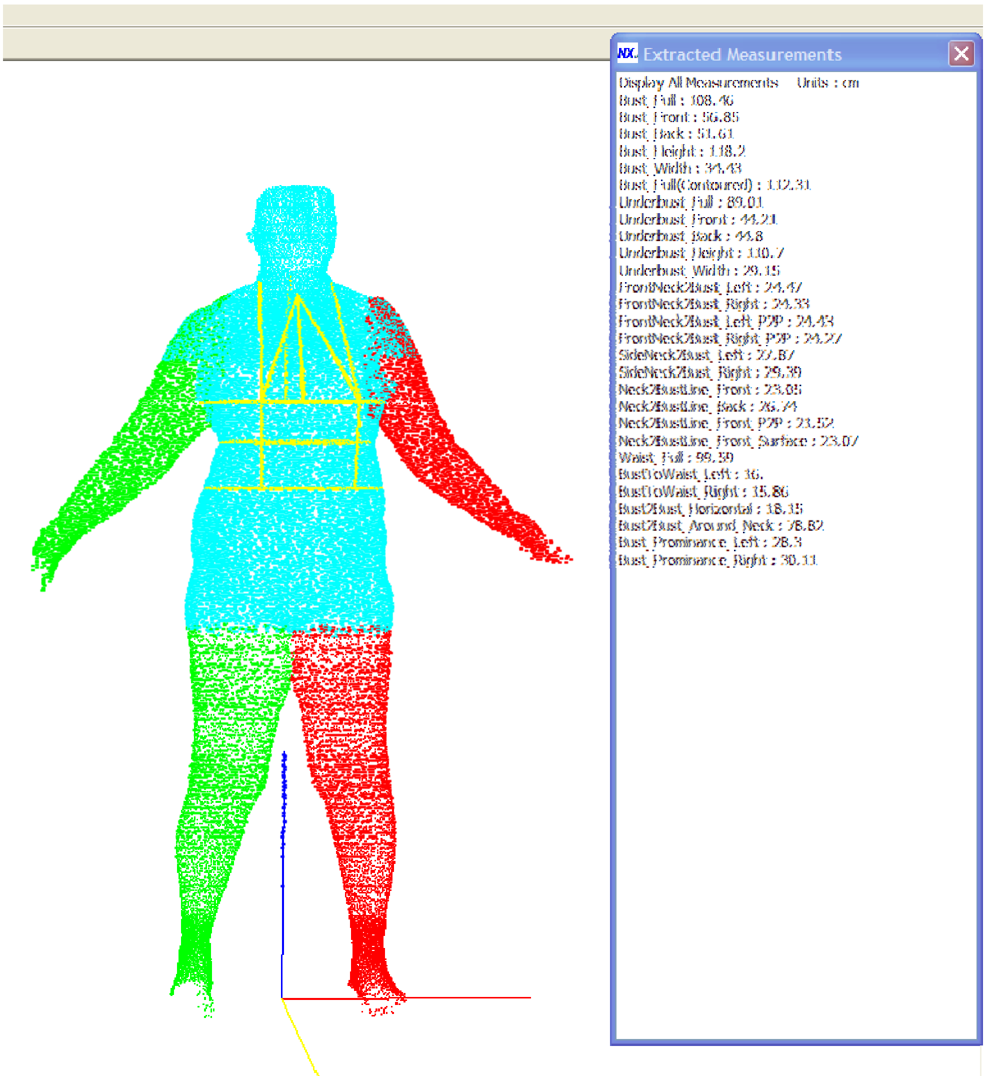
The subjects were divided into five age categories, namely 23~26 (n= 6), 27~36 (n=28), 37~46 (n=66), 47~56 (n=69), 57~66(n=7). The bra manufacturer was approached for permission to recruit the subjects and to provide the venue and the scanning garments for scanning. The company's management were taken through a power-point presentation on the rationale behind the study and the commercial benefits of being involved in a study of this nature (see Appendix 2), The demographic questionnaire (Appendix 3), letters to the subjects (Appendix 4), and consent forms (Appendix 5), were handed to the project coordinator from Playtex (Pty) Ltd. for distribution to the subjects and a date was chosen for the scanner to be moved to Durban. Every subject was time scheduled into a roster on the scheduled dates for the 3D scan data collection, so as not to disrupt production within the manufacturing plant.

The scanner was transported to Durban and assembled on a vacant area on the top floor of the Playtex building, thus ensuring that privacy was maintained at all times. Five designers were chosen to assist the researcher with the completion of the forms and to manually measure the subjects. At any given time, there were six women in the scanning area. The women changed into the scanning garments; all jewellery was removed and long hair tied up so that these did not interfere with the scanning process.

The subject's weight and height measurements were taken using an Adam® medical scale. This information was recorded on the subject's questionnaires. Instructions on the scanning position were communicated to the women by the researcher. The individual scans were numbered consecutively and saved and a printed copy handed to the women in the form of a certificate (see Appendix 6). Manual torso measurements, using a tape measure, were also taken of certain critical body points relevant to the manufacturing of bras. These measurements were recorded on the demographic forms. This process was repeated for each of the 176 women used in this study. The reference numbers were duplicated onto the subject's demographic questionnaire. The questionnaire was retained on a Microsoft Excel spreadsheet for further analysis and for reporting purposes. The actual automatic body data measurement points after the scan generating process are shown as the horizontal and vertical lines in Figure 4.2.

FIGURE 4.2

3D SCAN MEASUREMENTS AS EXTRACTED BY THE PROPERIETY PROGRAM



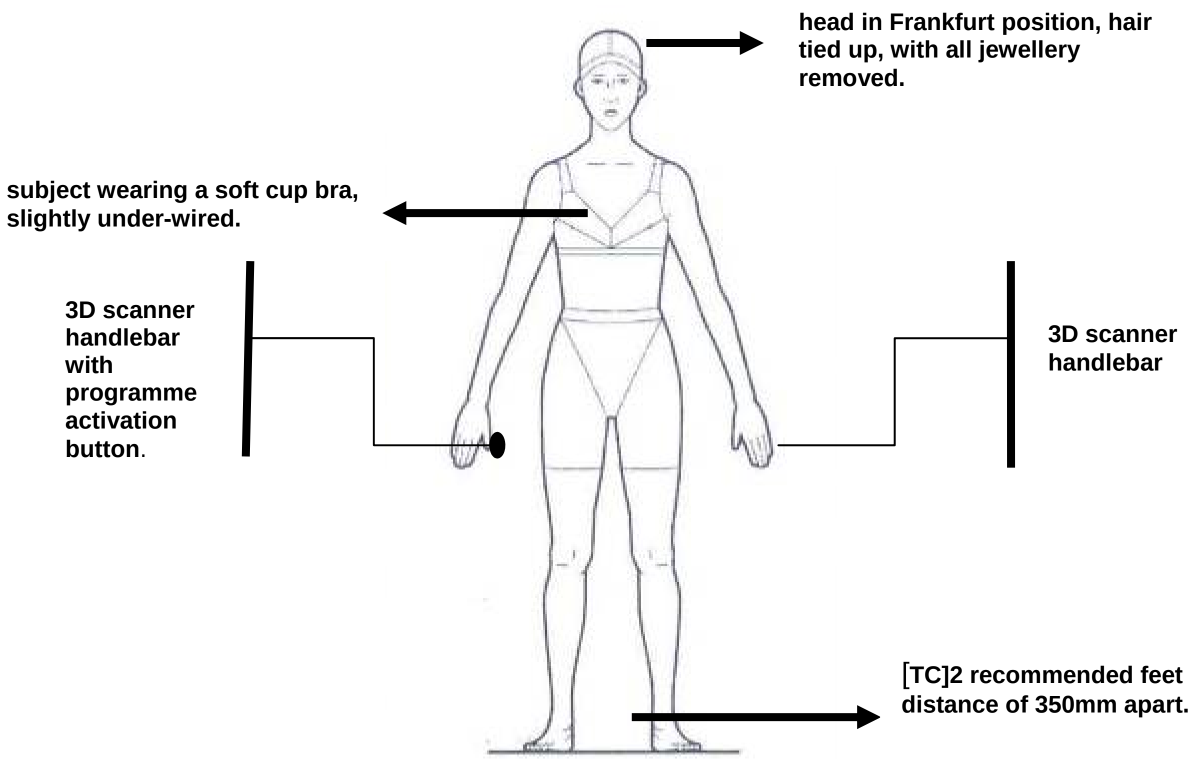
The 3D scans were "batch processed" into a Microsoft Excel spreadsheet. This data, once captured and saved, was used in the statistical analysis as discussed in Chapter 5. The process of collecting the 3D body scan data measurements was conducted over a period of a week.

4.3. SAMPLING AND 3D ANTHROPOMETRIC DATA ACQUISITION

The protocol used to manually measure the subjects, using a dressmaker's tape-measure, was with the subjects standing erect with the head in the Frankfurt plane as described in the ISO/DIS 20685 Standard.[69] The heels are together, with the upper limbs outstretched slightly at the side of the body, with the subject in a relaxed position. The standing position in the 3D scanner was erect, with the head in the Frankfurt position and with the feet parallel to each other, 350mm apart, as indicated by the marking on the floor inside the scanning booth. The arms are outstretched, holding onto the fixed handrails 1100mm apart, with the right hand thumb hovering over the right handle on the button to activate the 3D scanner. This position optimizes the automatic body measurement of both the vertical and the circumference of the upper and lower body. Subjects were requested to stand upright, but relaxed, as depicted in Figure 4.3.

FIGURE 4.3

3D BODY SCANNING POSITION



SOURCE: Adapted from ISO/DIS 20685[69]

Studies conducted by Chi and Kennon[71] indicate that the results of the 3D measurement data extracted by scanners are optimized for this natural anatomical position. The subjects were also requested to breathe normally, as similar studies conducted by Mckinnon and Istook[72] indicated that levels of breathing have a significant effect on the body scan and can affect the upper torso measurements, with maximum inhalation or exhalation either increasing or decreasing the breadth measurements. Hence, every subject was scanned twice to minimise this effect.

4.4 SELECTION OF PLUS SIZE WOMEN FOR SCANNING

Wang and Zhang[73] state that the varied breast shapes and sizes, complicated by the fact that even one person has several breast shapes, due to the pliable nature of the breast tissue, are the source of the most common bra fitting problems experienced by women.

As already mentioned initially 263 large women were 3D scanned, after which those with a Body Mass Index (BMI) equal to or larger than 25kg/m² classified as overweight or obese, were selected for inclusion in this study. On this basis 176 subjects were finally selected and only their data has been reported and analysed.

BMI is defined as the individual's body weight (mass) divided by the square of their height in metres. The United States Department of Health and Human Services developed the BMI based upon one’s body mass (weight) and height, calculated as follows:- **Body Mass Index = weight in kilograms / (height in metres)²**

TABLE 4.1

BMI INDEX CLASSIFICATION

Classification:	**Index Number:**
Overweight	25-29.9kg/m²
Obesity – Class I	30-34.9kg/m²
Obesity – Class II	35-39.9kg/m²
Extreme Obesity - III	>40kg/m²

SOURCE: Adapted from Exercise Physiology p 377[74]

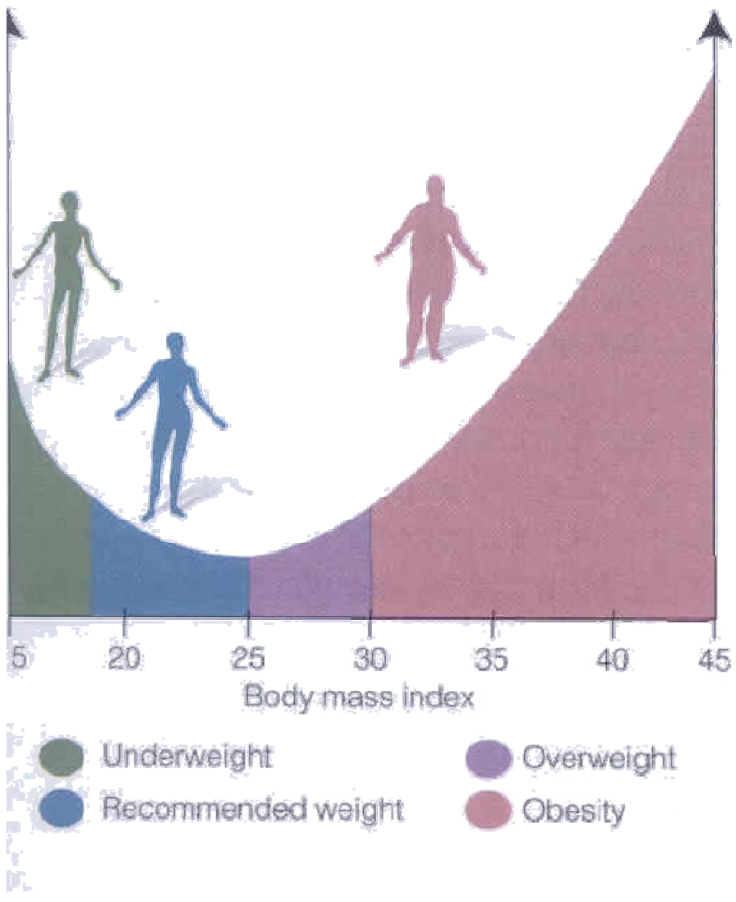
This formula is widely used in the medical field to produce a unit of measure in kg/m^2 as indicted in Table 4.1

Hoeger[75] describes BMI, has a statistical measurement which compares a person's weight and height. BMI does not actually measure the percentage of body fat, but it is a useful tool to estimate a healthy body weight based on how tall a person is. Due to its ease of measurement and calculation, it is the most widely used “diagnostic tool” to identify obesity problems within a population.

The different weight categories are indicated in Figure 4.4 by colour codes. The subdivisions are within the major class of Underweight, Normal, Overweight and Obese.

FIGURE 4.4

CLASSIFICATION OF BODY MASS INDEX



SOURCE: Adapted from Lifetime Physical Fitness and Wellness.p113 [75]

4.5 THE BMI INDEX OF THE 176 SUBJECTS

Figure 4.5 illustrates the BMI of the 176 women used in this study, rounded off to the nearest whole number. The information is taken from the demographic forms from Section B on Body Weight and Height (see Section B, page 2 of Appendix 3).

FIGURE 4.5

DISTRIBUTION OF BMI INDEX OF 176 PLUS SIZE WOMEN

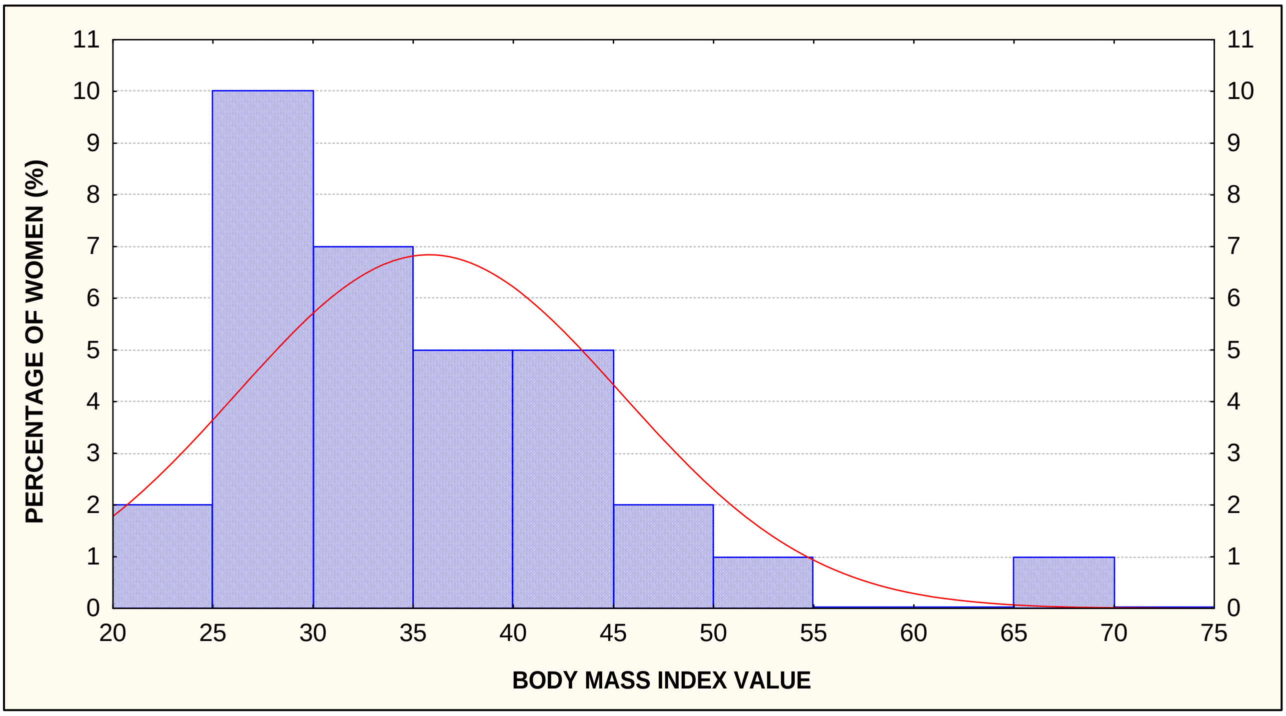


Figure 4.5, indicates that 23% of the women that took part in the study are classified as overweight and 77% as obese.

1. The average weight of the 23% women in the" overweight" category was 69 kilograms, with 95% confidence limits of 67 kilograms and 71 kilograms. The average height for this group was 1.59 metres, with 95% confidence limits being 1.58 metres and 1.61 metres.
2. The average weight of the 77% women in the "obese" category was found to be 90 kilograms, with 95% confidence limits of 88 kilograms and 92 kilograms. The average height in this category was 1.59 metres, with 95% confidence limits of 1.57 metres and 1.60 metres.

Chapter 5 – DATA ANALYSIS

This chapter presents the analysis of specific bra size and fit data from the 3D scan measurements of 176 plus size women using the quantitative and qualitative analysis methods. The analysis of the data does not differentiate between the different ethnic groupings. For reporting purposes the sample drawn consisted of 44% of Black; 48% of Indian; 4% of Coloured and 4% of Caucasian women.

The scan data was analysed using descriptive statistics, experimental research of visual observation of “live model fitting” trials and empirical analysis with limited inferential statistics. The sample size per bra category was relatively small and not necessarily representative of the larger population of plus-sized South African women since the sample was not acquired in a randomized fashion, and the results contained in this chapter are not expected to be extrapolated to the larger population of South Africa, except point 5.4.1, Figure 5.10. This study compared the manual anatomical body measurements, taken using a dressmakers tape-measure, with the 3D scan data extracted by the [TC]2-NX12 3D full body scanner’s two different bra extraction software programs. The manual anatomical measurements are the only currently acceptable “true values” as there are no other recorded 3D scan data measurements in South Africa with which to compare the 3D scan data collected during this study.

5.1 SUBJECTIVE INFORMATION

The empirical research was conducted on information supplied by the subjects on demographic forms. Table 5.1 tabulates the subject’s perceived retail dress size (as purchased from a retail store i.e. label size 36 or 38 etc.) and their perceived bra size category as stated in demographic forms and tabulated in a Microsoft Excel spreadsheet indicated in Appendix 7.

A frequency distribution table (Table 5.1) was used to establish the percentage of women whose claimed bra size correlated with their dress size. Women who claimed to wear more than one dress size were excluded from the analysis.

TABLE 5.1

CLAIMED BRA SIZE vs. PERCEIVED DRESS SIZE

	Claimed Bra Size						
Perceived Garment Size	**34**	**36**	**38**	**40**	**42**	**44**	**46**
34	**2**	1	0	**0**	0	0	0
36	6	**10**	1	**2**	0	0	0
38	1	7	**3**	**5**	0	0	0
40	2	4	7	**10**	1	2	0
42	0	4	4	**15**	**1**	1	0
44	0	0	6	**2**	3	**2**	1
46	0	0	1	**7**	2	1	**0**
TOTAL:	11	26	22	**41**	7	6	1

The frequency table shows, for example, that of the 41 plus-sized women with a claimed bra size of "40", 23.4% did in fact wear a dress size 40, whilst for 70.6% of the women their indicated dress sizes did not correspond to their bra sizes. The difference between the claimed bra and dress sizes indicated by the wearer is highly significant, ($p<0.0001$ from Fischer exact test), that it can be safely assumed that this finding will be true for plus- sized South African women from all nine provinces for dress size 40. The Fisher exact was used in the analysis as the sample size is small.

North *et al* [76] stated that there is a lack of research on how the intrinsic and extrinsic apparel product attributes influence the female buyer's decision making process. Every subject scanned completed a demographic questionnaire on bra shopping and purchasing habits to identify the value that is attached to each attribute, and to gain a better understanding of the decision making process that is involved when purchasing a bra. This information will ultimately assist the bra manufacturer in making informed decisions about the plus-sized women's shopping habits when purchasing bras.
The attributes discussed is that of bra style, bra features and general shopping habits of the women used in this study.

In response to the questions:-

5.1.1 What is your favourite style?

30% of the plus-sized women preferred a full cup bra; 32% preferred a bra that was under-wired; 15% a soft cup bra and 6% preferred a push-up bra.

5.12 Have you been manually measured for a bra before this study?

*48% of the subjects answered **YES.***

5.1.3 Do you wear more than one bra size?

*49% answered **YES.***

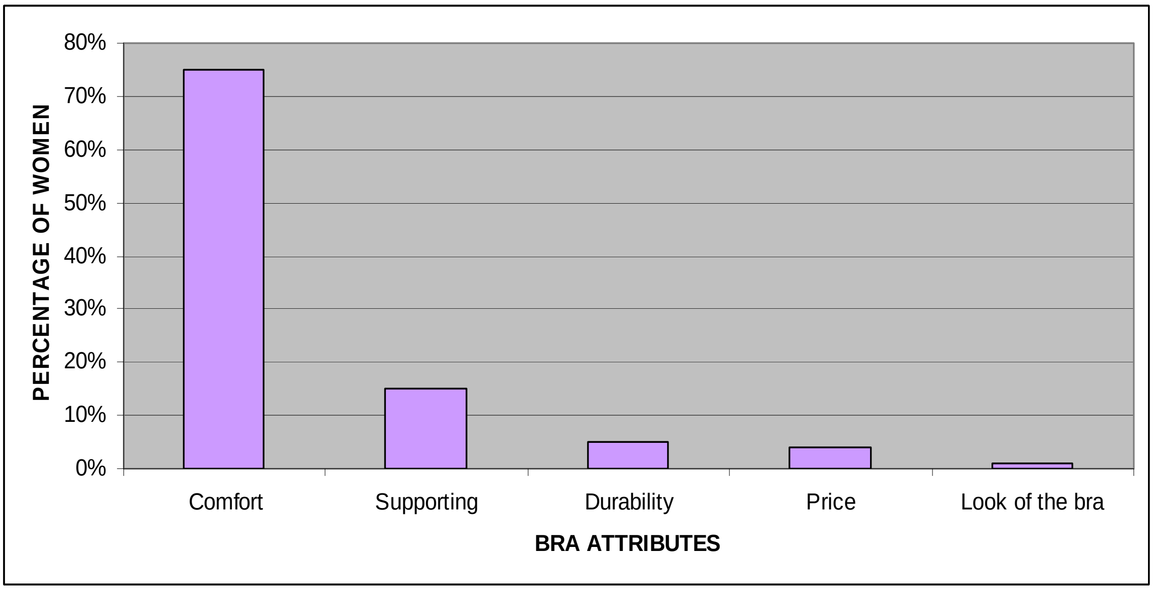
5.14 What is the most important feature/s that you would look for in a bra?

Feature	Percentage
Comfort	75%
Supporting	15%
Durability	5%
Price	4%
Look of the bra	1%

The responses are graphically displayed in the histogram in Figure 5.1.

FIGURE 5.1

GRAPHIC REPRESENTATION OF DESIRED BRA ATTRIBUTES



5.1.5 The above responses are supported by some of the following comments made by the women taken from their questionnaires:-

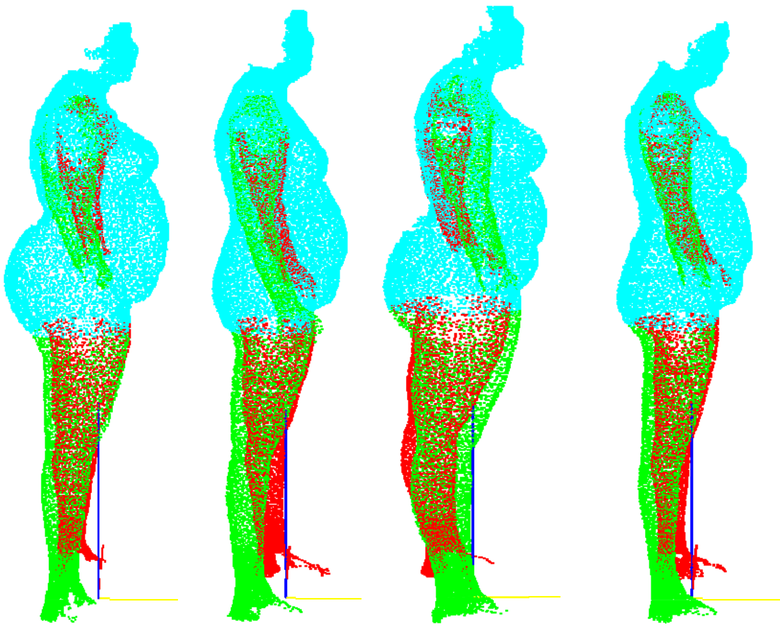
- ***a)*** 1.9% - *would like all the styles to fit the same.*
- ***b)*** 2.6% - *said that the underwire bras hurt.*
- ***c)*** 0.8% - *said that the double back slide hurts, sometimes not comfortable.*
- ***d)*** 2.3% - *would like bras with larger straps.*
- ***e)*** 0.8% - *would like bra that have better comfort and durability.*
- ***f)*** 2.6% - *would like the strap extension to have more adjustments provided.*
- ***g)*** 3.8% - *would like push-up bras in bigger sizes.*
- ***h)*** 2.3% *would like underwire bras in bigger sizes.*
- ***i)*** 0.8% - *said that the wing of bras is too low under the arm.*
- ***j)*** 0.8% - *would like the bigger bra sizes to be prettier.*
- ***k)*** 3.8% - *said that there is inconsistency in bra cup depth.*

Hart and Dewsnap[77] undertook a study on the consumer decision making process when purchasing intimate apparel which indicated that bra purchasing involves a complex array of physiological, psychological, functional, psychographic, psychosocial and economic factors as indicated in points 5.1.4 and 5.1.5 above. Nevertheless, Mintel's[78] research lists comfort and fit as the key criteria, but little is known on how consumers evaluate bras based on these attributes, although Beaudoin and Goldsmith[79] found that a good fit, durability, favourable price, comfort, quality, attractiveness, colour, brand name and choice of bra style are attributes that correlated with consumer attitudes when purchasing apparel.

The subjective study and dissatisfaction expressed in the questionnaires can be further explained by the 3D scans in Figure 5.2, which show the different shapes and sizes of four plus-sized women who claim to wear a bra size 40B; with body mass index ranging from 25kg/m² to 40kg/m².

FIGURE 5.2

3D SCANS OF FOUR PLUS-SIZED WOMEN WHO CLAIM TO WEAR A BRA SIZE 40B



5.2 BREAST MEASUREMENT

The [TC]2 system does not require the pre-scan land-marking of the body. Istook[64] explains that the extraction software is able to identify certain, if not all, of the body landmarks locations required to extract body measurements. The body points extracted are the raw calculated points and the data is processed by smoothing, filtering, filling and compressing, producing a 3D figure outline as shown in Figure 5.2.

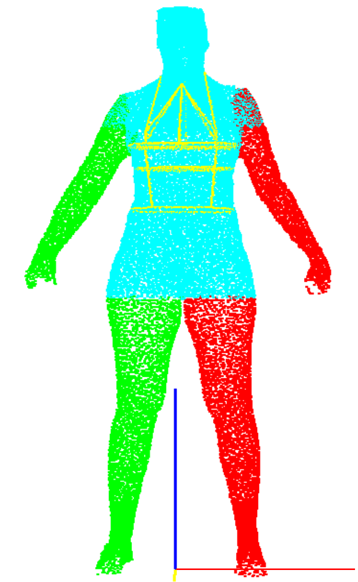
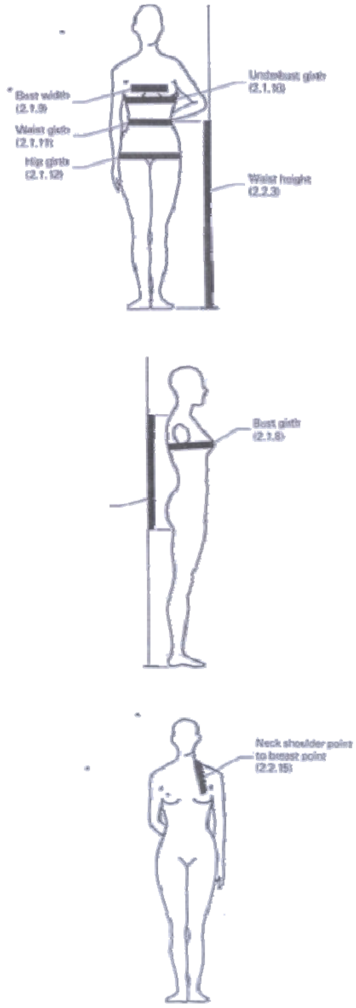
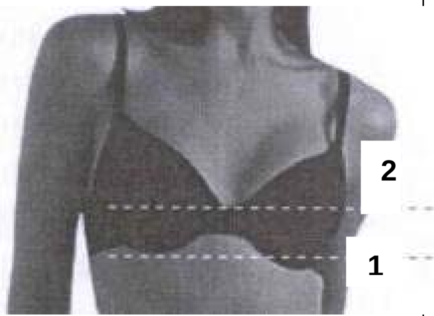
The descriptive and limited inferential statistical analysis and comparison were conducted as follows:-

1. Comparison of the body landmark points taken using a tape-measure with those extracted from the 3D scanner for the same subjects.
2. To establish how the different bra styles available for plus-sized women affect the 3D body measurement data extracted for the same subjects.
3. Comparison of the 3D scanner extracted bra cup size with that of the Playtex Body Measurements – Bra Size Chart.

5.2.1 COMPARISON OF 3D SCANNER WITH THE TAPE- MEASUREMENTS

To avoid any anomalies in the data collection process, the body landmark extraction procedure had to be standardized for this study. The pictogram in Figure 5.3 illustrates the landmarks and the body location points (i) as extracted by the [TC]2 scanner, (ii) that taken from the ISO 8559 Body Dimension Standard and (iii) by the manufacturer ((Playtex (Pty Ltd)) using a tape measure. The researcher found no universal standard which correlates the body landmark measurements and the definitions between measurements extracted by 3D body scanners and those taken manually using a tape measure. The body points of measure were coordinated between (i), (ii) and (iii) and programmed into the NX12 propriety software program for this study.

FIGURE 5.3
STANDARDISED BODY POINTS OF MEASURE

[TC]2 – (i)	ISO 8559 – (ii)	Playtex (Pty) Ltd.- (iii)
		 1. **bust under** 2. **over-bust (bust full)**

SOURCES: ISO 8559: Taken from the ISO 8559 Body Dimension Standard[66]
Tape Measurement: Adapted Playtex (Pty) Ltd.[52]

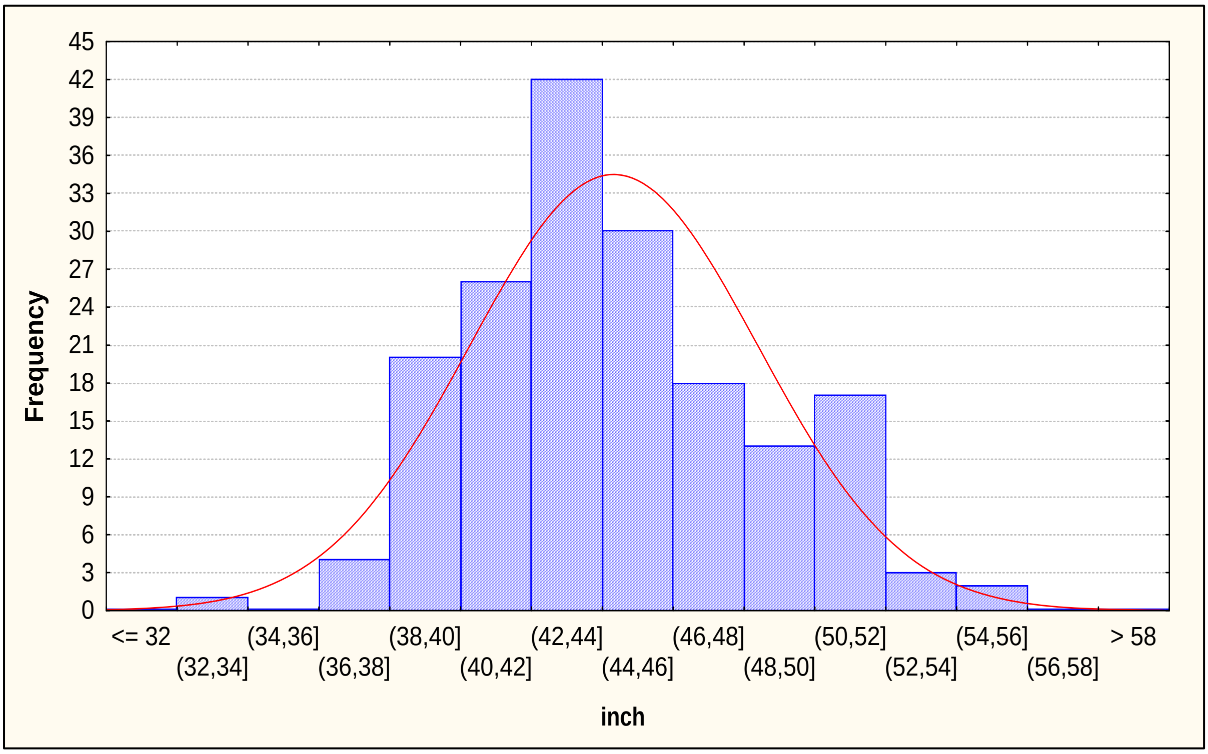
In order to conduct a meaningful and realistic comparison between the 3D body scan measurements and those taken using a tape-measure, it was decided that this comparison will only focus on the under-bust and over-bust torso measurements. The 3D scanner extraction program used for the analysis was user defined to extract bust measurements as explained on pages 52 to 53 of this dissertation and as illustrated in Figure 5.3. The tape-measurements were taken at the same body points of measure as those extracted by the 3D body scanner.

The researcher had to initially establish whether there is a significance difference between the 3D scan measurement data extracted in inches to that extracted in centimetres, in order to conduct a proper comparison with the body measurement data taken using a tape-measure by the Playtex (Pty) Ltd. team in centimetres.

Figure 5.4 shows a normally distributed graph of the bust full (over-bust) data extracted in inches. The distributions of the full bust measurement extracted in centimetres also show a normally distributed curve.

FIGURE 5.4

FREQUENCY DISTRIBUTION OF 3D SCAN BUST FULL MEASUREMENTS EXTRACTED IN INCHES



The maximum difference between the 3D scan bust full measurements extracted in centimetres and those extracted in inches then converted into centimetres were and inches is 0,000012cm and 0.000008cm respectively (see Appendix 8).

The statistical analysis of the body measurement data extracted from the 3D cloud forms of the women therefore show that, 3D scan data of the plus-size women extracted in centimetres and in that extracted in inches (converted into centimetres) are, for all practical purposes identical.

Table 5.2 is the results of the bra cup size determined by the scanner in centimetres and in inches. Only 6.3% of the cup size determined by the automatic measurements of bust and underbust in inches are the same as that in cm (p=0.133 by paired t-test).

TABLE 5.2

CUP SIZE DETERMINED BY 3D SCANNED MEASUREMENTS

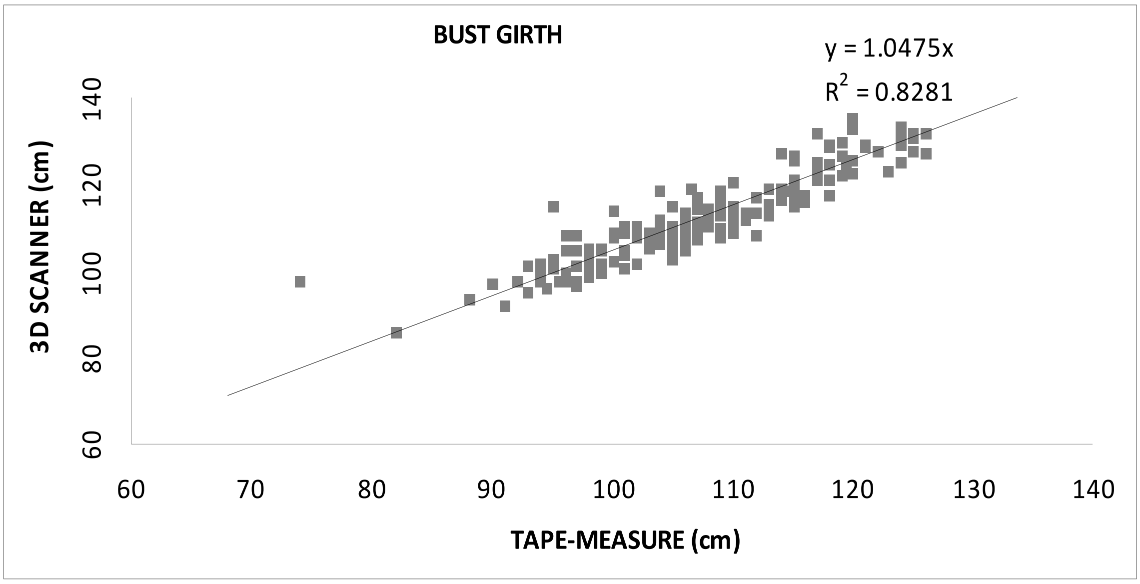
BRA CUP SIZE	DIFFERENCE	COUNT	%
AA	-2	2	1.1%
B	-1	72	41.1%
C	0	11	6.3%
D	1	87	49.7%
DD	2	3	1.7%
E	-	-	-
F	-	-	-
FF	-	-	-
G	-	-	-
	Total n	**175**	**100**

According to Yu's book[81] the metric sizing (cm-based) is more reliable than the imperial sizing (inch-based). In this study, 41.1% (n=175) of the inch-based data have under-estimated the bra cup by one size, and 49.7% (n=175) have over-estimated it by one size. Therefore the analysis in the following chapters will only focus on the 3D body points of measure extracted in centimetres.

There is no “average person”, but for the purpose of this study, the data was analysed and the median values for the bust full (over-bust) and the under-bust measurements as extracted using a tape measure were compared with those obtained by the 3D body scanner see Figures 5.5 and 5.6 respectively.

FIGURE 5.5

VALUES OF THE BUST FULL MEASUREMENTS OF 3D BODY SCANNER vs. TAPE MEASUREMENTS

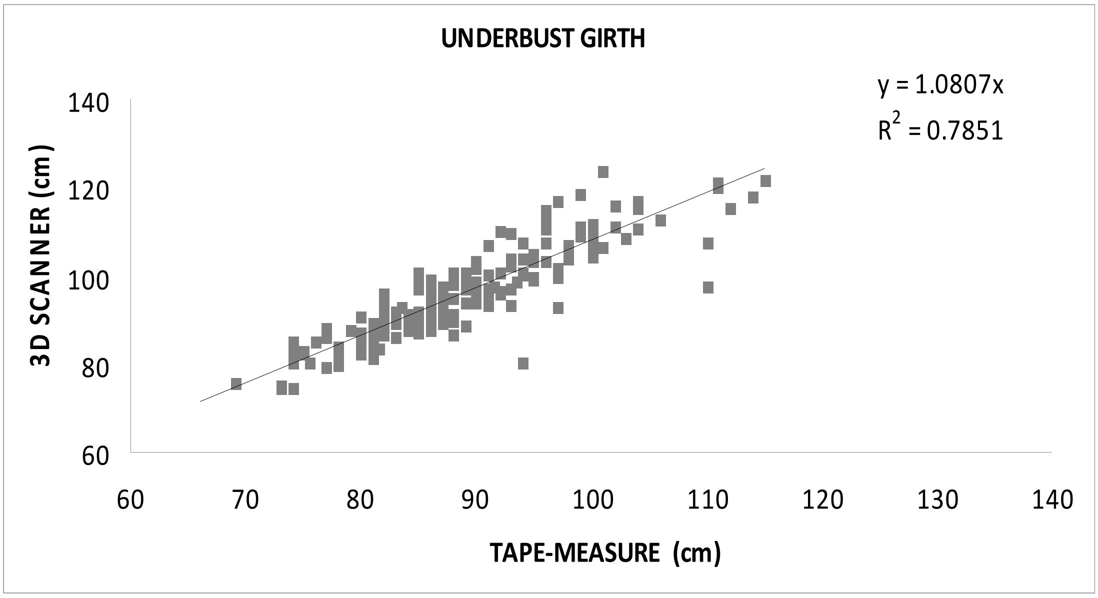


The median values for the over-bust as extracted by the 3D body scanner is 111cm with 95% confidence limits of 111cm and 114cm and the under-bust of 94cm with 95% confidence limits of 93cm and 97cm respectively. y = 1.048X, and R^2 = 0.823 where y denotes the values as extracted by the tape-measure and x denotes the values extracted using and a 3D body scanner both in centimetres.

FIGURE 5.6

VALUES OF THE UNDER-BUST MEASUREMENTS OF

3D BODY SCANNER vs. TAPE MEASUREMENTS



The median values for the bust full as extracted using a tape measure 106cm with 95% confidence limits of 105cm and 108cm and the under-bust of 89cm with 95% confidence limits of 88cm and 91cm respectively. y = 1081x, and R^2 = 0.785 where y denoted the underbust measurement as extracted using a tape measure and x denotes the underbust measurement as extracted by the 3d body scanner both in centimetres.

Table 5.3 show the bra cup sizes as derived from the 3D scanning torso measurements were compared with those derived from the tape-measurements using the Playtex Bra Sizing Chart.

TABLE 5.3

3D BODY SCANNER AND MANUAL BRA SIZE RECOMMENDATIONS ACCORDING TO THE PLAYTEX BRA SIZE CHART OBSERVED FREQUENCIES

		3D SCAN VOLUME							
		A	B	C	D	DD	E	F	TOTAL
	BRA CUP SIZE								
TAPE-MEASURE	DD	4	5	4	5	1	1	0	20
	C	4	5	7	4	2	0	1	23
	E	2	5	6	3	2	2	0	20
	B	4	5	4	5	1	0	0	19
	D	3	10	10	11	3	2	0	39
	A	0	4	0	1	1	0	0	6
	AA	0	1	2	1	0	1	0	5
	F	0	0	5	1	2	0	0	8
	FF	0	0	2	3	0	1	0	6
	G	0	0	1	0	0	0	0	1
	TOTAL	17	35	41	34	12	7	1	147

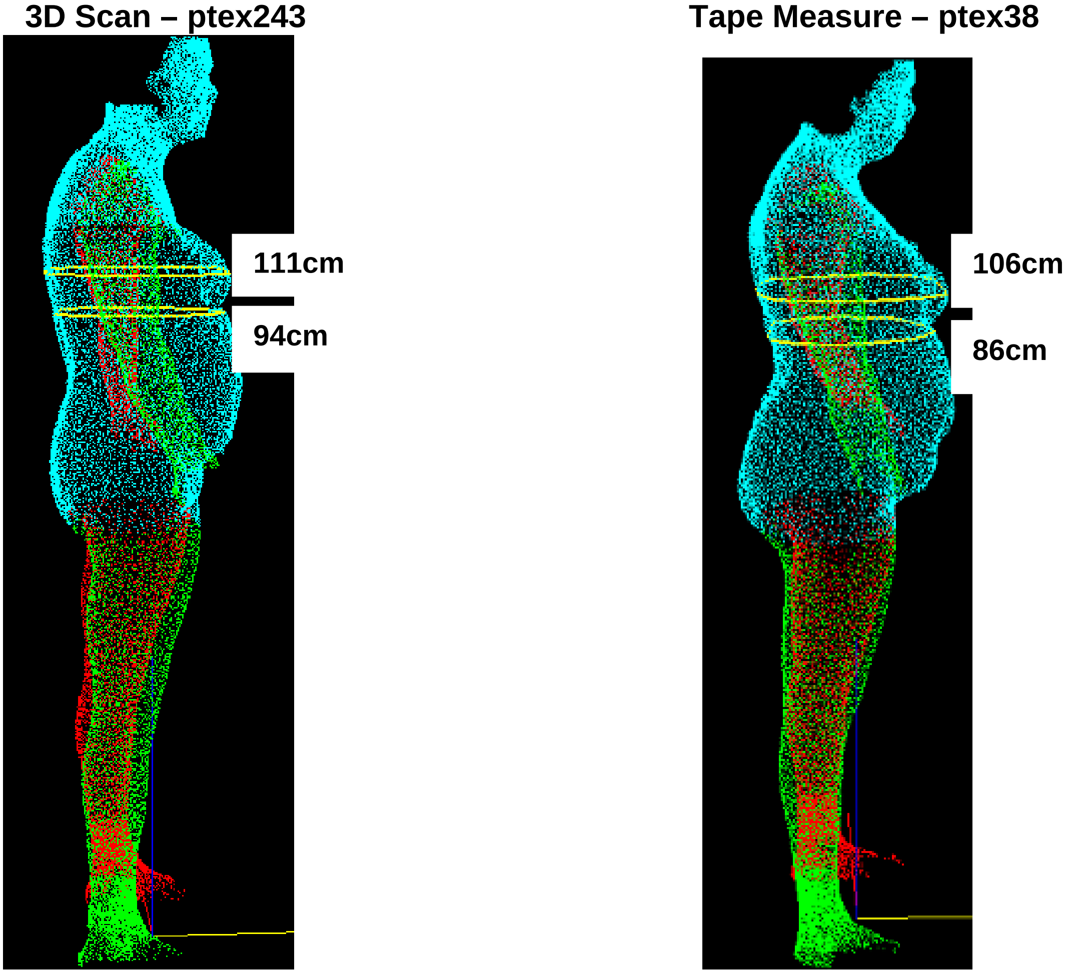
The table shows the frequency distribution of 147 of the 176 plus sized women bra cup sizes, from C to G. The data was extracted based on the subjects underbust and bust full measurement data as derived from the 3D body scanner and that derived by tape measure and the bra cup size was derived using the Playtex Bra Sizing Chart for both these methods. 39% of the bra cup sizes of the subjects were the same whilst 61% were different to that suggested on the bra size chart. The Pearson chi squared for this sample is 45.95, p-value (0.0774). The null hypothesis cannot be rejected as there is no difference between the 3D scanner and the tape measure bra cup sizes.

To better understand the differences in the 3D scanner and the tape measurement differences an explanation is given in Figure 5.7 are scans of a two figures; one corresponding to the 3D scan median value and the other scan of a figure corresponding to the tape measurement median value. The scan of the tape measurement median value was selected from a 3D scan for a subject whose underbust and bust full measurement corresponded to the median value.

These scans illustrate the median differences in the data measurement extraction processes. Subjects referenced as ptex-243; and ptex-38 was selected for this exercise.

FIGURE 5.7

ILLUSTRATION OF 3D SCANS OF SUBJECTS WITH MEDIAN VALUES CORRESPONDING TO THE 3D SCAN AND TAPE-MEASURE, RESPECTIVELY



The difference in the median value of the data generated is 5cms for both the bust full and under-bust measurement. In the bra retail and manufacturing industries, every increase of one inch is considered to represent and increasing bra cup size. It therefore follows that there is a bra cup size difference of two between the two methods, with that of the manual measurement consistently lower than that of the 3D scanning method.

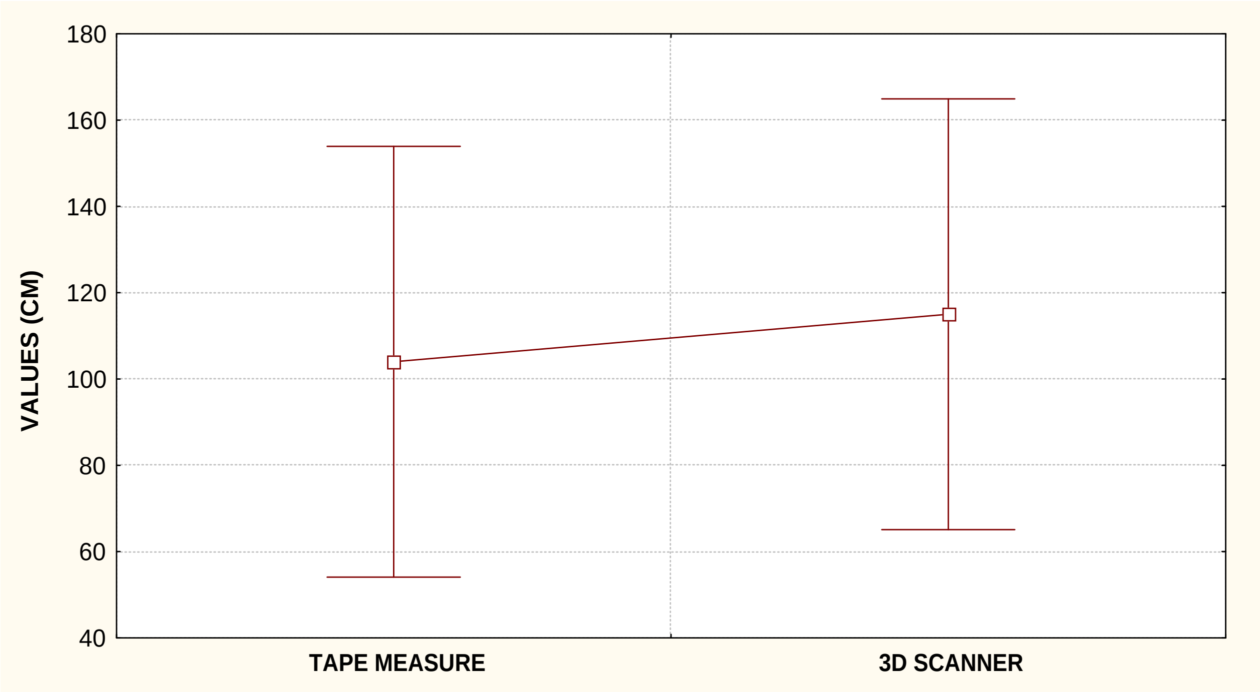
Table 5.2 gives the measurements and relevant information taken of subjects ptex38 and ptex-243 demographic forms (Appendix 3).

It is apparent that the two subjects, referenced ptex-243 and ptex-38, not only have different BMI indices, but their claimed bra sizes are also very different from those suggested by the 3D body scanner's expert system and those derived from tape measurements when using the Playtex Measurement - Bra Sizing Chart. There is a predicted average difference of 11cm in the bust full measurements and a predicted average difference of 7cm in the under-bust measurements between the two methods see Appendix 9.

TABLE 5.4
BODY MEASUREMENTS AND OTHER INFORMATION OF SUBJECTS ptex243 AND ptex38

SUBJECT REF NO:	**ptex243**		**SUBJECT REF NO:**	**ptex38**	
	BMI	**25kg/m²**		BMI	**27kg/m²**
	Height (cm)	167		Height (cm)	164.5
	Body Weight (kg)	70		Weight (cm)	73
	"Perceived" Dress Size:	38 or 40		"Perceived" Dress Size:	40
	Claimed Bra Size:	**38DD**		Claimed Bra Size:	**40B**
3D SCANNER MEASUREMENTS (CM)			**TAPE MEASUREMENTS (CM)**		
Bust Full	**Under-Bust**	**Bra Size**	**Bust Full**	**Under-Bust**	**Bra Size**
111	94	42C	106	86	42B

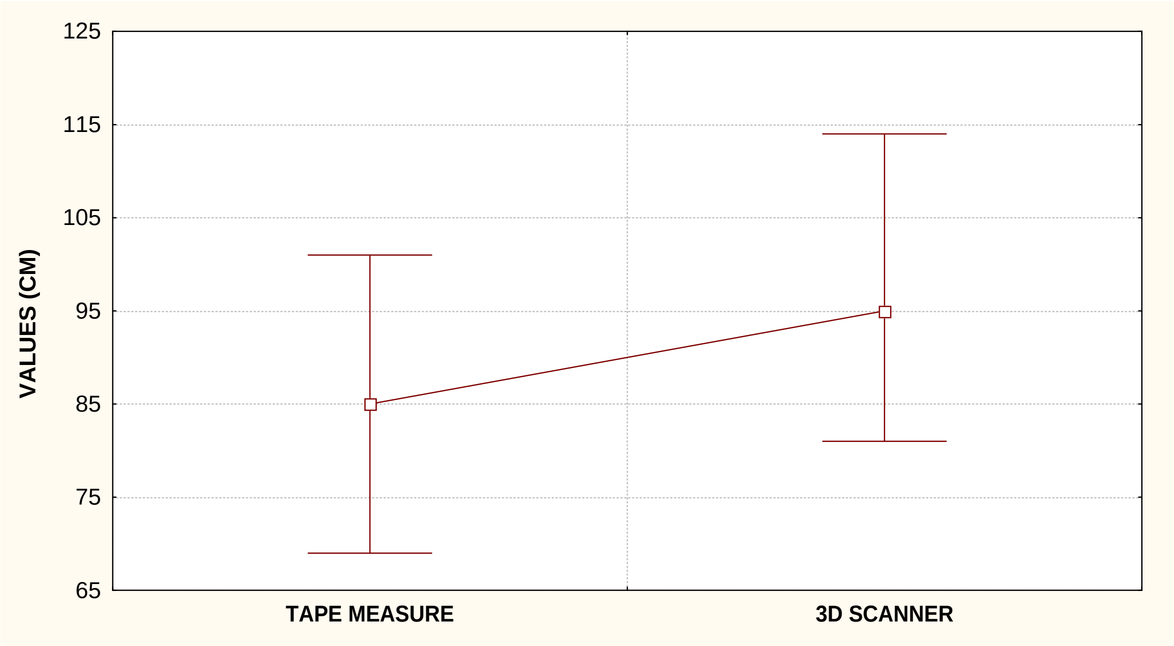
FIGURE 5.8
TAPE-MEASURE BUST FULL MEDIAN VALUES OF TAPE-MEASURE vs. THE CORRESPONDING 3D SCANNER VALUES



Statistically, the difference between the body measurement data extracted by the 3D body scanner and that obtained manually using a tape measure is highly significant (t-test, p<0.0001). The 3D scanner provides consistently higher values than the manual tape measure method. Personal communications with David Bruner[55] from [TC]2 suggest that there is no one to one relationship between measurements extracted by means of the 3D body scanner and those taken using a tape measure. The latter being more prone to human error. Therefore in practice the relationship between the different data sets has to be established by trial and error. This is clearly illustrated in Figures 5.8 and 5.9, using the bust full girth measurement as an example, taken at the 5% significance limit. For the under-bust the difference ranges from an under-band value of 2cm for the smallest measurement to 13cm for the largest measurement. For the bust full measurements the difference ranges from 4cm for the smallest measurement to 17cm for the largest measurement. This conclusion is confirmed at the 95% confidence level.

FIGURE 5.9

TAPE-MEASURE UNDER-BUST MEDIAN VALUES vs. CORRESPONDING 3D SCANNER VALUES



Despite the fact that body measurement data represents only for 176 subjects, and cannot be regarded as being representative of the larger population of South Africa, given the highly statistically difference between the two measurements (t-test $p<0.0001$) it is likely that this would apply to the larger population of plus-size women in KwaZulu Natal and possibly in South Africa.

5.3 VISUAL OBSERVATION METHOD – Bra Fitting Trials

Lyman and Hollies[82], in their study on physiological and field testing of clothing during wear mentioned that factors such as the "degree of control", the thoroughness of the measurement of the variables involved; the environment and the subjective responses of the subjects wearing the clothing item are important factors when conducting wear trials. This was taken into consideration during the bra fitting trials conducted for this study. This chapter will focus on:-

1) Establishing how the different bra styles currently available for plus-sized women relate to the bra cup size after 3D extraction.
2) Conducting “fitting” trials on selected subjects, where the cup notations recommended by the 3D scanner’s expert system is the same to that derived by the tape-measure, to establish whether the current bra cup notation derived from the expert system “New Bust Programme mep.“ provides sufficient data on bust volume, for the intimate apparel manufacturer to design better fitting bra cup panels and underwire bras for plus-size women.

5.3.1 DIFFERENT BRA STYLE FITTING TRIALS

A convenient sample of three women was used for this exercise. The women were selected based on their claimed bra size of 34C, 40DD and 38E respectively. All three plus-size women wore off-the-rack bras in different styles of their claimed bra sizes. Subjects were scanned thrice namely, bra-less; wearing a soft cup bra slightly under-wired and wearing a “crossyrheart” bra without a wire. Due to the limited availability of bra styles for plus-size women, the styles used in this study were limited to two. The aim was to determine how the different plus-size bra styles influences the 3D scanned measurement data of the three women. Digital images were taken of the women wearing the different styles for further assessment. Table 5.5 lists the bust volume readings of the left and right bust quadrants, of the three subjects when wearing the different styles extracted in centimetres, by the expert system.

TABLE 5.5

DIFFERENT BRA STYLES ON 3D BUST VOLUME DATA (cm³)

ptex-01	**Sum_Bust Quadrant_Volumes_Left**	**Sum_Bust Quadrant_Volumes_Right**
BRA-LESS	200	183
CROSSYRHEART BRA	216	182
SOFT CUP BRA	177	204
ptex-94	**Sum_Bust Quadrant_Volumes_Left**	**Sum_Bust Quadrant_Volumes_Right**
BRA-LESS	*** Error ***	*** Error ***
CROSSYRHEART BRA	367	418
SOFT CUP BRA	638	414

cont…

ptex-182	Sum_Bust Quadrant_Volumes_Left	Sum_Bust Quadrant_Volumes_Right
BRA-LESS	*** Error ***	*** Error ***
CROSSYRHEART BRA	770	872
SOFT CUP BRA	1189	1064

******* Scanner could not identify the “hidden areas” of the breast.

The bust quadrants were calculated by the software dividing the bust into four quadrants as indicated by Figures 5.10 to 5.13 for the left bust. The software is programmed to extract the sum of quadrants of the left and right bust as indicated in Figure 5.16, using the default computer generated formula [[a+b] + [c] +[d]].

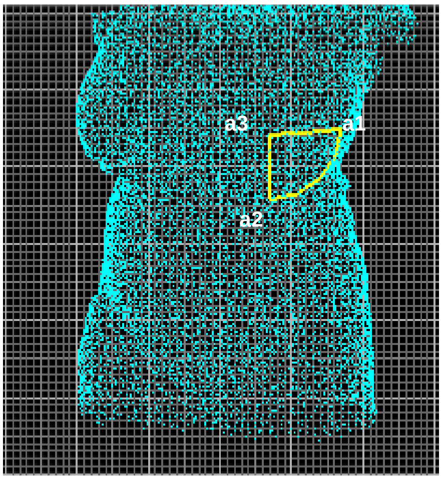


FIGURE 5.10

VOLUME OF THE “LOWER OUTSIDE LEFT” BUST

SUM ~ (a1+a2+a3+a1) = VLOL

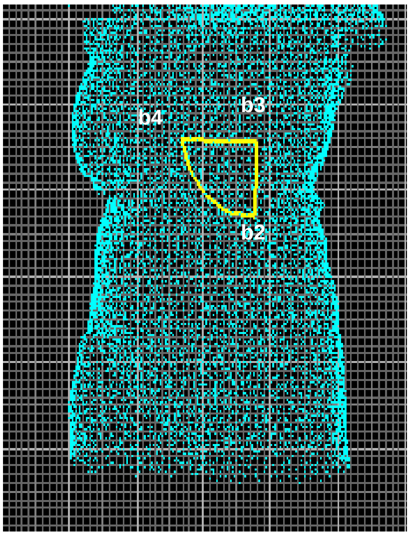


FIGURE 5.11

VOLUME OF THE ‘LOWER INSIDE LEFT” BUST

SUM ~ (b2+b3+b4+b2) = VLIL

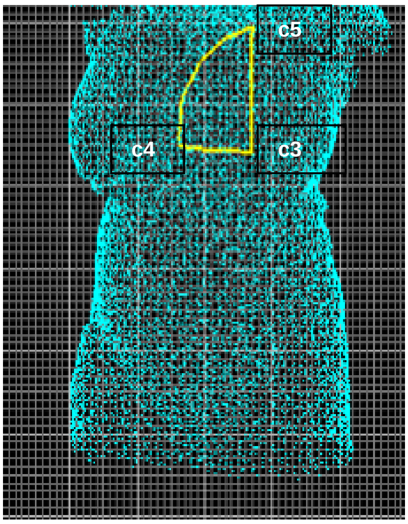


FIGURE 5.12
VOLUME OF THE "UPPER INSIDE LEFT" BUST
SUM ~ (c3+c4+c5+c3) =VUIF

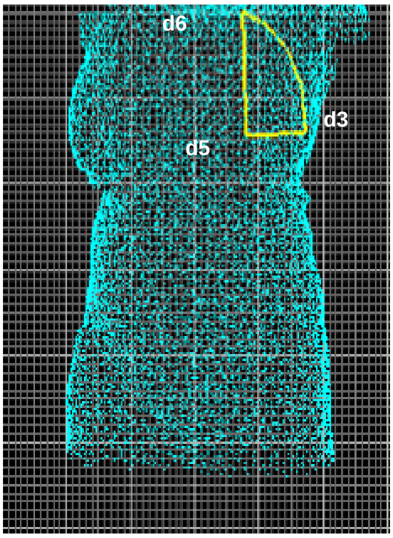


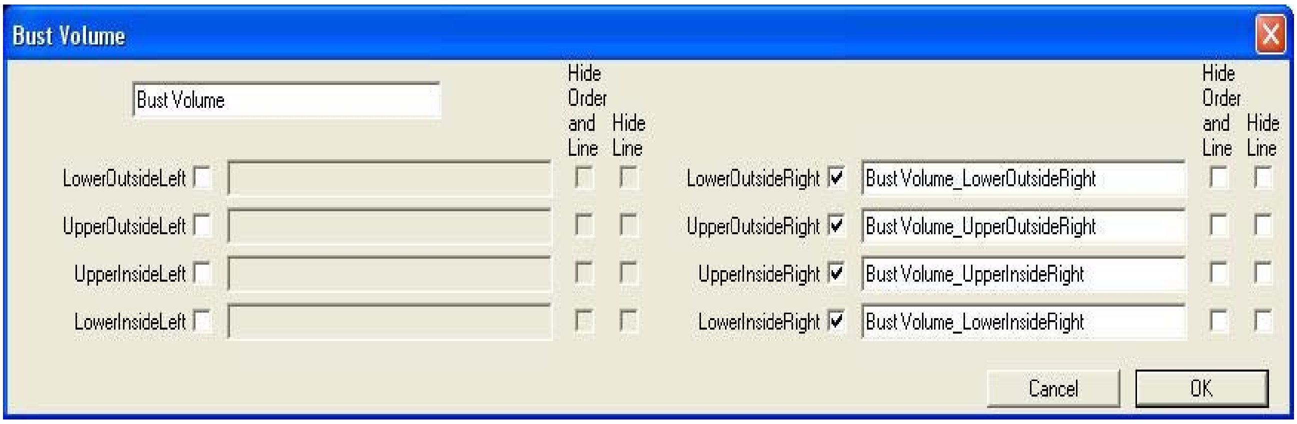
FIGURE 5.13
VOLUME OF THE "UPPER OUTSIDE LEFT" BUST
SUM ~ (d3+d5+d6+d3) = VUOL

The total volume of the four quadrants equals **VLOL+VLIL+VLUF+VUOL** as indicated by Figures 5.10 to 5.13, are the sum of the breast volume for that subject.
The corresponding calculations for the right bust are also as for the left bust.

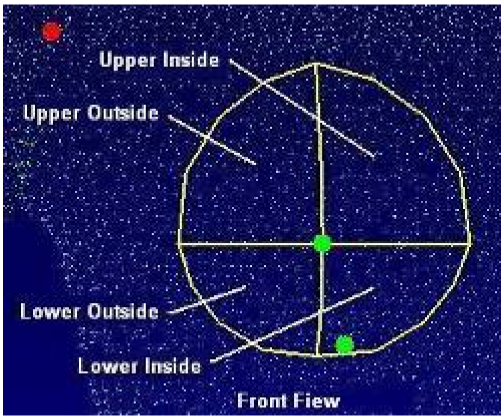
Figure5.14 is the input screen for generating the formula to calculated the sum of the breast volume

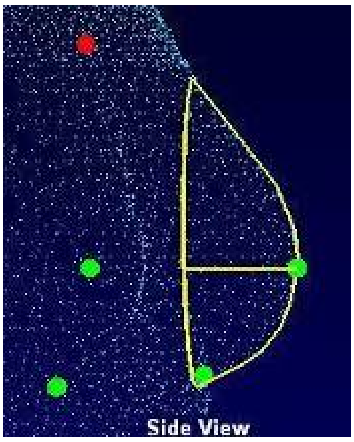
FIGURE 5.14

SCREEN FOR INPUTTING FORMULA CALCALUTIONS AND THE BREAST EXTRACTION POINTS



These measurements measure the volume of a quarter of each bust. To get the total sum of bust volume the different bust quadrant volume measurements are added together.





SOURCE: TC2 [83]

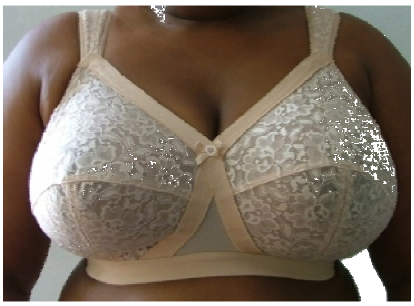
The illustrations above can be explained as, the front view is looking straight on to the bust point rather than from directly in front of the torso. The side view is also looking from slightly behind the centre of the side of the torso so that the plane of the measurements can be seen.

The bra style trials highlighted that:-

1. As the breast size increases, the NX12 software is unable to locate the default body landmark points as the bust "droops" downwards towards the waist. The subjects were not comfortable being photographed bra-less hence there are no images to collaborate this finding except that the 3D scan body measurement data, taken bra-less of subjects referenced ptex94 and ptex182 is indicated as "Error" readings, as the 3D body scanner could not identify the hidden areas of the breast. This finding is supported by Catanuto *et al*.[45] who mention that the problems with areas completed hidden by "glandular folding on the chest wall" cannot be overcome by using a light based scanner.
2. It is apparent that significantly different values are obtained when scanning the subjects "bra-less" and with the two styles of bras, but the trend is not consistent for the three subjects or for the left and right busts. For example, for subject ptex-01, the soft cup bra gives a lower value for the left bust than bra-less or with the crossyrheart, while the reverse is true for the right bust. Furthermore for the other two subjects, the soft cup bra tends to give higher values for both breasts that the crossyrheart bra and higher values for the left bust than the right bust.

FIGURE 5.15

CROSSYRHEART BRA STYLE



3. This exercise established that the different bra styles can affect the 3D scan bust volume values to a great extent, with the difference being subject to the scanned subjects torso shape and size. The different readings recorded could possibility be attributed to the type of fabric and trimmings used in the manufacturing of the two different bra styles and to the functions of the different bra styles as mentioned in Chapter 2. The crossyrheart bra is manufactured in

a fabric that is far more rigid and has a more structured bra style (see Figure 5.15), than that used in the manufacturing of the soft cup bra cup as illustrated in Figure 4.1. Both these styles are from different brands and have different manufacturing style numbers.

The above mentioned differences between the two bra styles can explained for ptex94 and ptex182, the bust volume readings of the crossyrheart bra style are generally lower than those of the soft cup bra, the former giving the wearer firmer support, than that provided by the soft cup bra, manufactured of a lightweight type fabric as illustrated in the Figures 5.16. These findings have to be collaborated with a larger sample size to establish if this is true for all large breasted women when wearing a crossyrheart and a soft cup bra manufactured of fabrics and trimmings similar to those used here. This contrasts with the view expressed by Hardaker and Fozzard[84] who cite marketing and branding, and not sizing, as reasons for the 'fit' variation between different bra styles even within the same manufacturer, as all bra manufacturers use identical or similar anthropometric body landmarks to extract the torso data for manufacturing their bras.

FIGURE 5.16

SOFT-CUP BRA STYLE

5.3.2 LIVE MODEL BRA FITTING TRIALS

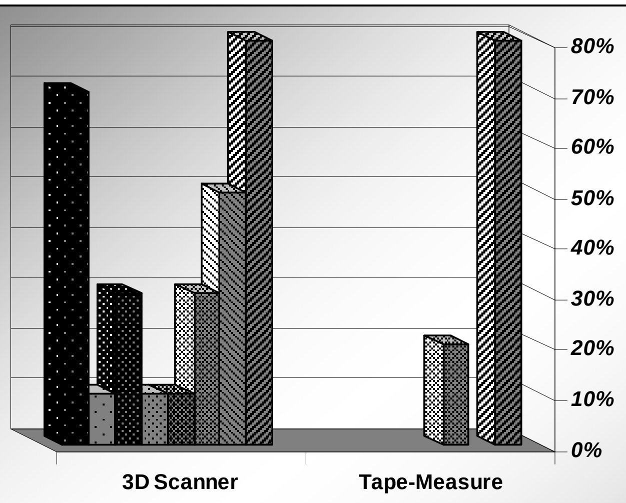
Garment "Fit"[85] is considered to be the normal distance between the body surface and the garment, with the designer specifying the fit required during the design process.

Ng *et al* [82] went further to rationalize a framework of fit measurements based on the mathematical concept of "algebraic mannequin", at four levels of indices, namely cross sectional index, the linear index , the signature curve index and the volume index. These indices measure the “space” between the body and the garment, but the pressure sensation on the body, in this case the upper torso, also influences the evaluation of fit.

In this chapter, the visual method of observation was conducted on a convenient sample of ten women, chosen from the design department, sampling room and the administration staff at Playtex, and not the staff involved in the manufacturing plant, so as to not disrupt production during the fitting trials. The women were requested to try on the bra sizes derived from the 3D scan data and that derived from the tape measurement data respectively. The Playtex Measurement Bra- sizing chart was used to calculate the women’s bra size for both of the methods. The fitting trials were conducted to establish which of the two bra sizes produced the best fit for that particular subject. The bra fitting trial was conducted in conjunction with a questionnaire see Appendix 10. The questionnaire consisted of 10 questions requiring a YES or NO response to the different bra fitting questions. A convenient sample of ten subjects all wore the same styled bra; soft cup slightly under-wired made of different fabrics and of different colours and the fit was rated against the questionnaire by the researcher. The fitting trials highlighted that eight out of the ten questions listed on the questionnaire, represented problem areas between the two different methods of data collection, as illustrated in Figure 5.17 below. The questions below are in response to those that reflect a “**YES”** answer.

FIGURE 5.17

FITTING TRIAL QUESTIONNAIRE "YES" RESPONSES



	3D Scanner	*Tape-Measure*
Are the sides bulging?	*70%*	
Does the underwire pinch or poke?	*10%*	
Is the strap slipping?	*30%*	
Is the breast bulging over the cup?	*10%*	
Is the front band pulling down?	*10%*	
Is the centre front lifting away from the body?	*30%*	*20%*
Are the cups to baggy?	*50%*	
Is one breast noticeably bigger than the other?	*80%*	*80%*

The Figure shows that there were more bra "fit" related problems with the bra size as recommended by the 3D body scanner as apposed to that taken using a tape measure. This could be explained by the last question in the Figure on "*Is one breast noticeably bigger than the other?"* where this was a problem with 80% of the women. When breast are asymmetrical, the scanner's expert system is recommending a bra size based on the larger breast.

TABLE 5.6

3D BODY SCANNER'S EXPERT SYSTEM vs TAPE MEASURE DERIVED BRA SIZE

Based on the results given in Table 5.6 the following conclusions can be drawn:

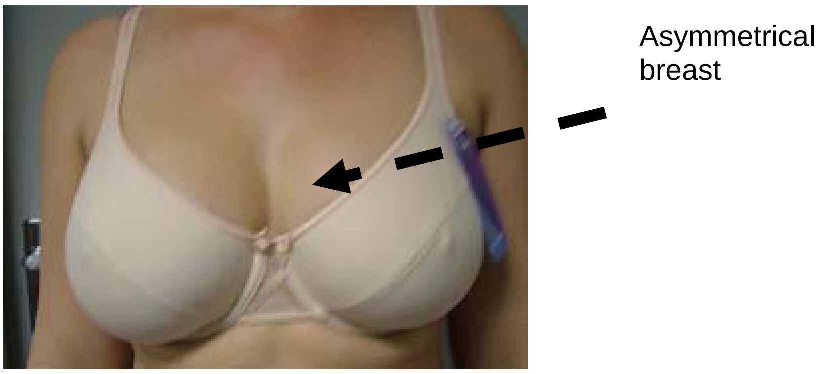
			New Bust Programme			
			B_Cup_	C_Cup_	D_Cup_	DD_Cup_
Subject	3D Scanner-recommended Bra Size	Tape Measure-recommended Bra Size	Bust_Volume_	Bust_Volume_	Bust_Volume_	Bust Volume
			5 to 30	25 to 45	40 to 50	45 to 80
PTEX-36	42B	40B	B			
PTEX-68	42B	40D	B			
PTEX-130	38B	34D	B			
PTEX-231	42D	40D		C	D	
PTEX-132	40C	36F		C		
PTEX-147	46D	44C		C	D	
PTEX-153	52C	50		C	D	
PTEX-183	40D	40B		C	D	
PTEX-187	36C	32E	B	C		
PTEX-235	40B	38DD	B			

1. The bra sizes derived from the 3D body scanner were different to those derived from the manual measurements. This is in line with the findings Illustrated in Figures 5.8 and 5.9 on pages 76 to 79, that the 3D scanner torso body measurements are generally greater than the manual tape measurements.
2. The torso body measurements extracted by the 3D scanner resulted in a larger bra size recommendation than those extracted by the manual method.
3. Eight out of the ten women used in this exercise are asymmetrical, four women having the left breast larger than the right breast and with four women having the right breast larger than the left (taken from Figure 5.17).
4. The expert system New Bust Programme mep. 3D extracted bra cup size recommendation is based on the larger breast when the breasts are not symmetrical in nature.
5. A problem common to both the 3D scanner and manual tape measure recommended bra sizes is that of the centre front lifting away from the body, which according to Figure 2.14 (page 37) is caused by a bra cup that is too small.

6. The difference in the bra size recommendation derived from the manually extracted measurements are due to the fact that the manufacturer uses a standard bra pattern block, for example, for bra size 40B; sample bras are manufactured from these dimensions and the fit is adjusted on a live fit model. The fit model's body dimensions may not represent all women who wear a bra size 40B.
7. The 3D scanner recommended cup size based on the larger breast. The tape-measure bra size recommendation is not based on asymmetrical breasts as illustrated in Figure 5.7.

FIGURE 5.7

EXAMPLE OF ASYMETRICAL BREASTS



The researcher further explored the "cross fitting bra chart "concept" as indicated in Table 2.1, by conducting live model fitting trials with the bra manufacturer's 34B fit model, to establish if this concept "works" in practice. The findings of this exercise is that the correct bra fit is largely dependent on the body shape and profile of the subject and the brand and style of the bra; and is largely dependent on how comfortable the individual is when wearing cross fitting bra sizes.

5.4 COMPARISON OF BRA CUP SIZES (VOLUMES) AS EXTRACTED FROM THE 3D SCANNER AND MANUAL TAPE-MEASUREMENTS, RESPECTIVELY

The long term objectives of the bra study for plus-size women is to develop a stand alone software programme to extract 3D upper torso body measurements, focusing more especially on the bra cup size or bust volume for South African women, as the current software was developed using American women's body dimensions This pilot study on bra sizing for plus-size women aims to establish the basis of that software program. This section compares the bra cup size recommended by the expert system New Bust Measurement mep.based on the 3D scanner data with those derived from the manual tape measurements.

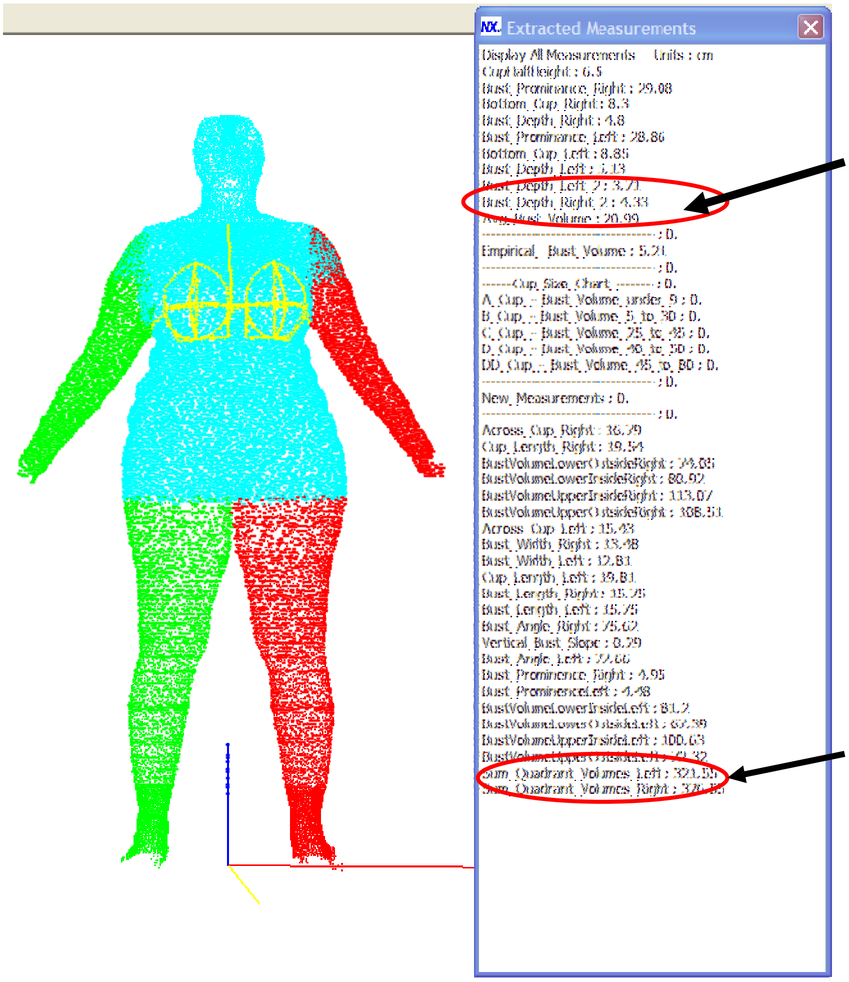
The bra sizes of the 176 women using the two different extraction methods. In both cases the Playtex – Bra Measurement Sizing Chart (see Appendix 1) is used to calculate the subject's bra size.

5.4.1 BUST VOLUME DATA EXTRACTION USING THE NEW BUST PROGRAM mep.

The software program divides the surfaces of the left and right busts into four quadrants. The total surface area and the single subunit areas are computed per left and right breast quadrants, as illustrated in Figure 5.10 to 5.13 on (pages 79 and 80), to obtain the sum of the left and right bust quadrant volumes (in cm^3).

FIGURE 5.19

SCAN WITH EXTRACTED BRA CUP QUADRANT INFORMATION

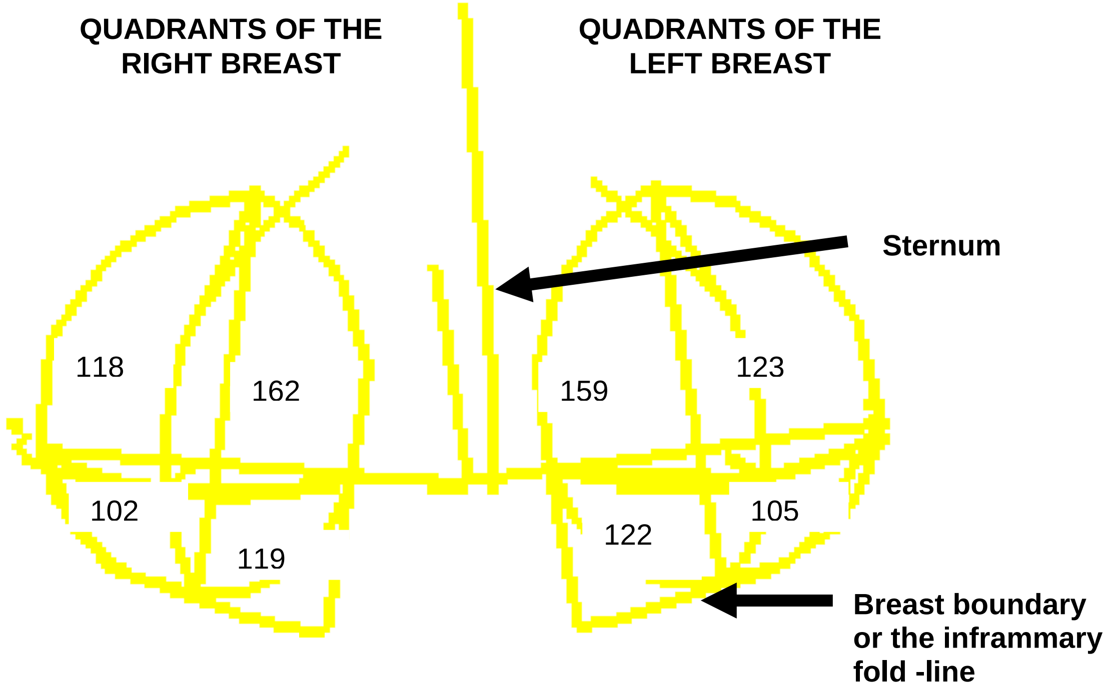


The bust output data from the expert systems program contains 22 extracted landmark points representing bra cup size or bust volume information based on the volumes of the left and the right breasts, the cup depth, cup length and breast angle. The analysis in this section focuses only with the Sum of the Quadrant Volumes of the left and right breasts of 176 women and relating this to a bra cup size. The Chambers dictionary[86] defines a quadrant as one quarter of a circumference or area of a circle. A proportion is defined as a relationship of one part of a whole to other parts. Eberle *et al.*[87] further explain this concept as an appreciation of natural proportions that represent the human figure and therefore clothing design.

The median volumes for the left and right busts of the 176 women, as extracted by the New Bust Programme in cubic centimetres are illustrated in Figure 5.20

FIGURE 5.20

MEDIAN VOLUMES (cm³) FOR THE QUADRANTS OF THE LEFT AND RIGHT BREAST OF 176 WOMEN



The 3D median values suggest that the busts are asymmetrical in shape, with the right breast with a total volume of 501cm³ being smaller than the left breast with a total volume of 509cm³ for the women used in this exercise. Extracted bust quadrant measurement data show that the upper inner right bust with a median value of 162.25cm³ and left breasts with a mean value of 159.14cm³ closer to the sternum is heavier than the lower outer right and left breast quadrants. This will have a significant impact not only on the bra cup design, but also on the bra strap design for plus-size women, as the upper quadrants of the bust are heavier than the lower quadrants. This suggests that when designing bras for plus-sized women, the designer should take into consideration factors such as:

- The bra cup should have enough depth to contain the breasts without any side spillage over the bra cup.
- The under-band design should be curved therefore ensuring that the under-band of the bra has an even distribution of "stress pull" across the back.

- Wide bra straps made of the correct fabric, elastic, and modulus of straps that are of the correct width should be used.

Table 5.7 tabulates the bra cup size and the bra band size and the average bust quadrant values as extracted by the expert system.

TABLE 5.7

AVERAGE BREAST VOLUMES RELATED TO A BRA SIZE

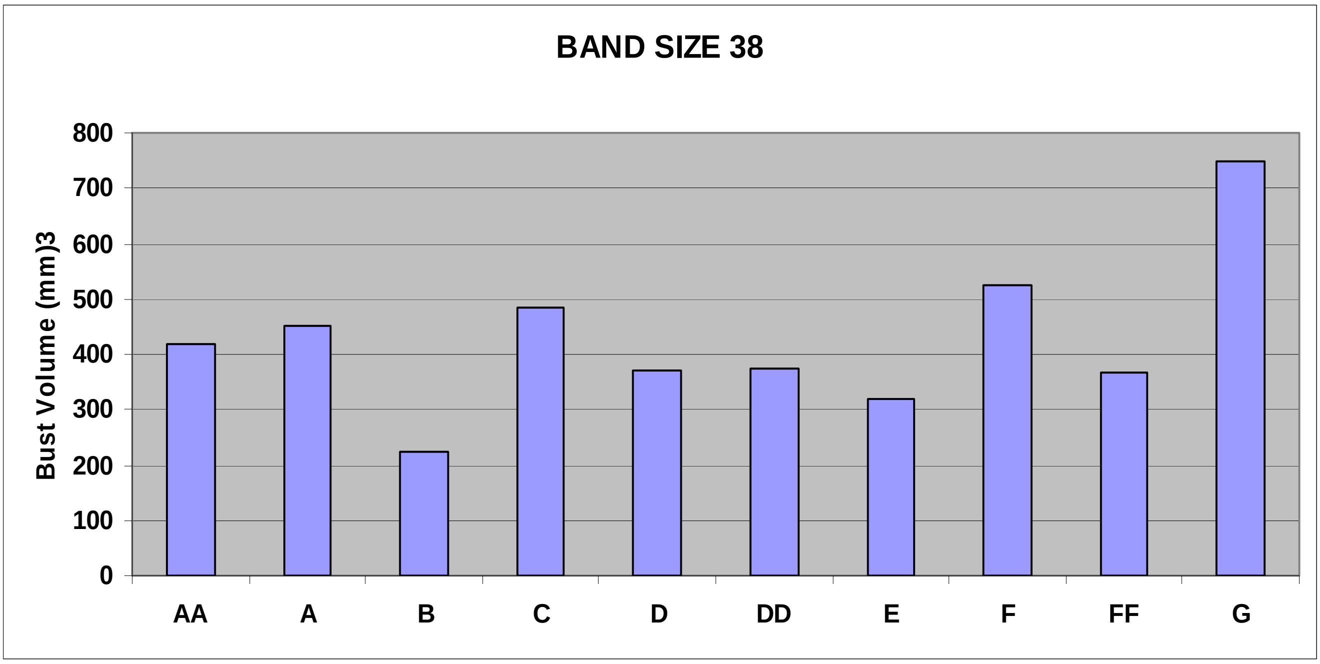
Bra Cup Size	Band Size									
	32	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**	**50**
AA	-	192	656	418	309	349	-	-	698	738
A	-	-	-	450	348	289	-	791	1056	-
B	-	519	503	225	395	658	521	548	357	-
C	-	257	486	485	299	618	557	-	765	-
D	-	542	509	371	608	311	796	308	-	-
DD	-	501	332	374	724	631	701	-	-	-
E	531	323	507	321	980	465	341	-	-	-
F	-	734	526	524	-	837	-	-	-	-
FF	-	503	990	367	797		-	-	-	-
G	-	-	-	750	-	396	-	-	-	-

There is no trend in the bra cup size (volume) from sizes AA to G relative to the bra band size. This supports the findings of an Edcon[34] study that bra fit is largely dependent on the extent of fatty tissue contained within the breast and that factors such as the actual “separation”, position of the nipples and the orientation of the breasts also influence the correct fit of a bra.

This is illustrated graphically in Figure 5.21 for band size 38 only.

FIGURE 5.21

AVERAGE BREAST VOLUMES RELATED TO BRA BAND SIZE 38



The graph above shows the cup size (volume distribution) for band size 38. The bust volume does not show a continuously rising trend with increasing cup sizes determined by tape measurements.

Two bra sizes namely 42B and 42D with sufficient subjects, to give a statistically valid sample. The body measurement data of the averages for the thirteen 42B and eight 42D plus-size women was used for this exercise. The expert system was used to extract the 30 body landmarks and batch processed into Microsoft Excel spreadsheet for analysis. Batch processing allows the user to process multiple body data files without having to load and process each scan individually into a Microsoft Excel Spreadsheet.[70]

The data analysis was conducted at the 95% confidence level.

TABLE 5.8

TORO LANDMARKS CALCULATED AT THE 95% CONFIDENCE LEVEL AS EXTRACTED BY THE EXPERT SYSTEM

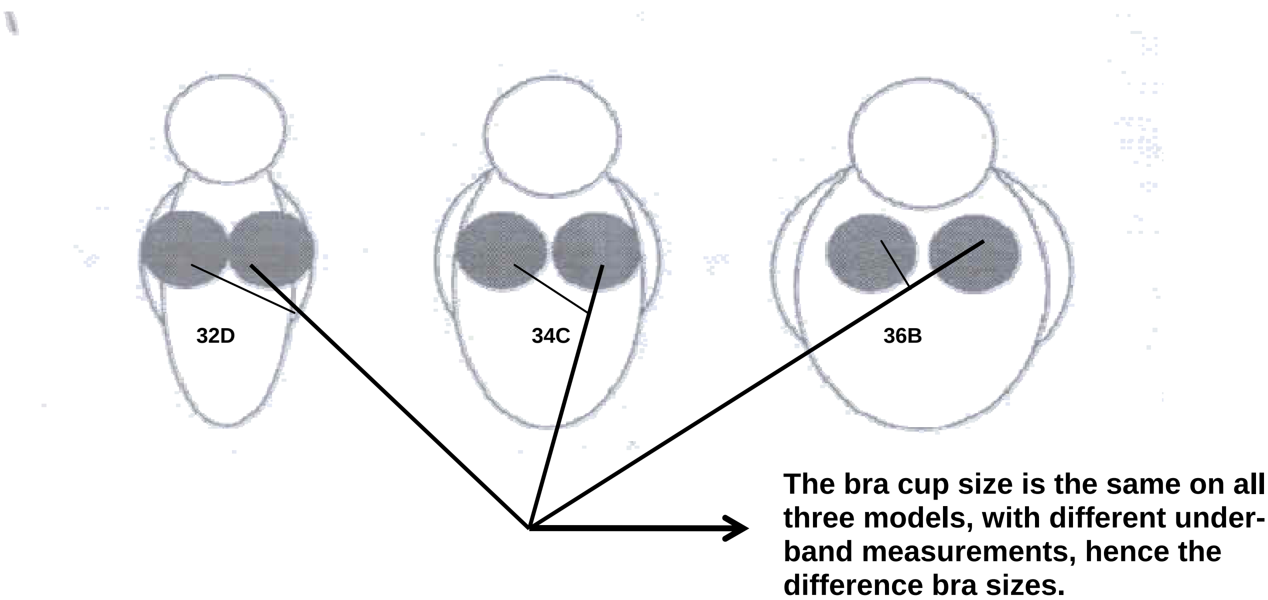
	Body Landmark	**Averages (13 subjects)**	**Average (8 subjects)**
		Bra Size 42B	**Bra Size 42D**
1	CupHalfHeight	7	7
2	Bust_Prominence_Right	29	30
3	Bottom_Cup_Right	8	9
4	Bust_Depth_Right	4	5
5	Bust_ProminenceLeft	28	29
6	Bottom_Cup_Left	9	9
7	Bust_Depth_Left	4	5
8	Bust_Depth_Left_2	5	5
9	Bust_Depth_Right_2	5	5
10	Across_Cup_Right	18	18
11	Cup_Length_Right	23	24
12	BustVolumeLowerOutsideRight	93	90
13	BustVolumeLowerInsideRight	108	124
14	BustVolumeUpperInsideRight	176	165
15	BustVolumeUpperOutsideRight	139	128
16	Across_Cup_Left	17	18
17	Bust_Width_Right	14	14
18	Bust_Width_Left	14	14
19	Cup_Length_Left	23	23
20	Bust_Length_Right	17	17
21	Bust_Length_Left	17	17
22	Bust_Angle_Right	77	75
23	Vertical_Bust_Slope	1	0
24	Bust_Angle_Left	78	74
25	Bust_Prominence_Right	5	5
26	Bust_ProminenceLeft	5	6
27	BustVolumeLowerInsideLeft	114	122
28	BustVolumeLowerOutsideLeft	94	94
29	BustVolumeUpperInsideLeft	180	170
30	BustVolumeUpperOutsideLeft	125	129
31	***Sum_Quadrant_Volumes_Left***	***513***	***515***
32	***Sum_Quadrant_Volumes_Right***	***515***	***506***

The study highlighted that there is no consistency between the average breast volumes related to a bra cup size extracted by the 3D scanner, when calculated to a bra size using the Playtex Measurement – Bra Size Chart

As an example the recommended bra cup size 34C average breast volume is 257 cm^3 while for the recommended bra cup size 34D the average breast volume is 447 cm^3.

The sample sizes per recommended bra cup sizes were generally not large enough for the researcher to draw any definite conclusions, although a similar study conducted by Smith *et al*.[88], involving linear measurements of the right and left breast volumes show similar inconsistencies in the results obtained in terms of the total breast volumes per bra cup size. The inconsistency in bra sizing could be explained by Horrell's[41] study on bra cup size, that found that one of the common misconceptions with bra sizing is the assumption that a D cup is always bigger than a C or a B cup, which is not correct. The bra's cup size is dependent on the band size and that a bra cup size 32**D** holds the same breast volume as a 34**C** or a 36**B** bra as illustrated in Figure 5.23. As can be seen the cup size is exactly the same on the three models, but the underbust bust or the girth measurements are different. This in practise means that for example, if a subject is currently wearing a 34C bra size and want to wear a smaller band size, but keep the same cup size, then the subject should be wearing a 32D bra size and not a 32C, to accommodate the breast size. This finding is collaborated by the Cross Fitting Chart on page 18, Table 2.1.

FIGURE 5.23
DIFFERENT ILLUSTRATIONS OF THE SAME BRA CUP SIZE



SOURCE: Adapted from The Bra Book[41]

The results obtained from Table 5.7 highlight that 10% of the plus-size women scanned are not accommodated by the current Playtex Body Measurements Size chart as the required cup notations are either not available or the band sizes are larger than the measurement of 115cms Statistical analysis of the sum of volumes of the left and the right bust quadrants show very little relationship to bra cup size when related to the manufacturers sizing chart. This suggests that one cannot predict a bra cup size based on the 3D scan sum of bust quadrants (volume) of the left and right busts alone, as extracted by the standalone New Bust Programme mep.calculated into a bra size using the Playtex- Measurement-Bra sizing chart.

Given the above findings, the researcher had to further interrogate the data set to find bra sizes that had sufficient subjects who are wearing the same bra size as that extracted by the 3D scan cloud form. Subjects were selected based on 3D scanner recommended bra cup sizes of 42B and 42D, since these bra sizes had sufficient subjects to give an indication of what parameters other than the average breast volume influence bra cup size or the breast volume. The subjects chosen for this analysis are highlighted in grey in Table 5.5, page 95 this dissertation.

To test the finding from Table 5.7 the following traditional body points of measure were selected as extracted by the 3D body scanner and calculated into a bra size using the Playtex-Measurement – Bra Size Chart; to establish the relationship between:-

Experiment (1) - average 3D bust volumes
Experiment (2) - bust full or over-bust
Experiment (3) - underbust

} Calculated into a bra size using the Playtex Measurement-Bra Sizing Chart

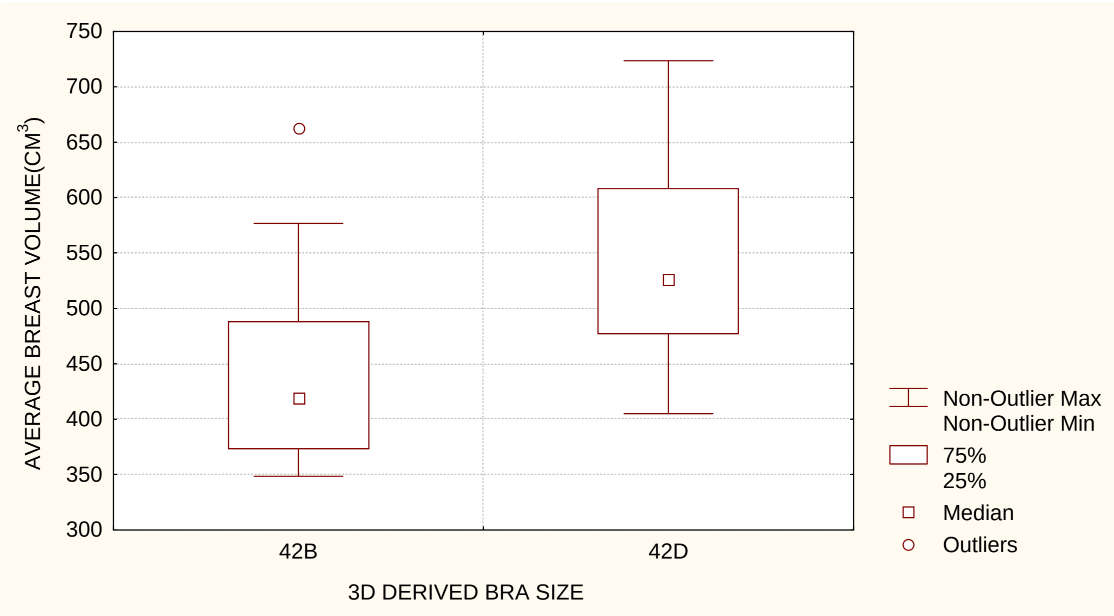
for the 3D recommended bra sizes 42B and 42D using the Box and Whisker Plots as illustrated in Figures 5.24 to 5.26 on pages 96-98.

5.5.4.1. **Experiment (1)**

The distribution of the Average Bust Volume for 3D Scanner Recommended Bra Sizes 42B and 42D is illustrated in Figure 5.24.

FIGURE 5.24

BOX PLOT DEPICTING BUST VOLUME DISTRIBUTIONS FOR BRA SIZES 42B AND 42D



The Box Plots in Figure 5.23 indicate that the median value for or the bust volumes for bra size 42B is 423cm³ and for bra size 42D is 526cm³. The lowest value recorded for bra size 42B is 348cm³ and the highest is 662cm³. Bra size 42D median value at the lower limit is 405cm³ and 724cm³ at the upper limit.

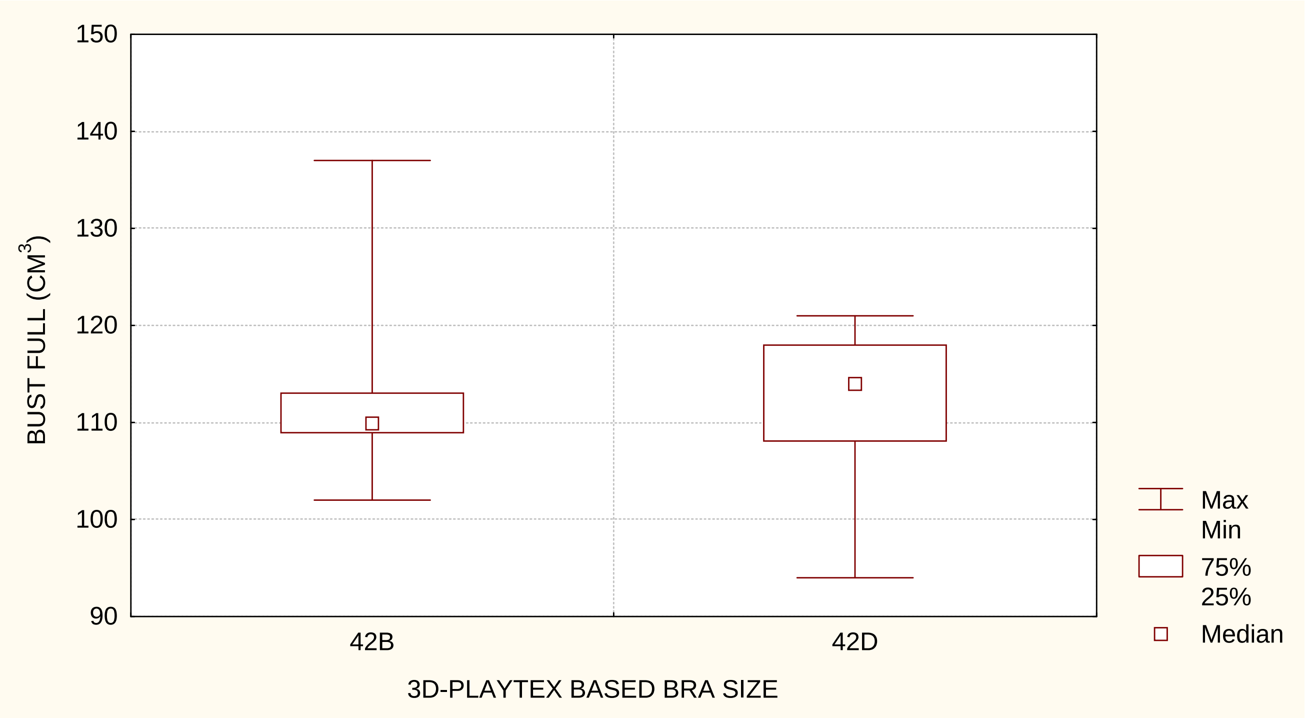
At the 25th percentile the bust volume for bra size 42B is 380cm³ and 510cm³ at the 75th percentile. For bra size 42D, the bust volume at the 25th percentile is 476 cm³ and 608 cm³ at the 75th percentile. The sample shows an outlier, with a bust volume of 662 cm³, for bra size 42B. An outlier maybe explained as the difference between the median and the 75th percentile.

5.5.4.2 **Experiment (2)**

The distribution of the Bust Full values of the 3D Scanner recommended Bra Sizes 42B and 42D, illustrated in the Box and Whisker Plots shown in Figure 5.25.

FIGURE 5.25

BOX PLOT DEPICTING BUST FULL DISTRIBUTIONS FOR BRA SIZES 42B AND 42D



The Box and Whisker Plots in Figure 5.25 indicate that the median values for the bust full for bra size 42B is 110cm and for bra size 42D is 115cm. The lowest recorded value bra size 42B is 102cm and the highest is 121cm. Bra size 42D bust full lowest recorded value is 107cm and 128cm at the upper limit.

At the 25th percentile the bust full distribution for bra size 42B is 109cm and for bra size 42D is 112cm. At the 75th percentile the bust full distribution for bra size 42B is 113cms and 117cm for bra size 42D.

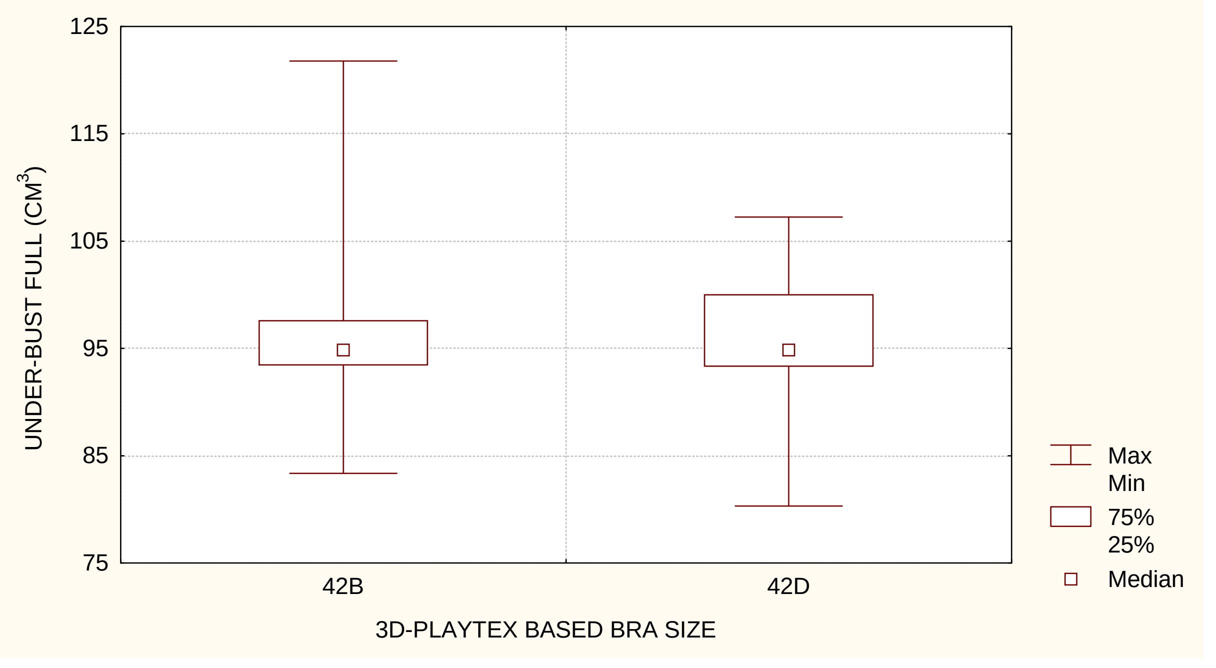
There is a 3cm difference in the bust full median values for bra size 42B and 42D whilst between the 25th to the 75th percentile for bra size 42B there is a 3cm difference and for bra size 42D a 4cm difference.

5.5.4.2. **Experiment (3)**

The distribution of the Under-bust values for the 3D Scanner recommended Bra Sizes 42B and 42D is illustrated in the Box and Whisker Plot shown in Figure 5.26.

FIGURE 5.26

BOX PLOT DEPICTING UNDER-BUST DISTRIBUTIONS FOR BRA SIZES 42B AND 42D



The Box and Whisker Plots in Figure 5.25 indicate that the median values for the under-bust for bra sizes 42B and 42D is 95cm, although both data sets shown extreme values.

The lowest recorded value for bra size 42B is 83cm and the highest is 122cm.Bra size 42D lowest recorded value for the under-bust is 93cm with the highest value being 107cm.

At the 25th percentile the under-bust distribution for bra sizes 42B 93cm and for bra size 42D is 94 cm. At the 75th percentile the under-bust distribution for bra size 42B is 98cms and 100cm for bra size 42D.

At the 25th to the 75th percentile for bra size 42B there is a 5cm difference and for bra size 42D a 6cm difference.

The reasons for the outliers as indicated in the Box Plots above were explored further by the using the TC[2] 3D body scanner's default function of "slicing" the bust full girth measurements for two randomly selected subjects wearing the recommended bra sizes of 42B and 42D, respectively. This is illustrated for the different subjects in Figures 5.27a to 5.27d.

In the 3D scan slice measurement box, the Height; Surface; Tape; and the Area body measurements data are displayed. This can be explained as follows:-

1) The Height represents the height of the slice from the floor in inches.
2) The Surface represents the distance around the slice surface in inches
3) The Tape represents the simulated tape measure of the slice in inches
4) The Area represents the area of the slice in square inches.

FIGURE 5.27a – ptex03

SLICES OF THE BUST FULL GIRTH MEASUREMENT

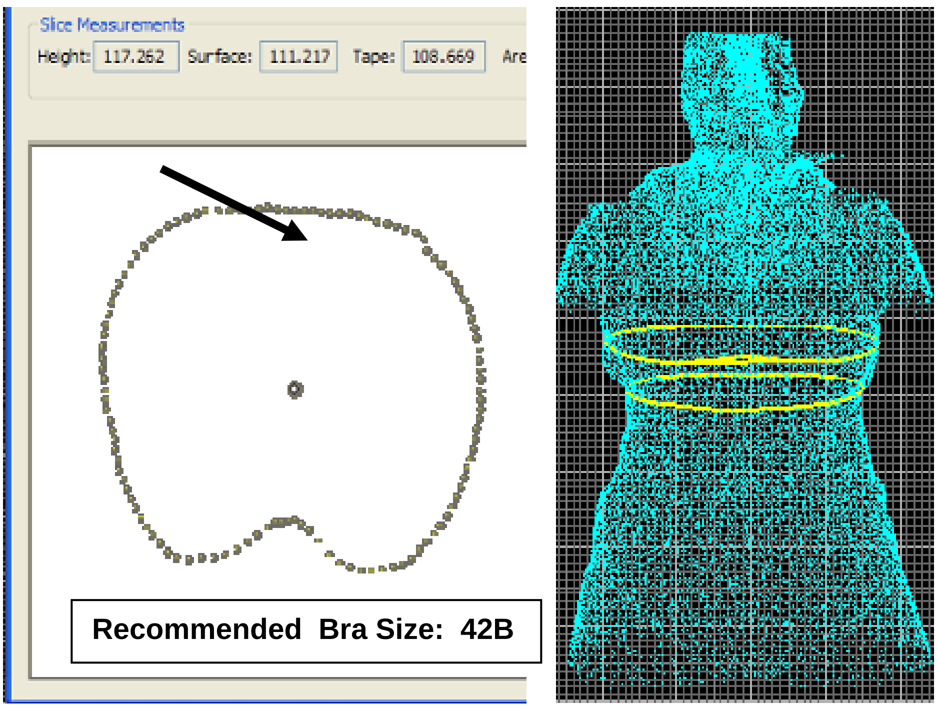


FIGURE 5.27b – ptex04

SLICES OF THE BUST FULL GIRTH MEASUREMENT

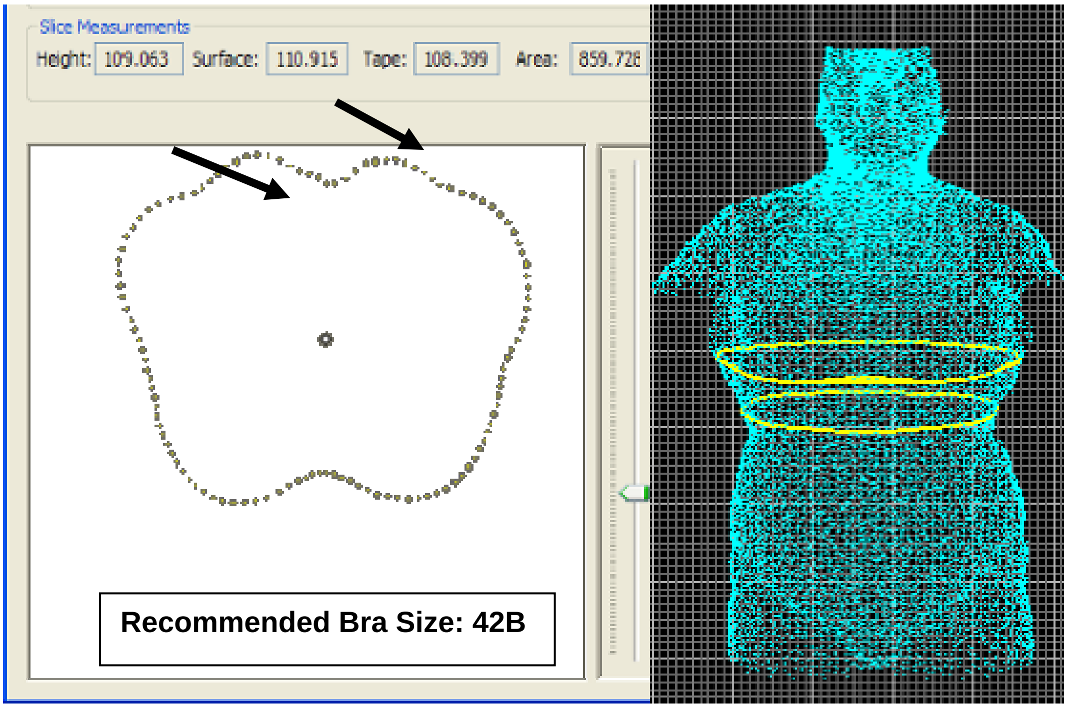


FIGURE 5.27c – ptex22

SLICES OF THE BUST FULL GIRTH MEASUREMENT

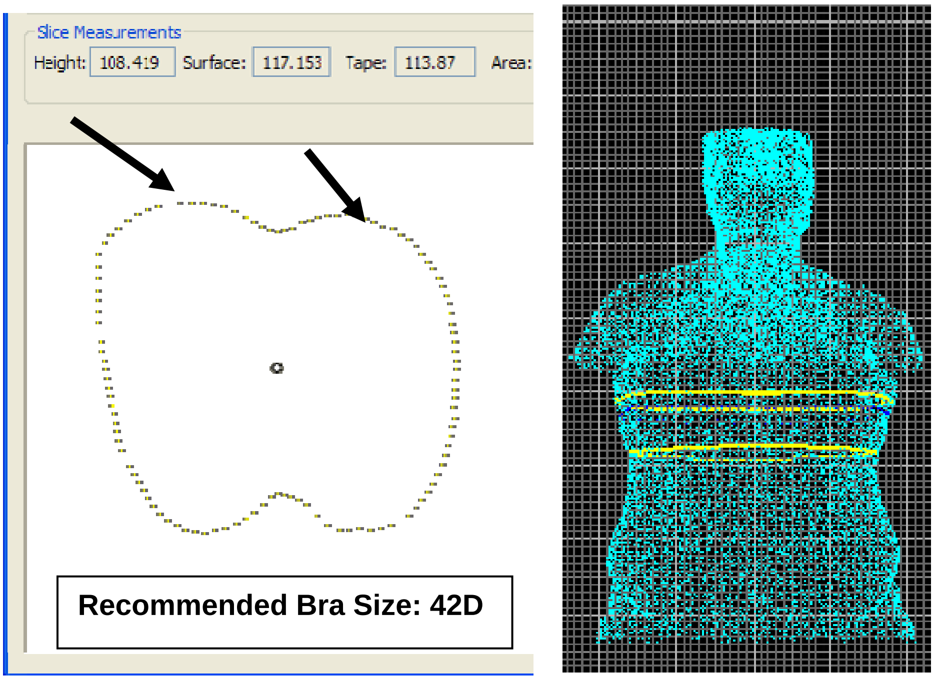
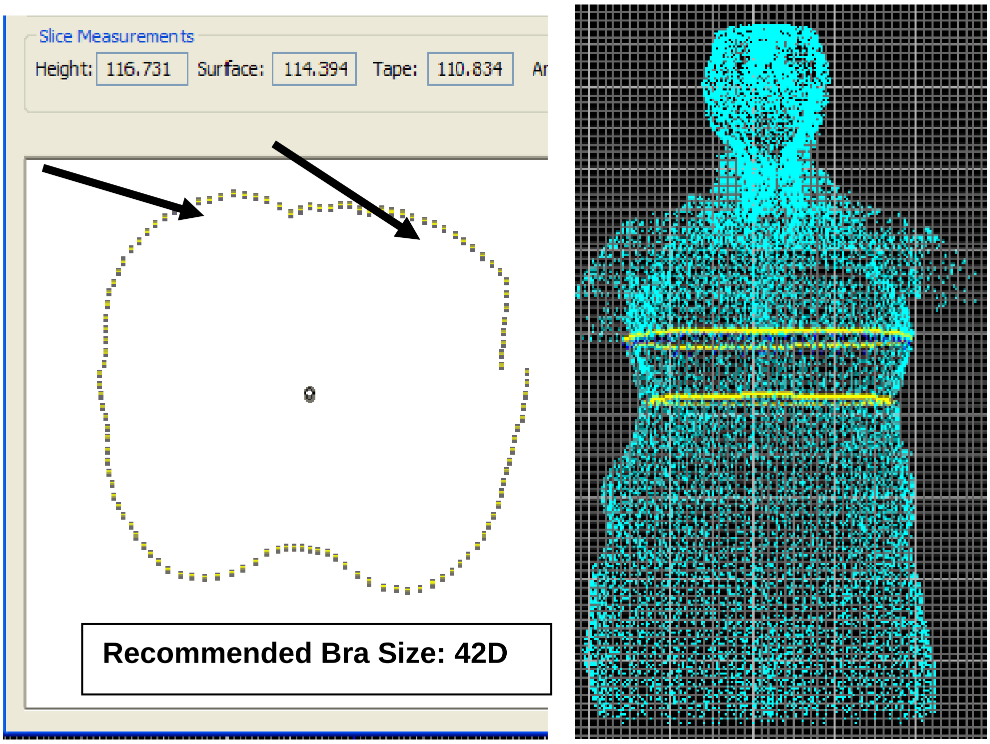


FIGURE 5.27d-ptex-83

SLICES OF THE BUST FULL GIRTH MEASUREMENT



As noted, the bust girth measurements taken on a horizontal plane indicate that the shape of the girth circumference of the subjects is different for all four subjects within and between the recommended bra sizes. This is an important observation, where the "rolls and folds" of the women torso are clearly indicated, and would influence the choice of the bra size. This finding is supported by Greenbaum *et al.*[89] who used multiple regression analysis to determine the various factors which contribute to incorrect bra sizing and noted that there was a strong relationship between obesity and the incorrect back measurement. The back shape classification is beyond the scope of this dissertation, but is mentioned here to support the findings in Experiment (1), (2) and (3) above in pages 96 to 98.

The data set was further analysed to determine which of the approximately 29 bust measurements as extracted by New Bust Programme mep., show a significant correlation with the average bust volumes for the recommended bra sizes 42B and 42D, since this could provide the bra manufacturer with sufficient data to be able to better understand the designing of the bra front panels and the underwire bras for plus-size women.

Correlation matrixes, and p-values, were used to select the other bust points of measure which correlated significantly with the bust volumes as extracted from the thirteen bra size 42B subjects and eight 42D subjects. The data set show no bust point of measure perfectly correlated with the average 3D bust volume for the two selected bra sizes of 42B and 42D. According to the correlation matrix, the following points of measure (listed in Table 5.9) having a significant correlation with the average bust volumes the two bra sizes with values < 0.05.

TABLE 5.9

CORRELATION MATRIC FOR THE SELECTED BUST POINTS OF MEASURE FOR BRA SIZES 42B AND 42D

	Cup_Length_L	Bust_Length_R	Bust_Length_L	Bust_Angle_R	Bust_Angle_L	Bust_Prominence_R	Bust_ProminenceL	BustvolLowerInL	BustvolLowerOutL	BustvolUpperInL	BustvolUpperOutL	Sum_Quadrant_vol_L	Sum_Quadrant_vol_R
Cup_Length_L	1.00												
Bust_Length_R	0.57	1.00											
Bust_Length_L	0.69	0.91	1.00										
Bust_Angle_R	0.12	-0.23	0.07	1.00									
Bust_Angle_L	0.10	-0.20	0.11	0.76	1.00								
Bust_Prominence_R	0.03	0.28	0.17	-0.33	-0.13	1.00							
Bust_Prominence_L	0.18	0.20	0.16	-0.07	-0.10	0.36	1.00						
BustvolLowerIn_L	0.81	0.56	0.61	-0.02	-0.13	0.18	0.49	1.00					
BustvolLowerOut_L	0.63	0.51	0.54	-0.04	-0.11	0.21	0.59	0.84	1.00				
BustvolUpperIn_L	0.41	0.83	0.67	-0.35	-0.38	0.41	0.43	0.58	0.61	1.00			
BustvolUpperOut_L	0.46	0.64	0.70	0.05	-0.02	0.24	0.49	0.66	0.71	0.72	1.00		
Sum_Quadrant_vol_L	0.67	0.71	0.75	-0.01	-0.08	0.27	0.55	0.86	0.89	0.81	0.91	1.00	
Sum_Quadrant_vol_R	0.67	0.72	0.81	-0.06	0.14	0.45	0.33	0.67	0.63	0.69	0.75	0.81	1.00

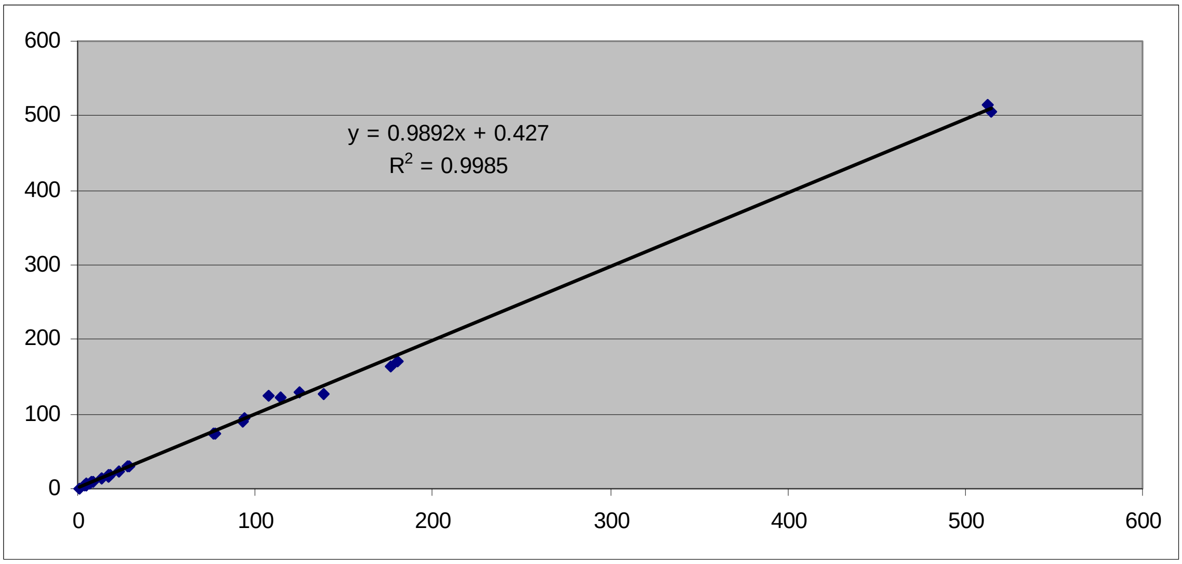
13 of the approximately 29 bust measurement points as extracted by the 3D body scanner's standalone New Bust Programme mep. was selected has having significant correlation to the average bust volumes at p=0.04 and p=0.041 respectively.

This supports the finding made by Greenbaum *et al* [89] and those of the researcher based upon the slicing of the bust girth measurements, of the four selected plus-size women. These correlations indicate that bra manufacturers need to extract more that the currently used over-bust and under-bust torso measurements to manufacture better fitting bras, as the aforementioned body points of measure correlate significantly with the breast volume data.

Illustrated in Figure 5.28 is the correlation matrix. This indicates that there is a linear relationship between bra sizes 42B and 42D.

FIGURE 5.28

GRAPHIC ILLUSTRATION OF THE CORRELATION MATRIX FOR BRA SIZES 42B AND 42D



y = 1.983X, and R^2 = 0.999 where y denotes the bra size 42D and x denotes the 42B bra sizes.

Further Pair sample t-tests conducted between the left and right breast volumes show that the left and right breast volumes are highly correlated (p=0.00) in the sum of the four individual Quadrant as indicated in Tables 5.10 and 5.11.

TABLE 5.10
PAIRED SAMPLE CORRELATIONS

		Paired Samples Correlations		
		N	**Correlation**	**Significance**
Pair 1	**Sum_Vol_L & Sum_Vol_R**	176	0.816	0.000
Pair 2	**VolLowInL & VolLowInR**	176	0.689	0.000
Pair 3	**VolLowOutL & VolLowOutR**	176	0.513	0.000
Pair 4	**VolUpInL & VolUpInR**	176	0.905	0.000
Pair 5	**VolUpOutL & VolUpOutR**	176	0.754	0.000

TABLE 5.11
PAIRED SAMPLES TEST

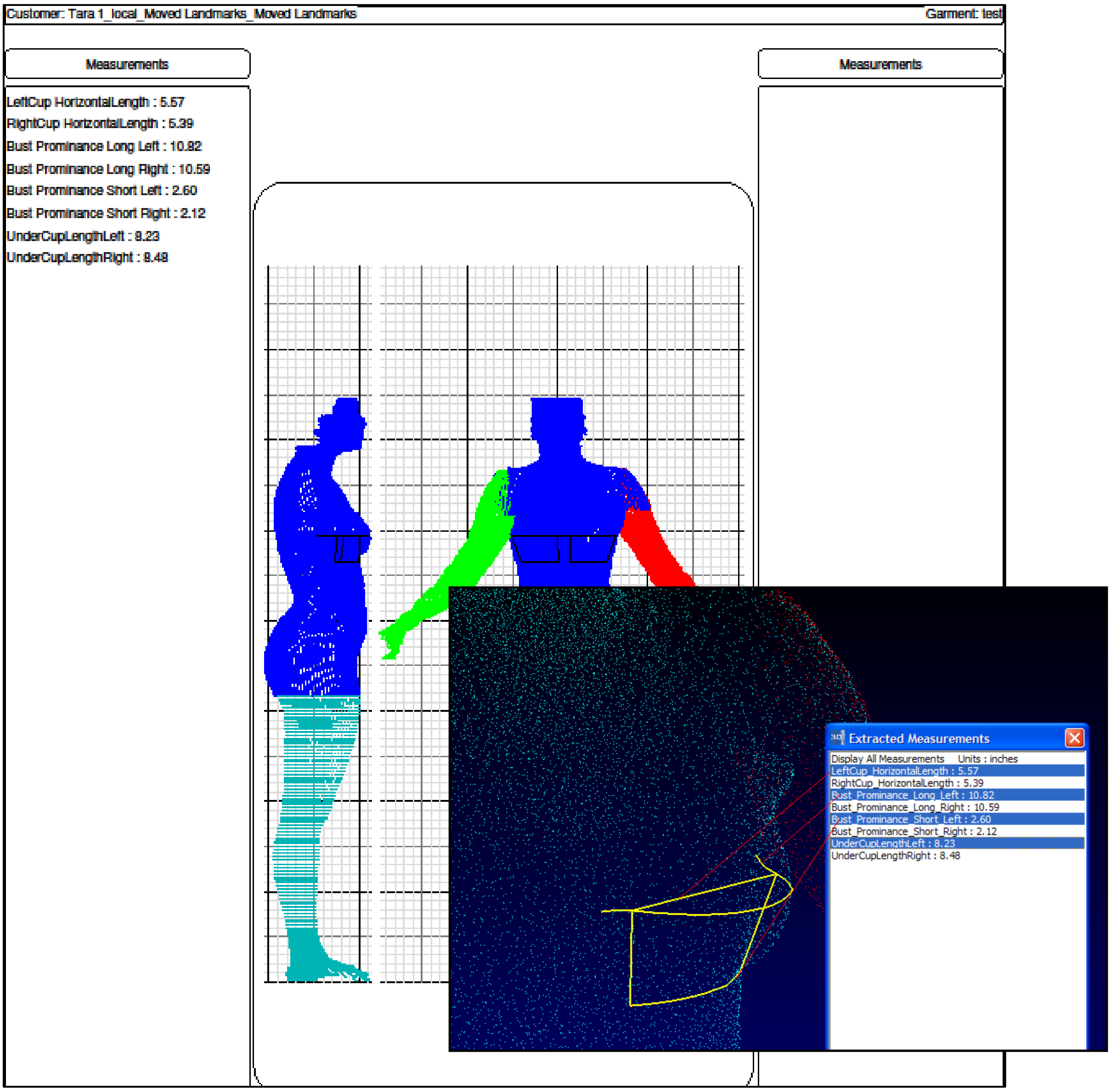
		Paired Differences							
		Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**		**t**	**df**	**Sig. (2-tailed)**
					Lower	**Upper**			
Pair 1	**Sum_Vol_L - Sum_Vol_R**	-7.240	144.933	10.925	-28.802	14.321	-.663	175	.508
Pair 2	**VolLowInL - VolLowInR**	-2.045	42.342	3.192	-8.344	4.254	-.641	175	.523
Pair 3	**VolLowOutL - VolLowOutR**	-3.779	56.151	4.233	-12.132	4.575	-.893	175	.373
Pair 4	**VolUpInL - VolUpInR**	3.130	39.465	2.975	-2.741	9.002	1.052	175	.294
Pair 5	**VolUpOutL - VolUpOutR**	-4.547	47.200	3.558	-11.569	2.475	-1.278	175	.203

The tables indicate that the right and left breast volumes are not significantly different ($p>0.005$). At the 95% confidence intervals of the lower and upper limits the differences is -2.74 and 14.3 respectively.

Due to the limitations of the NX12 software, the researcher was not able to extract the landmark body points of measure for the extraction of the bra underwire for the subjects. Figure 5.29, is an illustration of the potential of the upgraded software that is available on the NX16. The breast volume data collected in this dissertation should provide the bra manufacturer with sufficient data for the bra panels and underwire design.

FIGURE 5.29

3D EXTRACTION OF THE BRA UNDERWIRE MEASUREMENTS USING THE [TC]2- NX16



SOURCE: Taken From TC2 (personal communications) 60

NOTE:

The selection of the 176 plus-size women used in this a study was based on the Body Mass Index (BMI). It was found that the comparison between the BMI and the average bust volumes show a significant correlation (p=0.009). This reinforces the notion that BMI remains a significant tool for use in the classification of overweight and obese women (plus-size) for manufacturing bras.

CHAPTER 6 – SUMMARY

This study on size prediction for plus-size women intimate apparel using a 3D body scanner was undertaken to investigate and collect surface breast and body measurement data for plus-sized women. The focus of the study was on the difference in the data extraction methods and results of using a 3D body scanner's expert system bust extraction program and those of the manual tape-measurements with an emphasis on breast volume measurement data, This was done with an view to eventually provide bra manufacturers with more reliable and more accurate information on the women's torso for designing bra front panels and for underwire bras for plus-size women.

The **Key Findings** of the study are as follows:-

1) The average weight of the 77% women in the "obese" category was found to be 90 kilograms, with 95% confidence limits of 88 kilograms and 92 kilograms. The average height in this category was 1.59 metres, with 95% confidence limits of 1.57 metres and 1.60 metres.

2) The results indicate that the traditional over-bust and underbust measurements do not provide sufficient information for designing better fitting bras for plus-sized women. The shape and orientation of the breasts, and the bust girth circumference, more especially the back girth, are important parameters in the manufacturing of better fitting bras for plus-size women. The back girth was one of twelve bust measurements selected according to the correlation matrix as having a significant correlation with the average bust volume for the plus-size women.

3) The traditional measurement and data extraction method, using a tape measure, generally produced lower values than the 3D body scanner. The results obtained by means of the 3D cloud forms showed that some 10% of the 176 plus-size women are not accommodated by the current Playtex Body Measurements Size chart in that either the bra cup notations are not available or the band sizes are larger than those that are currently available.

4) The current problems related to bra fitting are due to the fact that bra manufacturers use the manually extracted measurements to produce a standard bra pattern block. Sample bras are then manufactured from these dimensions for a particular bra size and style. The fit is then adjusted on a live fit model who may not represent all women who wear such a bra size.

5) The 3D extracted bust quadrant measurement data show that the upper inner right bust quadrant, with an overall mean value of 162cm^3, and the left bust inner quadrant, with a mean value of 159cm^3, are heavier than the lower outer right and left quadrants for all the women. This will have a significant impact on the bra cup panel design, the choice of fabrics and underwire design for plus-size women.

6) The New Bust Measurement expert system mep. extracted breast volumes cannot be used on their own as an indication of bra cup size. The breast volume, so extracted, is influenced by other breast points of measure, such as the bust prominence; the bottom cup of the bra; bust depth; bra cup length; bust length; bust slope and torso girth back and torso girth front measurements.

7) There is no consistent relationship between the sum of the left and right bust quadrants or bust volume and the bra cup size as derived from the 3D scanner values converted into a bra size using the Playtex Measurement – Bra Size Chart.

8) The median values for the right and left busts for the 176 plus-size women were 501cm^3 and 509cm^3 respectively. This suggests that on average the left bust being larger than the right bust.

9) The relationship between the bra size and the average bust volumes for the 176 women can be represented by the linear regression equation $y=12.2x+307$, where y represents the bust volume and x represents the Playtex derived bra size.

10) The expert systems extracted breast quadrant measurement data of the upper inner right and left breasts closer to the sternum is greater than the lower outer right and left quadrants. Therefore the extracted bra size recommended, by the expert system, is based on the larger breast where breasts are not symmetrical in nature. Until a more sophisticated and integrated [TC]2-3D software is developed to incorporate features such as the different types of bra fabrics and possibly trimmings and the different bra styles available to plus sized women today, the relationship between the data extracted by the 3D body scanner and that using the traditional tape-measure will have to be established by trial and error.

11) The study highlighted that the is no consistency in the relationship between the average bust volume and bra cup size as derived from the 3D body scanner's expert system when calculated into a bra size using the Playtex Measurement-Bra Size Chart.

12) There are currently no standards or formulae available in South Africa that can be applied to bra cup or bust volume data that can be used for manufacturing bra cup panels and underwire bras for plus-size women, as there is very little 3D scan torso information available to bra manufacturers in South Africa.

13) The different retail bra styles, available to plus-size women affect the 3D scanned breast volume values. Bra design and bra size calculation was found to be unique for each bra style, and to every bra user; as the design attributes of the bra and the fabric characteristics are factors that will ultimately determine the bra size purchased.

14) Dress size is an unreliable indicator of bra size, since for 48.6% of the women in this study bra size differed from their dress size.

15) The data collected in this study suggests that there is no one-on-one relationship between the body measurements extracted by the 3D body scanner and those obtained using a tape measure. Until a more sophisticated

and integrated [TC]2-3D software is developed to incorporate features such as the different types of bra fabrics and possibly trimmings and the different bra styles available to plus-size women today, the relationship between the data extracted by the 3D body scanner and that using the traditional tape-measure will have to be established by trial and error.

16) Attributes, such as pressure sensation and comfort, are important factors to consider when manufacturing bras for plus sized women as this will ultimately determine the bra size worn. This is supported by studies conducted by Duan *et al*.[90] on factors affecting bra comfort, where wearers rated bra comfort on three levels of physiological, psychological and pressure comfort.

17) The correlation matrix indicates that there is a linear relationship between bra sizes 42B and 42D, y = 1.983X, and R^2 = 0.999 where y denotes the bra size 42D and x denotes bra size42B.

18) The paired sample t-tests conducted between the left and right breast volumes show that the left and right breast volumes are highly correlated (p=0.00) in the sum of the four individual Quadrant.

19) Bra design and bra size calculation was found to be unique for each bra style, and to every bra user; as the design attributes of the bra and the fabric characteristics are factors that will ultimately determine the bra size purchased.

This dissertation has achieved the objectives listed in Chapter 1. A protocol for future scanning for intimate apparel has been successfully developed in Chapter 4 of this dissertation. Data on surface breast volume for plus-size women has been obtained, using the [TC]2 expert system, and analysed and possible solutions proposed for better fitting bras.

6.1 RECOMMENDATIONS

1. The complex physical nature of the bra and the complex physiological response of every bra wearer as indicated in this study, suggest that consumer perception and behaviour regarding bras will be very different from those applying to other apparel, and that no other garment presents such a fitting and marketing challenge.[91] The bra is worn close to the skin, and for the entire day. Obtaining the correct fit is essential to avoid physiological problems of pain in the shoulders and tightness of the chest, through the use of the incorrect fitting bra.

2. The bra pattern and style for plus-size women should incorporate the following attributes:-
    I. Wide bra straps.
    II. Supportive fabrics and trimmings.
    III. Styles that will fit the different body shapes of plus-size women.
    IV. Sufficient bra cup capacity.
    V. Good supporting bra under-band.

3. This study highted that the inner breast quadrants i.e. those closer to the sternum, of both breasts tend to be heavier than the outer breast quadrants. This suggests that the design of the bra cup panels for plus-sized women should be reviewed, with more emphasis being placed on the bra cup panels that should incorporate a sling in the design, for additional support of the outer quadrants.

4. The alphabetical notations used for bra cup sizing may need to be reconsidered. With the advent of 3D body scanners it is now possible, with a sufficiently large sample size, to provide more accurate body measurements of the over-bust and under-bust or even torso and breast shape, the latter not being available when using the traditional tape measurement system. These control dimensions should be listed on the price swing tag as a pictogram attached to every bra sold. This suggestion is supported by studies conducted

by Winks [92] but replacing his manually extracted body measurement data with 3D body scan measurements.

5. Women need to be educated on the long term consequences of wearing the incorrect size bras, and should be encouraged to have their bra measurements taken using a trained professional, preferable using a 3D scanner, at least once a year. Consumer education should also highlight that bra sizing and fit depend on the style and varies from one manufacturer to another and even within products from the same manufacturer. Hence the focus should be on obtaining a good fitting bra as opposed to wearing a particular bra size.

6. Standardization of bra sizing within and between bra manufacturers is advisable since this would enable customers to become more self-service orientated when shopping for bras and to purchase good fitting bras irrespective of the brand or style.

7. Possible solutions for intimate apparel fitting problems, applied within the South African context, include that of the customization of sizes or that updated data on body measurements be made accessible to retailers, designers and garment manufacturers.

8. The expert systems extracted breast quadrant measurement data of the upper inner right and left breasts closer to the sternum is greater than the lower outer right and left quadrants. Therefore the extracted bra size recommended, by the expert system, is based on the larger breast where breasts are not symmetrical in nature. Until a more sophisticated and integrated [TC]2-3D software is developed to incorporate features such as the different types of bra fabrics and possibly trimmings and the different bra styles available to plus sized women today, the relationship between the data extracted by the 3D body scanner and that using the traditional tape-measure will have to be established by trial and error.

This study on the South African size prediction for plus-size women intimate apparel is the first step towards the ultimate aim of addressing some of the problems associated with bra sizing and fit. The 3D scanned data, of the larger South African population, when available and anaylsed will be made accessible to retailers, garment manufacturers, designers and students who are likely to use the information and body measurement data to design bra size categories that are more representative of the population.

6.2 FURTHER WORK

1. It is recommended that this work be continued with further 3D scanning of a larger sample of plus-size woman, ensuring that there are sufficient subjects in each of the different bra size categories.

2. The further work should be focused on developing a system that will address the following requirements relative to plus-size women:-
    a. classification of the breast shapes and the different bra styles and how shape of the breast influences the bra style and hence the choice of a bra size;
    b. Obtaining 3D data on the ratio of the chest circumference to the under-bust and over-bust girth measurements.

3. The use of Body Volume Index, rather than BMI should be investigated for future classification and selection of plus-size women to be scanned.

4. Consideration should be given to the development of a South African or international standard that relates the manual tape-measurements with those extracted using 3D body scanners, so as to remove any anomalies in the data extraction process currently existing between the two methods.

4. Attention should also be given to the standardization of bra sizing charts, within and between the different South African bra manufacturers and retailers, using 3D scanned body measurements for this purpose.

The above should result in the development of an intimate apparel sizing system for plus-sized women, together with up to date 3D body measurement data, that are reflective of the South African plus-sized women shapes and sizes of today.

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