

Anthropometric Measurement Extraction of Saudi Women Using 3D Body Scanning Technology within a Cultural Context: Implications for Apparel Design

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<https://doi.org/10.15221/25.56>

Abstract

When designing, sizing, and customising apparel, it is necessary to take accurate measurements of the human form. The current research sets out to examine Saudi women's anthropometric features by means of a three-dimensional (3D) body scanner, taking into consideration the relevant ethical and cultural concerns. A 3D body scanner was used to collect data for 250 women aged between 18 and 55 years, yielding volumetric, linear, and circumferential measurements. The findings indicate that there is considerable variation in terms of limb, hip, waist, bust, and height dimensions, thereby suggesting that imported size charts should not be relied upon. Moreover, the most common body shape categories revealed by cluster analysis are markedly different to those in the Western world. The research suggests that it is feasible to undertake 3D body scanning in a culturally sensitive way and the resulting data can be used by Saudi apparel brands to improve the fit of their garments, offer customisable features, and make their offering more competitive.

Keywords: Body shape, cultural considerations, apparel design, 3D body scanning, anthropometry

1. Introduction

Technological innovations are transforming various industries, including companies involved in designing apparel. One notable development in the field of apparel engineering and anthropometry is three-dimensional (3D) body scanning. Whereas anthropometric measurements would have traditionally been taken manually using callipers and a tape measure, 3D body scanners enable hundreds of measurements to be taken in a matter of seconds in a non-invasive and highly efficient manner (Wang et al., 2020; Yan & Kämäräinen, 2021). Indeed, the ability of 3D body scanners to conduct nationwide sizing surveys, improve customer satisfaction, and deliver garments offering a better fit has been acknowledged worldwide (Petrova & Ashdown, 2008; Simmons & Istook, 2003).

In order to produce apparel that is comfortable and culturally appropriate, the garment industry requires access to reliable anthropometric data. Despite this, it is often the case that the garment industry relies on anthropometric standards based on East Asian or Western populations, thereby resulting in a situation whereby Saudi women are routinely presented with apparel that clothing does not fit well (Almousa, 2021; Shin et al., 2015). Consequently, there is a clear need for research to be undertaken at the national level to collect and interpret anthropometric data. In the Saudi context, utilising 3D body scanners for this purpose provides an opportunity to collect the necessary data in an efficient manner that is also aligned with the local population's requirements for privacy and modesty (Shirazi & Afkhami, 2017).

The decision to study the Saudi population is of particular interest to those undertaking anthropometric research owing to its distinctive religious, social, and cultural context. Those producing garments for the Saudi market are not only required to consider aesthetic preferences but also the values of identity, tradition, and modesty (Al-Hazzaa, 2012). The garments worn in Saudi Arabia have traditionally been loose-fitting and reflected the prevailing culture (e.g., abayas) but there is now growing demand for contemporary fashion in the country, particularly garments that are fashion-forward, functional, and tailored (Almousa, 2021). Consequently, if the Saudi garment industry is to serve these changing demands, they require access to reliable anthropometric measurements. Notably, however, whilst 3D body scanners have been widely deployed throughout much of the world, their use in the Middle East has been limited to date. Given the distinct socio-cultural norms, lifestyle, and body morphology of the Saudi population, it is not possible to rely on generalising the results of research conducted in Western countries (Loker et al., 2005; Lee & Kim, 2007). However, the ability to collect anthropometric data in Saudi Arabia is complicated by cultural sensitivities regarding ethics, privacy, and body exposure (Ashdown & Dunne, 2006; Shirazi & Afkhami, 2017). Consequently, there is a need to examine the feasibility of utilising 3D body scanners in light of the cultural framework of Saudi Arabia.

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The current study sets out to examine the feasibility of collecting anthropometric data for Saudi women using 3D body scanners, paying careful attention to the country's cultural values which will have a significant bearing on how the technology can be utilised. More specifically, the research aims to:

- Explore the privacy concerns and cultural considerations associated with the use of 3D body scanners among the Saudi population.
- Determine whether measurements taken using 3D body scanners are more accurate than those produced using traditional methods.
- Utilise anthropometric data compiled by 3D body scanners to establish how the measurements of Saudi women differ from those of other populations.
- Consider the practical implications of the results for those engaged in the garment industry, paying particular attention to comfort, fit, and cultural considerations.

By realising these aims, it is anticipated that the current research will make a valuable contribution to the existing knowledge base and also establish the basis for creating a sizing system specifically tailored to Saudi women. Moreover, the results will be of practical use for the garment sector, supporting the production of apparel that fits well, is competitive on the global stage, technologically advanced, and culturally relevant.

Research Gap

The merits of 3D scanning technologies have been widely recognised throughout the world but the application of these scanners has been heavily concentrated in East Asian and Western countries, resulting in little research having been undertaken to explore Saudi women's anthropometric features. Indeed, the previous research based on 3D body scanners in Saudi Arabia has focused on health matters (e.g., body mass index and the prevalence of obesity), with little attention having been paid to body measurements for the purpose of the garment industry. Consequently, a gap has emerged between research for garment industry applications and health-related anthropometric analysis. Indeed, it continues to be the case that garment manufacturers in Saudi Arabia continue to rely on size charts compiled in East Asia or the West which are ill-suited for Saudi women's body morphologies. Notably, reliance on these size charts has resulted in customer dissatisfaction, misfitting garments, and elevated levels of product returns, demonstrating the requirement for reliable local data.

A further notable gap in the previous literature is the failure to consider ethical and cultural matters relating to the use of 3D body scanners. When using a body scanner to produce accurate body measurements, it is usually the case that those being measured will be asked to wear close-fitting garments but this presents a problem in the context of Saudi Arabia where religious and social norms require privacy and modesty. No formal efforts have been made to adapt 3D scanning methods to reflect the expectations of Saudi culture. However, in order for 3D body scanning to be widely utilised and accepted across Saudi Arabia, culturally sensitive methods must be devised.

Numerous international research studies have reported on the possibility that 3D body scanners will transform the garment industry in terms of sustainable production, virtual try-on apps, and mass customisation but little thought has been given to how the technology could be fully utilised in Saudi Arabia. Indeed, the failure of the garment industry to fully exploit Saudi anthropometric data represents a missed opportunity that is making companies less competitive and consumers less satisfied. If local fashion brands are able to effectively integrate Saudi anthropometric data, this will help them to make inroads in international fashion markets.

On balance, it is apparent that there is a need to devise 3D body scanning protocols tailored to Saudi culture so that reliable Saudi anthropometric data can be collected and applied to improve the design of garments for sale in the country. Such research will help to ensure that the latest technologies can be applied in a culturally sensitive manner, providing the basis for the establishment of a Saudi sizing system which is culturally relevant, highly accurate, and facilitates future innovations.

2. Literature Review

Background to Anthropometry

Anthropometry entails systematically analysing measurements of the human form and is widely recognised as being integral to understanding physical variations in populations. It used to be the case that manual methods were required to take anthropometric measurements (e.g., callipers or a tape measure) which could then be used to study health, nutrition, ergonomics, and apparel design

(Pheasant & Haslegrave, 2005). Such manual methods are associated with numerous limitations, however, including human error, the time required, and the difficulties measuring 3D body shapes. The globalisation of the garment industry presented further limitations and it has become apparent that new technologies are required to produce detailed and reliable body datasets (Wells et al., 2007).

Emergence of 3D Body Scanners

Anthropometry was revolutionised during the 1990s when the first 3D body scanners were developed. Initially, the technology was based on the use of structured light and laser triangulation which, whilst highly accurate, required controlled environments and the use of expensive components (Istook & Hwang, 2001). Subsequently, the technology became more accessible and commercially viable as a result of the use of portable scanners, photogrammetry, and infrared depth sensors (Wang et al., 2020). This was followed by the development of smartphone apps that utilise depth cameras, thereby enabling consumers to create their own avatar to test the fit of garments when shopping online (Zhang et al., 2019). Consequently, the collection of anthropometric data has become more scalable, more reliable, and less time-consuming over time.

Practical Application in Garment Design

Garment design has been transformed by the development of 3D body scanners because of the opportunities that have opened up in terms of mass personalisation, customised size charts, and the production of accurately fitting garments. Indeed, ill-fitting garments are widely cited as a key cause of consumer dissatisfaction and product returns to retailers (Petrova & Ashdown, 2008). Consequently, the hundreds of measurements taken by 3D body scanners enable designers to produce garments that are more likely to fit, accommodate a wide range of body shapes, and enhance customer satisfaction.

3D body scanners have contributed significantly towards the compilation of national sizing surveys and efforts to update sizing standards, including SizeMexico (2009), SizeUSA (2002), and SizeUK (2001) (Simeon & Istook, 2003). Such schemes have been used to update average body measurements but they have also made it possible to collect data that would not have been possible if relying solely on traditional measurement methods, including shape categories, body mass distribution, and details relating to posture. This additional insight offers the potential to significantly improve customer engagement and minimise waste through virtual try-ons and mass customisation (Bye et al., 2006; Suh et al., 2010).

Female-Specific Anthropometric Research

Given that women are the largest market for the garment industry and their body shapes are more complex than those of men, the majority of the previous literature has examined women's anthropometry. Research conducted in the West has emphasised the wide range of female body types, demonstrating the shortcomings with relying on a standardised sizing system (Loker et al., 2005). Lee and Kim (2007) demonstrated the ability of 3D body scanners to produce better-fitting women's garments when studying data for Japan and South Korea. This lends weight to the belief that the anthropometric features of women vary markedly from one population to another, thereby demonstrating the need for data to be localised.

The Middle East

The vast majority of anthropometric research conducted to date has been undertaken in East Asia and the West, with the Middle East having been largely overlooked. Researchers have sought to document the dimensions of women's bodies in Iran and Turkey but these have been based on conventional measurement methods rather than 3D body scanners (Erdem & Toktas, 2015). Anthropometric research utilising 3D body scanners in Saudi Arabia and the Middle East is very limited and has been confined to healthcare, workplace safety, and ergonomics (Al-Haboubi, 1992), leaving a research gap in the field of garment production.

In the absence of anthropometric data relating specifically to Saudi Arabia or the wider Middle East, garment manufacturers have been forced to rely on East Asian or Western sizing charts. Crucially, reliance on such charts means that the garments produced will not closely reflect Arab women's morphological features, resulting in poorly fitting apparel and dissatisfied customers (Alsulaiman, 2019). Therefore, those designing garments in Saudi Arabia will find it challenging to produce items that are culturally appropriate and fit well.

Previous Research Focusing on Saudi Arabia

There is a distinct lack of previous research addressing the anthropometry of women in Saudi Arabia with regards to garment manufacture. The anthropometric research conducted to date in Saudi Arabia has overwhelmingly focused on the body mass index, the prevalence of obesity or other health metrics, rather than garment production (Al-Hazzaa, 2012). Consequently, the need for such research in the context of Saudi Arabia is not solely limited to academic interest because there is also a practical business need to serve the interests of the country's garment industry.

Modesty and Cultural Considerations

Efforts to utilise 3D body scanners in Saudi Arabia are complicated by religious and cultural factors. It is typically the case that the collection of accurate anthropometric data requires individuals to wear closely fitting garments but this is at odds with Saudi Arabia's culture of modesty. Similar issues were previously noted by Shirazi and Afkhami (2017) who recommended amending scanning procedures to reflect cultural preferences when conducting research in Pakistan and Iran.

A particularly sensitive issue in Saudi society concerns digital security and privacy. Consequently, it is likely that many individuals in Saudi Arabia would be reluctant to have a detailed avatar of their body produced because of fears that their data could be misused or their image could be exposed. For these reasons, Ashdown and Dunne (2006) advised developing culturally appropriate consent processes whereby data are encrypted and anonymised in order for participants to have trust in the research process. Indeed, it is likely that the success of 3D body scanning initiatives in the country will rely on such challenges being adequately overcome.

Practical Implications for Saudi Garment Manufacturers

Whilst Saudi culture clearly represents a challenge for those conducting anthropometric research, it can also be regarded as an opportunity. The abaya and other traditional garments are loose-fitting but Saudi women are increasingly opting for more close-fitting, functional items, whether for the purpose of playing sport or going to work (Alhazmi, 2021). This comes at a time when Saudi Vision 2030 is encouraging more women to enter the workforce, thereby further increasing the demand for ergonomic and culturally appropriate garments.

If 3D body scanners can be used to develop a Saudi sizing system, this would remove the need to rely on unsuitable foreign charts and facilitate the production of garments that are modern in design whilst also incorporating features of modesty. Crucially, this would simultaneously benefit Saudi consumers and make Saudi garment manufacturers significantly more competitive, not only in the domestic market but also abroad.

3. Methodology

The current research seeks to examine Saudi women's anthropometric features by applying 3D body scanners as part of a quantitative approach. This study draws upon a sample of Saudi women aged 18 to 55 years who hold bachelor's and postgraduate degrees, are married, and reside in Taif, Saudi Arabia, as shown in Table 3. However, the sample for this study was selected randomly. The intention was to scan people of various body types, ages, and socio-economic backgrounds to better understand the variation in body shapes. Online platforms were used to recruit the sample, clearly stating the age limits for the research. All of the participants were provided with details of the research's aims and methods, and they were required to give their informed consent before their data were collected.

An advanced 3D body scanner was employed to capture the data. In a matter of seconds, the Size Stream SS20 is capable of taking several hundred body measurements.

Those taking part were required to wear closely-fitted garments which enabled accurate measurements to be taken whilst also maintaining modesty, with the application of supplementary draping when necessary to remain compliant with cultural norms. In an attempt to make the participants as comfortable as possible and maintain confidentiality, the scans were taken in private rooms. A calibration process was undertaken for each of the participants to ensure they were correctly positioned in the scanning field and numerous scans were taken to ensure that the measurements were repeatable and reliable. Having collected the data, software was used to extract and organise various anthropometric measurements (e.g., volumetric parameters, widths, lengths, and circumferences).

In recognition of Saudi cultural norms, various ethical considerations were incorporated into the methodology. For instance, all data were anonymised, encrypted, and saved to a database that only the researchers had access to. In addition, assurances were given to those taking part that their data would only be used for the research purposes and would not be shared with any external party. Furthermore, physical exposure during the scanning process was minimised, acknowledging Saudi culture with regards to modesty, whilst also enabling accurate data to be collected. Those taking part were made aware that they were able to withdraw from the process at any time without suffering any adverse consequences, thereby helping to ensure that the process was as ethical as possible.

A combination of inferential and descriptive analytical procedures were applied. For every individual anthropometric parameter, the mean, standard deviation, and percentile distributions were calculated, thereby giving a thorough interpretation of the variation in body shape among the sample. Population-specific trends were identified by undertaking comparative analyses to investigate discrepancies across body mass indices and age groups. Importantly, the data for the sample were compared with the international sizing systems currently in use to reveal the areas that need to be adjusted when designing garments for the Saudi market. Efforts were made to ensure that the methodology was scientifically rigorous whilst also accommodating cultural sensitivities. By doing so, it was possible to ensure that the findings were not only reliable but also applicable to the Saudi context.

The use of ethical procedures, innovative 3D body scanners, and an effective framework for collecting anthropometric data means that the resulting measurements are indicative of the variation in body sizes and have been collected in a manner that is not only efficient but also reflective of the participants' culture. As such, this approach has been designed to yield results that can be used for academic purposes and also in practice by those engaged in the production of garments.

4. Results and Discussion

Upon analysing the body scans, it became apparent that there was considerable variation in the participants' body measurements as shown in table 1 below, thereby demonstrating the need to use local data when designing garments. The mean height was 160.3 cm but the standard deviation of 5.2 cm indicated a considerable distribution. There was also considerable variation in the circumferential measurements, with the mean value for the hips being 98.7 cm, for the waist being 76.1 cm, and for the bust being 92.4 cm, whilst the respective standard deviations were 8.2 cm, 6.5 cm, and 7.1 cm. These results indicate that international sizing charts are unreliable, with many Saudi women finding that garments produced using these charts would fit poorly. Furthermore, this discovery corresponds with the findings of Almousa (2021) and Shin et al. (2015), who observed that Saudi women are frequently presented with clothing that does not fit properly due to the garment industry's reliance on anthropometric standards that are derived from East Asian or Western populations.

In order to better understand the body proportions, volumetric and linear measurements were taken. The mean leg length was 88.3 cm, arm length 58.5 cm, and shoulder breadth 41.2 cm, indicating differences which may impact the fit of professional attire, tailored abayas, and structured garments. Whilst individuals' height remained broadly stable, both volumetric and circumferential measures typically increased with age, demonstrating how the distribution of fat as well as the body composition naturally change. Percentile analysis revealed that distinct sizing categories are required to reflect the variation from small to large body types.

When the body measurements were subjected to cluster analysis, this revealed that Saudi women's body shapes for the selected sample can be broadly categorised as the 'hourglass', 'pear', and 'apple' types widely referred to in the garment industry. In order to facilitate the choice of appropriate garment construction methods and sizing decisions, the bust-to-hip measurements were presented as a scatterplot (see Fig 2), whilst the waist-to-hip ratios were presented as histograms (see Fig 1).

The results of the current study can be used to influence how garments are designed for the Saudi market. Whilst abayas and other traditional garments tended to be loose-fitting, consumers in Saudi Arabia are increasingly demanding clothing requiring attention to comfort, fit, and aesthetics. International sizing charts fail to reflect the variation in the measurements and body shapes of the Saudi population, thereby demonstrating the need to utilise 3D body scanners to devise sizing systems that are population-specific and highly accurate. The use of national sizing systems will help to reduce the number of returns, enhance consumer satisfaction, and make Saudi garment manufacturers more competitive.

Comparing the data obtained in the current study with that used in the previous literature, it is apparent that the anthropometry of Saudi females is distinct Relative to Western databases, the data for the sample of Saudi women reveal markedly different body volumes, bust-to-hip proportions, and waist-to-hip ratios. This further demonstrates the impracticality of relying on sizing charts compiled using foreign data. This observation is in accordance with what has been reported in the previous literature when conducting 3D anthropometric research for culturally distinct populations (Loker et al., 2005; Lee & Kim, 2007). The current study presents accurate measurements in a culturally sensitive framework, thereby helping to use modern technology to meet the needs of the local garment industry.

Cultural and ethical factors were taken into consideration at every stage of the current research. The approach selected for the scanning process helped to ensure that the participants' modesty was maintained by enabling closely-fitted clothing to be worn, with additional draping when required. Notably, this confirmed that it is feasible to collect accurate anthropometric data in Saudi Arabia without contravening local cultural norms.

Table 1: Anthropometric Descriptive Statistics

Measurement	Mean (cm)	SD (cm)	Min (cm)	Max (cm)
Height	160.3	5.2	148.0	175.0
Bust Circumference	92.4	7.1	78.0	110.0
Waist Circumference	76.1	6.5	60.0	92.0
Hip Circumference	98.7	8.2	80.0	115.0
Shoulder	41.2	3.5	34.0	50.0
Arm Length	58.5	4.2	50.0	70.0
Leg Length	88.3	5.1	78.0	100.0

Table 2: Key Measurement Percentile Distributions

Percentile	Height	Bust	Waist	Hip
5th	149	81	62	84
10th	152	84	65	87
25th	156	88	70	93
50th	160	92	76	99
75th	165	97	82	105
90th	170	102	88	110
95th	174	106	92	114

Table 3: Participant Demographics

Value	Variable
250	N (participants)
30.2 (5.8)	Age — mean (SD)
Age range	18-48 years
Bachelor's degree	55.0%
Postgraduate degree	15.0%
Married	70.0%
Reside in Taif	35%

Table 4: Anthropometrics (Height, Weight, BMI)

Value	Measure
158.1 (6.0) cm	Mean height (SD)
62.5 (11.8) kg	Mean weight (SD)
24.8 (4.5)	Mean BMI (SD)
45 / 35 / 20	BMI categorisation: Normal/Overweight/Obese (%)

Table 5: Body Circumference Measures

Value	Measure
92.0 (8.2) cm	Bust circumference
78.5 (9.7) cm	Waist circumference
100.3 (9.1) cm	Hip circumference
58.2 (6.0) cm	Thigh circumference
28.4 (2.9) cm	Arm circumference

Table 6: Circumference Mean Values by BMI Category

Hip (cm)	Waist (cm)	Bust (cm)	BMI group
96.0	72.1	88.5	Normal
102.7	81.3	94.2	Overweight
108.9	89.5	99.8	Obese

Note. Groups based on WHO BMI classification

Table 7: Body Circumference Correlation Matrix

Arm	Thigh	Hip	Waist	Bust
0.65	0.72	0.81	0.78	1.00
0.60	0.69	0.76	1.00	0.78
0.66	0.74	1.00	0.76	0.81
0.58	1.00	0.74	0.69	0.72
1.00	0.58	0.66	0.60	0.65

Note. All correlations are significant at $p < .01$.

Table 8: Waist Circumference Predictions Based on Multiple Regression

p-value	SE	B Predictor
0.0001	4.5	35.2 Intercept
0.0001>	0.04	0.31 Weight (kg)
0.03	0.02	0.05 Age (years)
0.01	0.05	0.12 BMI

Note. Model $R^2 = .62$, $p < .001$

Figures 1-3: Body shape patterns

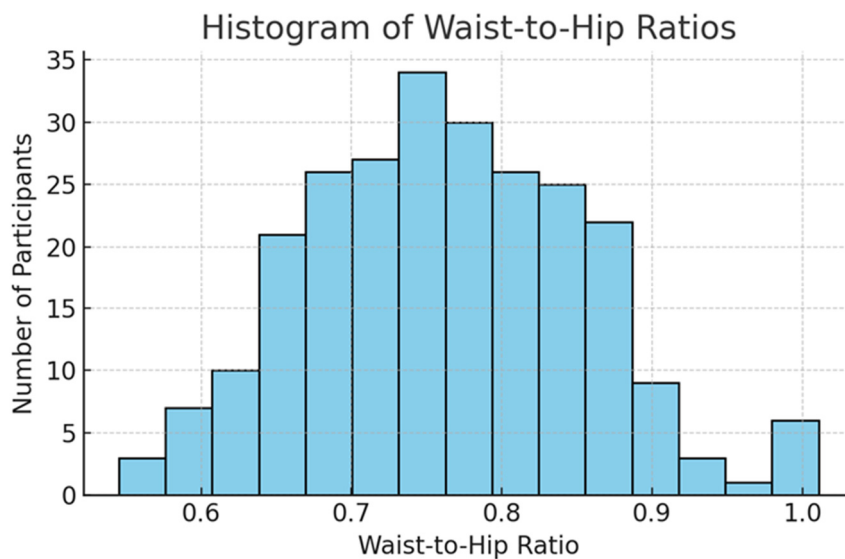


Figure 1 illustrates that there is a left-skewness to the waist-to-hip ratios, thereby representing a greater proportion of people with bodies that are pear-shaped.

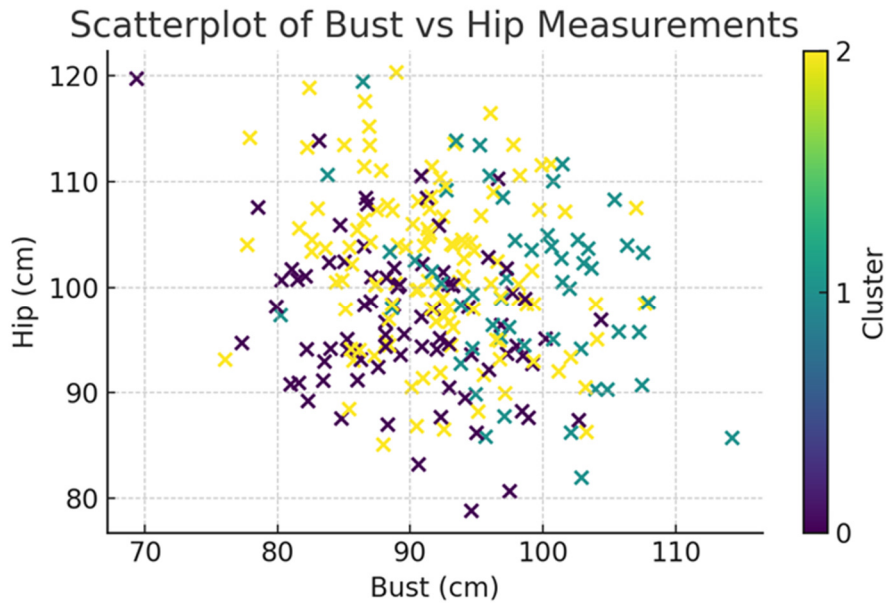


Figure 2 portrays the bust-to-hip circumference relationship, indicating clusters which relate to three distinct categories of body shapes. Used in conjunction with the descriptive statistics, these figures help to better understand the anthropometry of women in Saudi Arabia.

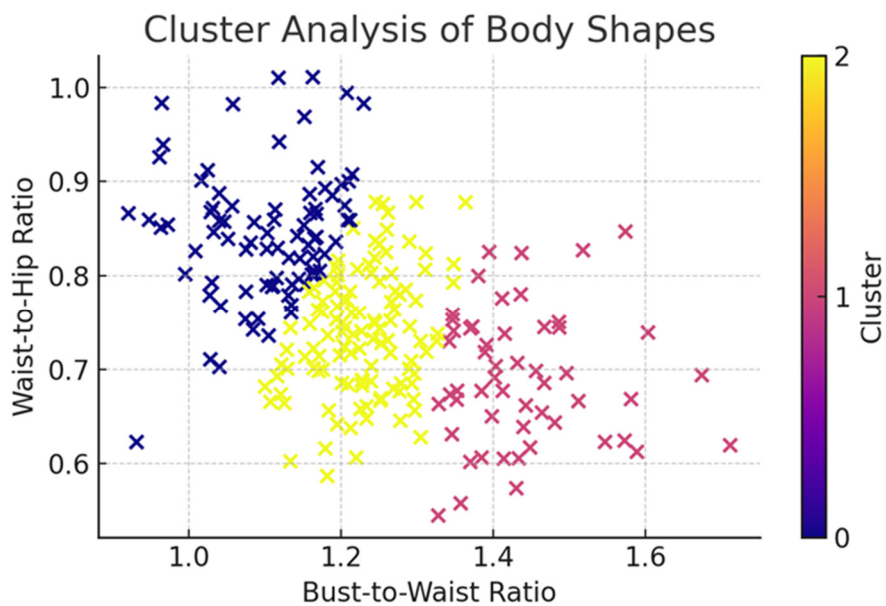


Figure 3: Body shape cluster analysis

The results of the cluster analysis indicated that the Saudi sample had three main body shapes: hourglass (narrow waist with balanced hip and bust measurements), pear (large hips and low bust-to-hip ratio), and apple (moderate hip measurements and high bust-to-hip ratio). Whereas Almousa (2021) utilised measures taken manually from a relatively small sample, the current research has compiled highly accurate measurements for a larger sample obtained from a 3D body scanner, indicating greater variability, especially in terms of their waist and hip measurements.

Al-Hazaa (2012) had previously reported that lifestyle changes had resulted in the waist circumferences of Saudi women increasing over time, and the findings of the current study support this conclusion, revealing evidence that women in older age groups have larger hip and waist measurements. Meanwhile, Shin et al. (2015) and Loker et al. (2005) found evidence to suggest that females in East Asia and the West typically have narrower waists and higher bust-to-hip ratios, and based on table 7, the findings of the current research suggest that women in Saudi Arabia have broader hips and smaller bust-to-hip ratios. This demonstrates the need to develop national size charts rather

than relying on international data. Similarly, Simmons and Istook (2003) noted the need for sizing charts to be tailored to the local population, and this is borne out by the findings of the current research, with women in Saudi Arabia being more likely than their counterparts in the West to have pear-shaped bodies, as shown in figure 1 above. Meanwhile, the variation in height for the different age groups was marginal, but the hip and waist circumferences were found to be slightly higher in the 45–55-year age group, although their bust measurements were slightly smaller, in accordance with what was reported by Shin et al. (2015).

The results will have practical implications for those who design garments because it is necessary to take variations in body dimensions into account when grading patterns and fitting apparel. Notably, the use of 3D body scanners provides scope for virtual fitting and mass customisation, creating opportunities to improve both customer satisfaction and fit, whilst also offering garments for the most common body shapes. On balance, the current research supports the findings in the previous literature and goes further by creating highly accurate anthropometric data for women in Saudi Arabia, demonstrating the need for domestic sizing systems.

5. Conclusion and Recommendations

This research has comprehensively analysed the anthropometric features of women in Saudi Arabia using a culturally sensitive approach to enable the application of highly accurate 3D body scanners. The results indicate significant variance in the body measurements of the sample, thereby demonstrating the need to develop national sizing charts. The hourglass, pear, and apple body shapes were found to be most prevalent in Saudi Arabia, suggesting the need for patterns to be tailored to the population. With reference to the findings reported in the previous literature, it is shown that whilst trends such as the prevalence of pear-shaped bodies and broader hips are still evident, the data yielded from 3D body scanners is far more detailed and accurate. In order to take accurate measurements in this way, it was necessary to consider the local culture regarding modesty and privacy. The research has practical implications for those responsible for drafting garments, including the development of national sizing standards, virtual fitting, and mass customisation. It is important to acknowledge the limitations associated with the current research, including the cultural factors preventing full body scans and the use of a relatively small sample, indicating that researchers in future should seek to utilise larger samples, undertake longitudinal research, and take dynamic measurements. On balance, the current study shows that 3D body scanners can be used in culturally sensitive settings to produce accurate measurements that are of practical use to garment manufacturers, designers, and policymakers, enabling the Saudi garment industry to operate within cultural boundaries and outcompete foreign rivals.

6. References

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