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# Mobile 3D body scanning applications: a review of contact-free AI body measuring solutions for apparel

Sadia Idrees, Simeon Gill and Gianpaolo Vignali

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**ABSTRACT**

This paper reviews current mobile body scanning applications, exploring strengths and weaknesses and proposals to develop product development and selection approaches. Body scanning delivers a greater depth of data to support product development and advancements in mobile technology, bringing body scanning into the hands of the consumer. Detailed analysis of the human body is possible with mobile scanners; distances, girths, heights, width, surface area, body fat percentage and circumferences can be obtained on a personal smartphone. 3D body scanning apps offer contactless full-body scanning, while some scan body parts individually by identifying landmarking points required to extract body dimensions for product selection and development. The key application themes such as features, benefits, proposed solutions and mechanisms were identified and analysed comparatively after content analysis of eighteen 3D mobile scanner apps. Consequently, it is determined that the mobile scanning process is fast (maximum 5 min and minimum 30 sec), and image capture requirements for scanning use a front and side view image. However, for some applications, the scanning requirement is a back and side scan; front, back and side scan; multiple front and side scans and some apps require a 360-degree scan to generate a 3D personalised avatar and a list of measurements. The applications provide not only digital measurements for customisation but also offer advanced features of virtual try-on, virtual dressing room, body tracking (body fat monitoring/body surface area/BMI), size and fit visualisation and recommendation (Body fit, regular and loose fit preference in garment selection) for personalised online shopping. Therefore, the enhanced opportunities of mobile body scanning applications permit users to enjoy personalising, empowering the consumer to select or produce products to wear and enhance online shopping.

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3D body scanning; mobile scanning; mass-customisation; fashion e-commerce; Artificial Intelligence (AI); size recommendation; virtual try-on

## 1. Introduction

Body scanning is recognised as an important driver in developing solutions to body-worn product development (Almalki et al., 2020; Apeagyei, 2010). Whilst it has not gained mass adoption, mobile scanning applications promise to bring benefits directly to the consumer. Fixed booth scanners have been around for several years, though they have not gained the traction initially envisaged (Daanen & Ter Haar, 2013). More recently, mobile scanning using smartphones or smart devices has been made more accessible to consumers. This paper reviews the current mobile scanner apps and explores their strengths, limitations, and their potential to enhance product development and selection. Mobile scan applications can identify body landmarks and measurement parameters such as distances, girths, heights, widths, surface area, body fat percentage and circumferences. Some mobile scanners scan the full body, while some scan body parts separately (3DLook, 2022; TechMed3D, 2020). The body parts measurements mainly include head scanning to deliver personalise helmets and head-worn sports equipment or foot scanning to help select the right sized footwear; there are also scanners focused on separate body parts to deliver medical assistance such as custom orthotics and prosthetics (Netvirta, 2022; TechMed3D, 2020).

The mobile scanning technology is a combination of computer vision and deep learning, proprietary statistical modelling and (AI) machine learning & 3D matching (3DLook, 2022; 3DMeasureUp, 2020; Krafft et al., 2020). The photos taken by the smart device are analysed using computer vision and deep learning algorithms, which identify the human body in any background. Neural networks establish landmarks and produce probability maps, often referenced against an ever-growing scanning data set. To generate data, statistical modelling is applied; this is often proprietary and supports producing the 3D human avatar and the extraction of measurements. Machine learning and 3D matching are central to developing body scan outputs (3DLook, 2022). In addition, the scanner companies offer various custom branding hardware and plug-in software to provide interactive shopping solutions. The key three features of 3D body scanning mobile

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applications are 3D body scanning, measurement extraction, and the display of digital body measurements with personalised Avatar creation. Moreover, virtual try-on technology using a personalised Avatar offers product assessment comparable to the information gained from direct product examination (Kim & Forsythe, 2008).

Whilst Body scanning has struggled to connect directly with consumers (Januszkiewicz et al., 2019), mobile scanning technologies offer promising developments. Formerly, for virtual size and fit recommendation, manual body dimensions data entry effort was required to generate a personalised 3D avatar for fit visualisation and virtual try-on. The consumers were required to enter body measurements and garment data, such as past purchase history, preferred fit and preferred style, in a fashion e-commerce interface (Januszkiewicz et al., 2017). With the growth in online retail and an increase in consumer-facing technology, mobile body scanning offers new opportunities to engage with clothing selection as well as to enhance existing methods of clothing production (Idrees et al., 2020). Historically manual tape measurements were the only way to record dimensions to make clothing (Aldrich, 2007). Body scanning is recognised to provide a greater depth of data to support product development (Bye et al., 2006; Gill, 2015). Mobile scanning offers a portable, convenient, and contactless method to record the body and use this as the basis for product selection and development. There is an important potential for empowering the consumer as they select or produce products to wear, and many promising opportunities for enhancing online retail (Idrees et al., 2020b). It is necessary to gain an overview of comparative features, benefits, proposed solutions, and mechanisms of this developing technology, to understand how each app has proposed its online fashion buying and selling solutions for consumers and retailers. Moreover, to determine the individuality of each app mechanism in terms of ease of navigation (easy, medium, and difficult) and how each app's features can best support and enhance the fashion e-commerce environment.

## 2. Literature review

In 2013 Daanen and Ter Haar conducted an overview of booth body scanners outlining new developments in sensing and processing technology. The structured light scanners presented a new era of fast, inexpensive, high resolution and accurate scanners. This development has initiated a vision of using technology for virtual trying on, additionally to revolutionise mass production to mass customisation to offer well-fitted personalised garments in online fashion environments (Daanen & Ter Haar, 2013). Booth scanners were not user-friendly and expensive and did not meet the fashion industry's requirements for online settings. Therefore, mobile app scanners have been developed as a user-friendly approach using front-side images to capture the 3D avatar, support fit visualisation, and extract body dimensions. The technology offered by mobile app scanners is accurate, dependable, and exact, as claimed by the companies. Lim and Jafari (2021) evaluated ten mobile scanners to determine their characteristics, methods, and advantages. The results concluded that apps displayed the potential to be applicable in the fashion industry as garment customisation and size recommendation technology (Lim & Jafari, 2021). Additionally, Smith et al. (2021) compared the Size Stream MeThreeSixty mobile app, conventional anthropometry and the Size Stream SS20 booth scanner. Their results revealed that smartphone app accuracy is similar to the conventional tape measurement procedure, which is managed by a trained technician to obtain the data (Smith et al., 2021). Further benefits of body scanning are shown by Almalki et al. (2020), where they determined that scanners provide opportunities for new measurements which are not easily extracted by manual tools. The scanning method is the fastest method to capture the body. It enables CAD tools to be combined, which aids retailers in constructing a personalised garment more quickly and precisely than manual tools for garment construction (Almalki et al., 2020). Surc et al. (2020) describe an integrated solution for personalised made-to-measure (MTM) knitwear garments grounded on 3D body scanning using automatic data transfer from the scanner to the flat knitting machine. The process lowers the complexity of the production of individualised lot-size-one garments. After the user is scanned and displays body dimensions, the size charts automatically suggest the best fitting size and corresponding fit rules for the selected garment type. Therefore, the knitted garment can be personalised using the appropriately configured flat knitting machine (Surc et al., 2020).

Thi Nguyen et al. (2022) present an algorithm for automatic extraction of the size and body shape of a 3D scanned model. They use factor analysis, linear regression equation, cluster analysis, and discriminant analysis to assess the body shape and choose the best primary dimensions for instituting the sizing system table. The study utilises fuzzy logic to create the mathematical model. Inseam height and neck girth measurements are the input variables, and numbers of the human size coding and body shape are the output variables in this model. Additionally, the rotation matrix and optimal function have been utilised to produce an algorithm to assess the neck girth and inseam dimensions. Moreover, an easy method grounded on vertices and surface normal vector data, along with optimal searching, is adapted to assess the primary measurements. The estimation algorithm, blended with the fuzzy logic model, has created an automated process of extracting the size and body shape. The study's outcomes indicate a novel research method for rapidly notifying people about their body shape. Furthermore, the technology supports purchasing ready-to-wear clothes and customised garments and facilitates garment purchases in both online and offline settings (Thi Nguyen et al., 2022).

Idrees et al. (2020a) conducted a study in Pakistani on the Unstitched Apparel Industry for supporting bespoke fashion. The respondents showed positive response towards using 3D body scanning mobile application technology for online bespoke shopping. The participants were comfortable with their bespoke garment constructed with digital body measurements and were happy with home scanning. However, they highlighted that technology should be effortless and user

friendly (Idrees et al., 2020a). Similarly, Saudi Arabian female consumers' experiences have been explored using 3D Body scanning technology and acceptance level of applications to adopt for fashion e-commerce. The application includes three scenarios which include size prediction, customization, and virtual try-on. The results indicated that the technology has strong potential and a higher chance of adoption in online fashion shopping (Almousa, 2020). Hwangbo et al. (2020) conducted a study exploring the basic meaning of virtual try-on as the user experience and evaluated the impacts of 3D virtual try-on on online sales. The study concluded that virtual try-on impacts the sales outcomes women's casual L brand: the average sales per consumer improved by 14,000 won (13USD). The most vital conclusion is that the return rate reduced by 27% by sorting out inaccurate sizes and fits. Therefore, virtual try-on can replace the physical garment fitting rooms and bring positive benefits to both retailer and consumers (Hwangbo et al., 2020).

## 3. Methodology

The study adopted an exploratory qualitative research approach with a systematic review of 3D body scanning mobile apps.

### 3.1. Data collection phases

The qualitative data was collected in four phases, keywords search strategy, selection criteria of apps for inclusion in the study, apps information provided by the app producers, and mechanisms of testing of each app.

#### 3.1.1. Phase 1: keywords search strategy

In the first phase, the applications were identified writing keywords '3D body scanning mobile applications, 3D body scanner, 3D body scanning application'. The keyword searches and identified applications names further lead to identifying various 3D body scanning apps. The data was obtained from peripheral databases sources such as Google, Google scholar, App store, Google play and academic publication for initial search of 3D body scanning apps. The sampling method adopted for data collection was snowball sampling. Snowball sampling is a non-probability sampling method. In this sampling technique the existing subjects provide referrals for recruitment of identical samples needed for a research study (Goodman, 1961). Therefore, this sampling technique has been employed to find out the existing 3D Body scanning mobile applications through online secondary data sources. Secondary data is the data compiled from prior studies, interfaces and books (Ghauri & Gronhaug, 2010). Secondary data is essential as it supports identification of the research problem and describing the research questions, assisting to formulate project, elucidate the data, provide awareness and validate the conclusions (Malhotra et al., 2012).

#### 3.1.2. Phase 2: selection criteria of 3D body scanning mobile applications

The selected applications were further scrutinised. The selection criteria include user-friendly interface, easily accessible (free or inexpensive) 3D body scanning services for extracting body dimensions and 3D avatar in a short span of time, by capturing 2D body image (screenshot or selfie) using personal smartphones while using app scanner and offering various interactive and virtual apparel shopping benefits. Some applications were rejected because they can only facilitate in creating 3D images of objects. The selected applications for study have been providing one of the online shopping solutions using 3D body scanning tool. After going through the selection criteria, eighteen mobile applications were selected for comparative review which offer size and fit solutions in online platforms.

#### 3.1.3. Apps information provided by the company

After finding 3D body scanning applications, in the second phase, the applications were further studied through providers' information available on their websites, App Store, and Google Play. The information was collected in the form of descriptive notes available in their interfaces, collated in Excel for content analysis to formulate themes to allow systematic overview and comparison. Moreover, to gain in-depth knowledge about each application, the applications were further examined by mechanism testing of the application.

#### 3.1.4. Phase 4: mechanism testing of each application

The fourth Phase was based on understanding the mechanism of the different applications. To test their functionality a user account was set up for each app and they were systematically reviewed to determine the similarity and difference in each app under study. Therefore, the apps were installed on a personal mobile device to find out the requirement of capturing the scan. In addition, steps to process scanning, time to process a scan and number of measurements displayed by each app were recorded. The applications were further categorised according to their capture requirements such as front and side view scan, back and side view scan, multiple scanning options and 360-degree scans. The applications mechanism has been demonstrated in the tabular form for comparative analysis. Throughout the data collection journey, the data has been collected in note form for each application and screen shots of interfaces were captured. The images and notes were investigated through thematic content analysis with NVIVO qualitative analysis software (QSR, 2016). The information has been classified through content analysis of applications into common meaning groups (Henri, 1992). This allowed the key themes to be categorised such as key features, benefits, consumer facing and retailer facing app, mechanism and application proposed usage for an in-depth comparison.

### 3.2. Exploratory qualitative research

Exploratory research is demarcated as research employed to study a phenomenon which is not clearly described and does not focus on providing conclusive outcomes (Saunders et al., 2016). This research aimed to gain a better understanding of the current of mobile body scanning and

employed literature review and primary data sources. This study is exploratory since 3D body smartphone app scanners which deliver digital body measurements and 3D avatar are a novel technology offered by 3D body scanning enterprises in various geographical locations. Therefore, to define an area with more precision, exploratory qualitative research methodology has been adopted (Malhotra et al., 2017). Qualitative research delivers prospects to discover the origin of a phenomenon, discover probable details for its existence, collate what the knowledge of the phenomenon meant to those encompassed, and discover if the experience generate a theoretical framework or conceptual understanding linked with the phenomenon (Williams & Moser, 2019). This review paper adopted content analysis method for qualitative data analysis. Both grounded theory and qualitative content analysis adhere to coding methods. Though, content analysis does not concentrate on understanding relationships among categories or generating a theory. Alternatively, it aims on developing categories from the collected data to summarise it systematically (Stemler, 2015). In the time of 'big data', the content analysis methodological approach is a compelling tool for researchers. Content analysis is adaptable and can be applied on textual, visual, and audio data (Stemler, 2015). Moreover, coding method is vital in organisation of data structure in qualitative research. 'A code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data' (Saldafia, 2009, p.3). Coding in qualitative research consists of procedures that facilitate gathered data to be assembled, categorised, and grouped thematically, delivering an arranged platform for building meaning of collected data. Coding techniques engage procedures that bring out themes embedded in the data, in turn advocating thematic directivity towards classifying data through which meaning can be concluded, codified, and proffered. Coding is a significant underlying procedure in qualitative research, allowing data analysis and sequential steps to fulfil the objective of the study (Williams & Moser, 2019). Therefore, a systematic qualitative review of 3D body mobile app scanners has been conducted through content analysis by formulating categories and coding method.

## 4. Findings

### 4.1. Overview of 3D body scanning mobile applications

This first comprehensive overview of 3D body scanning mobile applications allows comparative analysis of features, benefits, proposed solutions offered by each app for consumers and retailers, scanning mechanism of each application and output data delivered after scanning. The comprehensive comparison is helpful for fashion industry to augment itself in establishing interactive fashion shopping domains.

#### 4.1.1. 3D body scanning mobile applications

The apps have been developed in a variety of geographical locations, by a range of different companies (Table 1). This displays the widespread potential of the creative technologies as well as broad identification of the potential benefits and proposed use of the apps. With the introduction of mobile scanning technology, the global population has been targeted as smartphones have become an integral part of everyday life. It is evidenced that with the number of smartphone users worldwide surpassing six billion and anticipated to expand by several hundred million in the next few years. The highest number of smart phone user countries are China, India and the United States (Statista, 2021). Therefore, mobile scanning has paved the way for introducing interactive shopping domains for mass customisation, size recommendation and virtual try-on options globally. The 3D virtual reality shopping interfaces/apps offers more information and playfulness than conventional 2D shopping tools such as still image and a video. Interactivity with 3D VR tools and visual-spatial cues suggestively enhance perceived informativeness and playfulness as well as encourage purchase decision making process (Kang et al., 2020). In addition with 3D body scanning, new technologies such as internet of things, Augmented reality, mixed reality, virtual assistants and chatbots are dramatically transforming consumer shopping journey experience (Hoyer et al., 2020).

#### 4.1.2. Technology comprised in 3D body scanning mobile applications

There are three key technologies used in creating mobile scanning apps, these include computer vison and deep learning: proprietary statistical modelling and AI machine learning and 3D matching (Table 2). The 3D body scanning applications have been developed extensively to deliver user-friendly interfaces. The technology comprises by each app to deliver proposed retailing solutions have been demonstrated in Tables 6–9.

#### 4.1.3. Retailers facing solutions provided by 3D body scanning applications

The 3D body scanning companies have been offering various hardware and software solutions such as custom branding apps and plug-in software. The solutions offered by each app show common areas, like how consumer dimensions are provided as well as some common retailer facing solution are like API, PAAS, OEM and SDK provision (Table 3). It is clear that not all applications serve all potential user areas.

#### 4.1.4. Features and benefits of 3D body scanning mobile applications

The Table 4 displays comparative analysis of features offered by 3D body scanning mobile applications. The main features each application offers are 3D body scanning, extraction and display of digital body measurements and the creation of personalised avatars. Additional features have been summarised to show the further benefits provided by companies using 3D body scanning technology for interactive marketing and enhanced online shopping journey.

**Table 1.** 3D body scanning mobile applications.

| Sr No. | Application Name | Application Developer | Country of Origin | Price | Application Store | URL | Languages | Proposed Use of App |
|---|---|---|---|---|---|---|---|---|
| 1 | **3DsizeME** | TechMed 3D | Canada | Free, Purchase equipments | iOS 11 .0 or higher iOS 14 compatible with Structure sensor Mark II iPhone and iPad | https://techmed3d.com/ | English, Croatian, Dutch, French, German, Italian, Simplified Chinese, Spanish, Swedish | Medical Industry |
| 2 | **3DLOOK** | 3D Look | USA and Ukraine | Free | iOS/Android | https://3dlook.me/ | English | E-tailoring, Size and Fit Recommendation, Virtual try on and In-store Size Recommendation Omni Chanel Fashion Brands and Retailors |
| 3 | **Nettelo/Nettelo Pro/Nettelo-E** | Nettelo | USA and France | Free | iOS | http://nettelo.com/ | English, French, Simplified Chinese | E-Tailoring and Size Recommendation for Ready to Wear |
| 4 | **Me-Three-Sixty** | Size Stream | USA | Free | iOS/Android | https://www.sizestream.com/technology | English | E-Tailoring and Body Tracking, Collaborated with Lectra for Garment Customisation |
| 5 | **Mirrorsize** | Mirrorsize | India | Free | iOS/Android | https://www.mirrorsize.com/#/ | English | E-Tailoring and Size Recommendation |
| 6 | **Verifyt Body** | Netvirta | Boston USA and Singapore. | In-App purchase | Android | https://www.netvirta.com/ | English | Sports Equipment, Medical Industry, E-Tailoring, Size Recommendation and Footwear |
| 7 | **3D Avatar Body (IBV)** | Universitat Politècnica de València Instituto de Biomecánica | Spain | In-App purchase | Android/Google Play | https://www.ibv.org/en/3d-avatar-body-3/ | English, Espanol, Spanish | Virtual Try-on, E-Tailoring, Size Recommendation, Body Tracking and Medical Industry |
| 8 | **Sizer Me/Sizer M2M/Sizer Pro** | Sizer | Israel | Free | Windows, iOS/Android | https://sizer.me/ | English | E-Tailoring and Size Recommendation |
| 9 | **SizeYou/Size You Pro** | Size You | Italy | Free | iOS/Android | https://www.sizeyou.it/en | English and Italian | E-Tailoring and Size Recommendation Biomedical Field |
| 10 | **SizeMeRight** | Better Body Image, Inc | Pittsburgh, USA | Free | iOS | https://apps.apple.com/us/app/sizemeright/id1142062983 https://www.betterbodyimage.com/ | English | E-Tailoring and Body Tracking (health and Fitness) |
| 11 | **ASizer: Virtual Fitting Room** | ASizer | San Francisco, USA | In-App purchase | iOS/Android | https://www.asizer.com/ | English | Virtual Dressing Room, Size Recommendation and E-Tailoring |
| 12 | **1Measure** | The Hong Kong Polytechnic University (PolyU) | Shenzhen TOZI Tech Co., Ltd. China | Free | iOS | https://www.prnewswire.com/news-releases/polyu-intelligent-3d-human-modelling-technology-projecting-body-shape-and-size-accurately-within-10-seconds-679290783.html https://jp.emtailor.com/1measure_tozi/ | English, Simple Chinese and Japanese | E-Tailoring and Body Tracking, Collaborated with Lectra for Garment Customisation |
| 13 | **Fashion Tech** | Mondial Atelier Holdings Limited | Hong Kong, China | Free | iOS/Android | https://apps.apple.com/us/app/fashion-tech/id1119634435 | English, Simplified Chinese | E-Tailoring |
| 14 | **RightFit** | RightFit Technologies | India/UK | Free | iOS/Android/PC | https://rightfit.ai/our_technology.html | English | Size Recommendation |
| 15 | **ZOZO App** | Fashion retail website zozo town https://zozo.jp/ | Japan | Purchase equipment ZOZO Suit 2 | iOS/Android | https://corp.zozo.com/measurement-technology/ | English/Japanese | E-Tailoring and Size Recommendation, Body Tracking and Medical Industry |
| 16 | **3D MEASURE UP** | ProtoTech India | India | API based delivers measurements from external 3D Body Scanners | All platforms | https://3dmeasureup.com/ | English | E-Tailoring and Size Recommendation, Body Tracking and Medical Industry |
| 17 | **Presize.ai** | Presize GmbH | Germany | Free | PC/Mobile interface (for scanning user has to scan QR code find-size.com – perfect fit without trying) | https://www.presize.ai/ | English, Deutsch, Nederland, Francais | Size recommendation, Body measurements |
| 18 | **Meepl** | Fision AG | Zurich Switzerland | Free | iOS/Android | http://www.meepl.com, https://www.linkedin.com/company/fision-ag/about/, https://www.youtube.com/watch?v=q6q-dg7_EBA | English, Deutsch, Francais | Made-to-Measure, Size Recommendation, Virtual Dressing Rooms, and Advanced Body Analytics |

**Table 2.** Technologies used to create mobile scanning applications.

| *Technology* | | |
|---|---|---|
| *Computer Vision & Deep Learning* | *Proprietary Statistical Modelling* | *(AI) Machine Learning & 3D Matching* |
| The photos taken in body fitted dress with smartphone and on any background are analysed with computer vision and deep learning to process the required results. A set of probability maps have been produced by neural networks to determine body landmarks. | Proprietary statistical modelling is accountable for producing human avatar of arbitrary complexities. Statistical modelling and dataset of the raw scans which is consistently growing in scan labs, is used to generate synthetic data. | Artificial Intelligence has been discovered as the Foundation of Fourth Industrial Revolution (FIR) (Krafft et al., 2020). Machine Learning & 3D Matching is used to build personalise 3D Model of scanned consumer, based on detected landmarks permits to obtain human body measurements. |

**Table 3.** Retailers facing solutions provided by 3D body scanning applications.

| *Sr No.* | *Application Name* | *3D Scan, Import and Export Files in Format* | *Customer Dimensions* | *PAAS* | *OEM* | *API* | *SDK* |
|---|---|---|---|---|---|---|---|
| 1 | **3DsizeME** | IMED, VRML, STL, AOP, PLY, or OBJ. | CSV | No | No | Yes | Yes |
| 2 | **3D Look** | OBJ | CSV | No | No | Yes | No |
| 3 | **Nettelo** | OBJ and STL customer dimensions in CSV | CSV | No | No | Yes | Yes |
| 4 | **Me-Three-Sixty** | OBJ and STL customer dimensions in CSV | CSV | No | No | Yes | Yes |
| 5 | **Mirrorsize** | OBJ and STL customer dimensions in CSV | CSV | No | No | Yes | Yes |
| 6 | **Verifyt Body** | OBJ and STL | CSV | No | No | Yes | Yes |
| 7 | **3D Avatar Body (IBV)** | OBJ and STL | CSV | No | No | Yes | Yes |
| 8 | **Sizer Me/ Sizer M2M/ Sizer Pro** | OBJ and STL | CSV | No | No | Yes | Yes |
| 9 | **SizeYou / Size You Pro** | OBJ and STL | CSV | No | No | Yes | Yes |
| 10 | **SizeMeRight** | No | No | No | No | No | No |
| 11 | **ASizer: Virtual Fitting Room** | No | No | No | No | Yes | No |
| 12 | **1Measure** | OBJ and STL | CSV | No | No | No | Yes |
| 13 | **Fashion Tech** | No | No | No | No | Yes | No |
| 14 | **Right Fit** | No | No | No | No | Yes | No |
| 15 | **ZoZo app** | OBJ and STL | CSV | No | No | Yes | Yes |
| 16 | **3D Measure Up** | OBJ and STL | CSV,PDF,HTML | Yes | Yes | Yes | Yes |
| 17 | **Presize.ai** | No | CSV/JSON *via* URL | Yes | Yes | Yes | Yes |
| 18 | **Meepl** | No | No | No | No | Yes | No |

Note:
**OEM** stands for original equipment manufacturer version. It is designed by the original manufacturer and offered for custom branding.
**PaaS** is Platform as a service, which is a cloud computing model delivers both hardware and software tools.
This service can be integrated into personal brand apps.
**API** is the acronym for Application Programming Interface, an intermediary software that permits two applications to interact with each other.
A software development kit (**SDK**) is a hardware platform, operating system (OS), or programming language.
Which aid software developers to use specific platform to develop personalise application.

*4.1.4.1. Benefits of 3D body mobile application scanners.* 3D body scanning is a metaverse technology tool which has a potential to offer various benefits to fashion retailers and fashion buyers. Using 3D Body scanning tool, companies are offering five main benefits.

*4.1.4.1.1. Capturing individual body data.* Instant generation of custom measurements and 3D Avatar from 2D photos captured by personal mobile for introducing mass customisation fashion market.

*4.1.4.1.2. Personalise size recommendation.* Mobile application scanners have rendered the size recommendation process easier for the fashion industry. By using the body scan, data can be mapped to brand/countrry's intended fit.

*4.1.4.1.3. Virtual trying on.* Shoppers can select and try-on different products at home virtually on their personalised avatar. 3D Body scanning technology has reduced the need of in-store try on to view how it will look on the wearer.

*4.1.4.1.4. Sustainability.* Ready to wear garments using standard size charts heightened the wastage of fabric and consumers are dissatisfied in terms of size and fit (McKinney et al., 2017). Sustainability can been achieved by minimising the fabric wastage, by establishing a system which would fulfil the needs of indivdual consumer (Nayak & Padhye, 2016). Body scanning technology has a potential to develop a sustainable personalised system to ensure all body types and sizes are served equally.

*4.1.4.1.5. Low return rates.* Free online returns are offered by fashion e-commerce platforms. Therefore, due to size and fit issues higher return rates has been noted, which increases substantial operational costs to retailers (Abdulla et al., 2019). 3D body scanning technology has the potential to serve all body types and sizes equally. Therefore, it is envisaged to have low return rates with more targetted customer size selection or targetted product developmnent.

### 4.1.5. Comparison of mechanism of 3D body scanning mobile applications

The 3D Body scanning mobile applications vary in their mechanism requirements. The consumer is required to create a user profile by registering with an email id and adding demographic information (Table 5). The comparative analysis of mechanism of mobile application has been displayed in the Tables 6–9 such as Mode of Scanning, photo capture requirement and time required during scanning process and output features displayed by each app to enhance online shopping.

*4.1.5.1. 3D Body scanning with front and side view photo capture requirements.* The body scanning applications demonstrated in Table 6 have front and side view photo capturing requirement. The distance required for scanning is 2 or

**Table 4.** Features of 3D body scanning mobile applications.

| *3D Body Scanning Mobile Applications* | *3D Size Me* | *3D Look* | *Nettelo* | *Me-Three-Sixty* | *Mirrorsize* | *Verifyt Body* | *3D Avatar Body (IBV)* | *Sizer* | *Size You/ Size You Pro* | *Size Me Right* | *Asizer: Virtual Fitting Room* | *1Measure* | *Fashion Tech* | *Right Fit* | *ZoZo App* | *3D Measure Up* | *Presize.ai* | *Meepl* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ease of Navigation Easy/Medium/difficult | **Difficult** | **Easy** | **Difficult** | **Easy** | **Easy** | **Easy** | **Easy** | **Easy** | **Easy** | **Easy** | **Easy** | **Difficult** | **Easy** | **Easy** | **Difficult** | **Medium** | **Easy** | **Easy** |
| Virtual Try - on | N | Y | Y | N | N | N | Y | N | N | N | Y | N | N | N | N | N | N | Y |
| Size Recommendation (for different brands and countries) | N | Y | Y | Y | Y | Y | Y | Y | Y | N | Y | Y | N | Y | Y | Y | Y | Y |
| Virtual 3D Avatar (view from various angles, zoom, rotation, spin) | Y | Y | Y | Y | Y | Y | Y | N | Y | N | Y | Y | Y | Y | Y | Y | N | Y |
| Body Tracking (compare and analyse body changes) | Y | Y | Y | Y | N | N | Y | N | N | N | N | Y | N | N | Y | Y | N | N |
| Sharing 3D models visualisation and size with fashion retailers | N | Y | Y | Y | Y | Y | Y | Y | Y | N | Y | Y | N | Y | Y | Y | Y | Y |
| Body measurements for customisation | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | N | Y | Y | Y | Y |
| Option of selecting body fit preference (Tight, Regular, Loose) | N | Y | Y | N | Y | N | N | N | N | N | N | N | N | N | N | N | Y | N |
| Body Parts Scanning/Full Body Scanning | Y | FBS only | FBS only | FBS only | FBS only | Y | FBS only | FBS only | FBS only | FBS only | FBS for Virtual try on | FBS only | FBS only | FBS only | Y | Y | FBS only | FBS only |
| Body Fat monitoring/ Body surface area | Y | N | N | Y | BMI | N | Y | N | N | N | N | N | N | N | N | N | N | N |
| Scanning for customising PPE, uniform and workwear | Y | Y | Y | Y | Y | Y | Y | N | N | N | N | Y | N | N | Y | Y | Y | N |

**Note:**
**Difficult:** require extra gadgets and manual work to complete the process.
**Medium:** needs external application for scanning and then using application to get required results.
**Easy:** require only mobile application to capture image to receive results .

Table 5. Demographic information to create a user profile for 3D body scanning.

| Sr No. | Application Name | Name | Gender | Height | Weight | Year of Birth/Age | Location |
|---|---|---|---|---|---|---|---|
| 1 | 3DsizeME | Yes | Yes | Yes | Yes | Yes | Yes |
| 2 | 3DLOOK | No | Yes | Yes | No | No | No |
| 3 | Nettelo/Nettelo Pro/Nettelo-E | Yes | Yes | Yes | Yes | No | No |
| 4 | Me-Three-Sixty | No | No | No | Yes | No | No |
| 5 | Mirrorsize | Yes | Yes | Yes | Yes | Yes | No |
| 6 | Verifyt Body | Yes | Yes | Yes | No | Yes | Yes |
| 7 | 3D Avatar Body (IBV) | Yes | Yes | Yes | Yes | Yes | No |
| 8 | Sizer Me/Sizer M2M/Sizer Pro | Yes | Yes | Yes | No | Yes | No |
| 9 | SizeYou / Size You Pro | Yes | Yes | Yes | Yes | Yes | No |
| 10 | SizeMeRight | No | No | Yes | No | No | No |
| 11 | ASizer: Virtual Fitting Room | Yes | Yes | Yes | Yes | No | No |
| 12 | 1Measure | Yes | Yes | Yes | Yes | No | No |
| 13 | Fashion Tech | No | Yes | Yes | Yes | No | No |
| 14 | RightFit | No | Yes | Yes | Yes | Yes | No |
| 15 | ZOZO App | No | No | No | No | No | No |
| 16 | 3D MEASURE UP | No | No | No | No | No | No |
| 17 | Presize.ai | No | Yes | Yes | Yes | Yes | No |
| 18 | Meeple | Yes | Yes | Yes | No | No | No |

3 meters away from mobile camera. The front photo capture prerequisite is an A-pose. Whereas requirement for side/-profile pose is, both arms touching the thighs, and legs & feet joined together in standing position. While capturing a photo the user is required to wear tight fitting clothing with bare feet so that the contours of the body can be examined with high accuracy (required by all applications). These applications have three scanning process steps which includes profile creation, front scan, and side view scan. After scanning, applications deliver the output in the form of body measurements for customisation of garments, personalised avatar, size recommendation, virtual dressing room, virtual try on of various fashion brands options, and body tracking.

The applications 1Measure and Nettelo require silhouette creation with tapping fingers on the body image to create body contours for accuracy, which is a time-consuming process as well as requiring exactness. Therefore, without making accurate body outline the user cannot get accurate results. Consequently, ease of navigation is difficult (Nettelo, 2022). Me-Three-Sixty's former application required 360-degree scan using mobile application with wide angled lens, a grip, a mat and a scan suit to get required results. To improve ease of navigation of mobile app without additional accessories, the company has updated the app for easier operation. Therefore, the scanning process can be completed just by using the app on a personal mobile phone with front and side view capture requirement (Size Stream, 2022). 3D Look has an easy operational method with Snapshot and Selfie, one front and side photo capture requirements. Moreover, the application is offering mass customisation, size recommendation and virtual trying on (3DLook, 2022).

Asizer is a virtual trying on application using 3D body scanning and clothing simulator technology. The application user can choose the desired clothing from hundreds of different brands that allow visual assessment of how different clothes would look on the wearer. Once the consumer has selected the item from the online store, they can choose their own background that will appear in the virtual dressing room. The user needs to take a photo in any dress using the mobile camera. Various background options are available on Asizer such as red-carpet background, outdoor background, and the indoor background just to have a clearer imagination about user's appearance. With Asizer, the user can virtually try any item from the inventory to see how the consumer will fit in a particular item and the dress that suits his/her more (Asizer, 2022).

To achieve the requirement of 3D Body scanning, meepl app has been introduced by swiss corporation. Mobile app scanner deliver body dimensions, 3D avatar, size recommendations, virtual dressing room and made-to-measure services with just 2 pictures (Meepl, 2020; Saha, 2020). ProtoTech's 3D Measure Up is a measurement technology interface that can deliver hundreds of measurement parameters such as distances, girths, heights, surface areas, volumes etc (full or partial) to help consumers to get a perfect fit. This platform takes a 3D body or an object scan in various formats (OBJ, STL, etc) as input and automatically detects the body landmarks and measures. The output is obtainable as annotations on 3D model and is also presented in numerous forms such .csv, .xls, .html (3D). 3D Measure Up is composed of a mix of geometry, computational, and machine learning (ML) algorithms for accuracy in results (3DMeasureUp, 2020).

*4.1.5.2. 3D body scanning with more than one photo capture requirements.* Verifyt Body by Netvirta requires 2 front and side photos for body scanning (Netvirta, 2022). Whereas Sizer Me require 2 front photos and 1 photo while moving slowly 360 degrees while raising arms in U-shape. Therefore, due to the increased number of photos the scanning steps for Verifyt Body and Sizer is 5 and 4 respectively. Presize.ai requires demographic information along with tight, regular, and loose fit preference selection. Subsequently, users need to scan a QR code in their personal smart phone. Scanning is done *via* video scan in selfie mode by one front picture and one rotation video in 360 degrees by opening arms in A-pose. Within 60 sec user receives the personalise body measurements and size recommendation (Presize.ai, 2022) (Table 7).

**Table 6.** Applications with a front and side view photo capture requirements.

| Sr No. | Application Name | Capture Requirements | App Technology | Steps to Process Scan | Measurement Time for Scan | Output = List of Measurements | Output = Features | Reported Accuracy | Modes |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **3D Avatar Body (IBV)** | 1x Front photo<br>1x Side Photo | Machine Learning & 3D Matching | 3 | <60 Sec | Y = 100 | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1 cm for Large Girths | Snapshot |
| 2 | **1Measure** | 1x Front photo<br>1x Side Photo | AI, Computer Vision & Deep Learning<br>Proprietary Statistical Modelling<br>(Silhouette Creation After Taking Picture) | 3 | 10 sec | Y = 90 | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1.5 cm for Large Girths | Snapshot and Selfie |
| 3 | **3D Look** | 1x Front photo<br>1x Side Photo | Computer Vision & Deep Learning<br>Proprietary Statistical Modelling<br>Machine Learning & 3D Matching | 3 | <60 Sec | Y = 70+ | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1 cm for Large Girths | Snapshot and Selfie |
| 4 | **Nettelo** | 1x Front photo<br>1x Side Photo | Machine Learning & 3D Matching<br>(Silhouette Creation After Taking Picture) | 3 | <60 Sec | Y = 80 | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1 cm for Large Girths | Snapshot and Selfie |
| 5 | **Me-Three- Sixty** | 1x Front photo<br>1x Side Photo | 3D Modelling, Machine Learning | 3 | 5 min | Y = 240 | *Measurements, *Body Shape | +/- 5 mm precision | Selfie |
| 6 | **MirrorSize** | 1x Front photo<br>1x Side Photo | AI, Computer Vision & Deep Learning<br>Models and Mesh Processing | 3 | 60 sec | Y = 100+ | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1 cm for Large Girths | Selfie |
| 7 | **RightFit** | 1x Front photo<br>1x Side Photo | 3D Modelling, Machine Learning | 3 | <120 Sec | Y = 3 Chest, Waist, Hip | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1 cm for Large Girths | Snapshot and Selfie |
| 8 | **SizeMeRight Virtual Tape Measure** | 1x Front photo<br>1x Side Photo | Computer Vision & Deep Learning | 3 | <120 Sec | Y = 11 | *Measurements | +/- 1 cm for Large Girths | Selfie |
| 9 | **Asizer** | 1x Front photo<br>1x Side Photo | Visual Computing, Fabric Simulation and Artificial Intelligence | 3 | <60 Sec | Y = 7 | *Measurements, *Body Shape<br>*Size Recommendation<br>*Virtual Dressing Room<br>* Pose Video of Consumers While Trying on | $1/10^{th}$ of an Inch | Selfie |
| 10 | **3D Measure Up** | 1x Front photo<br>1x Side Photo | Computer Vision & Deep Learning<br>Proprietary Statistical Modelling<br>Machine Learning & 3D Matching | 3 | 60 sec | Y = 100+ | *Measurements, *Body Shape<br>*Size Recommendation | +/- 1 cm for Large Girths | Snapshot and Selfie |
| 11 | **Meeple** | 1x Front photo<br>1x Side Photo | Advanced image processing, Visual computing technology, AI & Computer Vision | 3 | <120 Sec | Y = 20 | *Measurements, *Body Shape<br>*Size Recommendation<br>*Virtual Dressing Room | +/- 1 cm for Large Girths | Selfie |

**Table 7.** Applications with more than one photo capture requirements.

| Sr No. | Application Name | Capture Requirements | App Technology | Steps to Process Scan | Measurement Time for Scan | Output = List of Measurements | Output = Features | Accuracy | Modes |
|---|---|---|---|---|---|---|---|---|---|
| 12 | **Verifyt Body** | 2 x Front photo<br>2 x Side Photo | Computer Vision & Deep Learning | 5 | <120 Sec | Y = 200+ | *Measurements<br>*Body Shape<br>*Medical Assistance | +/- 0.5 mm for large girths | Selfie |
| 13 | **Sizer Me/Sizer M2M/Sizer Pro** | 2 x Front photo and 1 photo with slow circular movement by raising arms in U shape | Computer Vision & Deep Learning | 4 | <120 Sec | Y = 80 | *Measurements<br>*Size Recommendation | +/- 1 cm for large girths | Selfie |
| 14 | **Presize.ai** | 1 x Front Photo with slow circular movement (one rotation) by opening arms in A-pose | Computer Vision & Deep Learning | 4 | 60 sec | Y = 20 | *Measurements<br>*Size Recommendation | +/- 1 cm for Large Girths | Selfie |

**Table 8.** Applications with front, side and back view photo capture requirement.

| Sr No. | Application Name | Capture Requirements | App Technology | Steps to Process Scan | Measurement Time for Scan | Output = List of Measurements | Output = Features | Accuracy | Modes |
|---|---|---|---|---|---|---|---|---|---|
| 15 | **SizeYou** | 1 x Back photo<br>1 x Side photo | Proprietary Statistical Modelling, (AI) Machine Learning & 3D Matching | 3 | <120 Sec | Y = 80 | *Measurements<br>*Body Shape<br>*Size Recommendation<br>*Medical Assistance | +/- 1 cm for large girths | Snapshot |
| 16 | **Fashion Tech** | 1 x Front photo<br>1 x Side photo<br>1 x Back photo | AI, Computer Vision & Deep Learning | 4 | 120 Sec | Y = 7 | *Measurements<br>*Body Shape | +/- 1 cm for large girths | Snapshot |

**Table 9.** Applications with 360-degree scanning using additional accessories.

| Sr No. | Application Name | Capture Requirements | App Technology | Steps to Process Scan | Measurement Time for Scan | Output = List of Measurements | Output = Features | Accuracy | Modes |
|---|---|---|---|---|---|---|---|---|---|
| 17 | **ZOZO App** | 1 × 360-degree scan with ZOZO suit containing marker points | 20,000*2 Fiducial marker points technology to generate body measurements and Avatar | 3 | 60 sec | Y | *Measurements<br>*Body Shape<br>*Size Recommendation<br>*Medical Assistance | ZoZo suit average error of 3.7 mm, ZoZomat average error 1.4 mm | 360-degree scan |
| 18 | **3DsizeME** | 1 × 360-degree body scan with Structure sensor Mark II | Computer Vision & Deep Learning | 3 | >60 Sec | Y = Body parts measurements | *Measurements<br>*Body Shape<br>*Medical Assistance | +/- 1 cm for large girths | 360-degree camera scan |

***4.1.5.3. 3D body scanning with front, side and back view photo capture requirements.*** SizeYou requires 1 back and side view facing image to deliver output features and digital measurements (SizeYou, 2018). Fashion Tech platform photo capture requirement is 1 front, side and back view photo. It uses intelligent data-driven measuring system and technology, which provide made-to-measure services by extracting body dimensions data through mobile body scanning. The application has integrated global brands and designers for best style advice by choosing favourite styles, designs, fabrics, and features (Fashion Tech, 2021) (Table 8).

***4.1.5.4. 3D body scanning with 360-degree scanning using additional accessories.*** 3DsizeME requires 360-degree scan using Structure sensor Mark-II used for the 3D modelling that virtually allows user/doctor to connect with the patient. MAid with Structure Sensor improves the digitization process which enhances the output formed by the scanning. Msoft application is used to import the scan from an application to extract measurement (TechMed3D, 2020). This application is especially designed to serve in medical Industry for orthotics and prosthetics.

Similarly, ZOZO app also requires 360-degree scan using a scan suit. The ZOZOSUIT 2 is introduced with noteworthy development in resolution which is powered by a 50-times (20,000 in average (50x)) enhancement in fiducial markers, which empowers a smartphone camera to extract complete information of the body, containing the body curvature. The features of Body suit include 1) Enhanced Fiducial Recognition: ZOZOSUIT 2 is comprised of 6 mm fiducial markers. The improved markers are better documented by smartphone cameras, empowering higher resolution scans. 2) Increased Fitting Accuracy: Silhouette fitting, progressive body movement and posture recognition sustain

a more seamless scanning experience and produce a significantly comprehensive 3D model (ZOZO., 2020) (Table 9).

## 5. Discussion and conclusion

3D Body scanning technology has developed considerably and has moved onto more consumer accessible devices with mobile smartphone scanning. Mobile scan applications are established in a variety of geographical locations, by a range of different companies. The apps offer a variety of end uses such as customisation, size recommendation and virtual try-on of apparel products. Thus, reducing the uncertainty of how to find the garment size online without trying-on. The metaverse 3D body scanning apps have a user-friendly approach for buyers and retailers both by aiding artificial intelligence (AI) technology such as computer vision and deep learning, proprietary statistical modelling and machine learning & 3D matching (Table 2). The 3D body scanning enterprises are offering different and easy interactive interface solutions for fashion brands to display fashion products with personalise interactive fashion apps, interfaces, and widget by providing various retailer facing solutions such as OEM, PaaS, API and SDK. The apps features, benefits, mechanism, and proposed solutions are comprehensively analysed, demonstrated in (Tables 4 and 6–9). The applications reviewed in the study have different modes of capturing body image such as snapshot, selfie and 360-degree scan. The scanning time of apps are fast (time of scanning, min = 10 sec, and max = 5 min), deliver digital body measurements (min = 7, max = 240) and a personalised Avatar. Moreover, sharing of virtual model (OBJ and STL formats) and size chart (csv format) are also available. The OBJ files could be imported directly for virtual fit as it is a clean avatar outline, in contrast to noisy data from booth scan whereas csv can be directly sent to retailers to be utilised further for pattern making, using software such as Lectra and Gerber to introduce automated tailoring for enhancement in mass customisation services worldwide by MeThreeSixty and 1Measure app (Table 1).

Mobile scanners have the potential to empower consumers in product selection and development. The application developers have different business models and intersect at different points in the current garment supply chain. For instance, Size Me Right and Fashion Tech are offering only bespoke garment construction services. However, 3D Look, Nettelo, Meeple, 3D Avatar Body (IBV) and Asizer are offering customised services, virtual trying on with size recommendation to brands/country intended fit, to visualise the dress on personal avatar and chosen dresses can be added into virtual dressing room for future buying option. Body tracking (measurements and Avatar) and body fat monitoring services (body surface area/BMI) are also offered to view results of change in body measurements after workout. Moreover, Nettelo, Presize.ai and Mirrorsize provide additional feature of fit preference such as body fit, regular and loose fit garment in size recommendation service. Additionally, 3D Size Me, Verifyt Body, Zozo app and 3D Measure Up app are offering full and partial body scanning measurements and avatar for acquiring medical assistance (Table 4). 3D Size Me (structure sensor), ZoZo App (scan suit) and 3D Measure up (3D body scan avatar from an external source) requires additional accessories for getting the required results. Nettelo and 1Measure require effort in silhouette creation for getting digital measurements. Therefore, they are concluded as difficult applications. The applications are offering various benefits with 3D body scanning such as garment customisation, virtual try-on and size and fit visualisation and recommendation, virtual dressing room, body tracking and medical assistance, sustainability, and low online return rates. The technology has the potential to enhance online shopping by finding the right size and fit of garments. This will improve confidence to buy functional, stylish, and right fit garments in a fashion e-commerce environment. The applications have also paved the way to establish sustainable business environment by aiding in the reduction of mass production costs, resulting from standard fit mass production sizing system returns.

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No potential conflict of interest was reported by the authors.

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