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3D Human Body Modeling Methods

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ABSTRACT: *Establishing a method for constructing a human body model from 3D scanning data aims to create a model that fully and accurately represents the data of the human body surface. However, the generalization of methods for building human body models to respond to requirements in garment design has not been fully mentioned. Methods for building 3D human body models on computers are presented systematically in this article. The studies are collected and classified according to 2 groups of methods for building 3D human body models. Thereby, the advantages and limitations of the research are also pointed out in the article, contributing to the selection of methods for building human body models in practice and for more effective research. From there, exploit the advantages of each method to solve the problems of the garment industry.*

Keywords: *human body model, method of constructing a human body model, 3D model*

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I. INTRODUCTION

Modeling of the human body allows the collection of a lot of information from scan data [1] and is the basis for applications in the garment industry. Establishing a method to build a human body model from 3D scanning data aims to create a model that fully and accurately represents the data of the human body surface, thereby determining the data relevant to the research.

3D human body modeling methods on computers can create 3D human body surfaces using different methods with different input requirements. An overview of methods for building 3D human body models helps classify research content, contributing to choosing methods for building human body models in practice and more effective research. Researching the method of building 3D human body models aims to systematize advances and innovations in building human body models, helping researchers have a more general view. From there, we provide comments and evaluations for methods of building human body models and propose future research directions and applications in the garment industry.

II. RESEARCH METHODS

Methods of analyzing and synthesizing published research are used to overview methods for building 3D human body models. To connect and search for research on methods of building 3D human body models, EndNote software was used. The key academic databases in the textile field searched were *Textile Technology Index* and *World Textiles*. Published studies were searched based on two key phrases: *3D human body surface,* and *3D human body model construction*. Articles are categorized by journal and research questions for review.

III. RESULTS AND DISCUSSION

Modeling the human body allows a lot of information from scan data and is the basis for applications in the garment industry such as developing mannequins, deforming the human body, and designing custom clothing. A high-quality and accurate complete body model is essential. After reviewing research related to methods of building 3D human body models on computers, model building methods are generalized and classified into several typical types.

3.1. 3D human body data and models

Anthropometric landmarks [2] are located by anatomical points and grouped according to their location on the body to speed up body measurements. Defined measurement landmarks and standardized measurement methods ensure reliability. Body measurement terms and methods [3] are divided into four groups: stature, length, body width, and girth. When extracting anthropometric landmarks, it is necessary to ensure the extraction of reference points for the manual measurement process, feature points for 3D human body measurement, body shape reconstruction, and algorithm development automatic measurement.

According to I. Dabolina et al. [4], anthropometry is a method of a comprehensive study of morphological features whose measurement procedure can be influenced by different factors: selected measuring tools and equipment, and the influence of human body posture. Morphological analysis of the human body [5] from which clothing is designed must be carried out by knowledge of the human body, with its characteristic features and proportions concerning gender. The three main planes used in anthropometry divide the human body, figure 1, in the following way: The sagittal xy plane separates the body symmetrically into two parts (right half and left half) through the cervical spine and middle of the sternum. The front vv plane divides the body along the longitudinal axis perpendicular to the xy plane and divides the body into front and back. The TT plane is horizontal, through the waist horizontally, and is perpendicular to the xy plane and vv. The human body identification plane consists of two parts: upper and lower. The intersections of these planes help determine the three axes of the Cartesian coordinate system of the human body including the vertical axis is created by the intersection of the vv and xy planes, the horizontal axis is created by the intersection of the planes vv and TT, the sagittal axis is created by the intersection of the xy and TT planes.

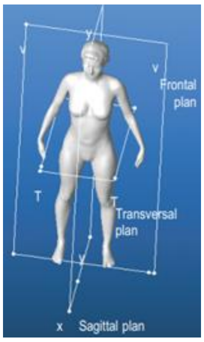

Figure 1. Main planes of the human body [5]

According to Yong-Jin Liu et al [6], to define human body model geometry, it is necessary to use semantic features to facilitate the design of clothes on the model. The authors used two sets of size parameters to characterize the body: height h_i when specifying a set of planes parallel to a base plane in the model and measured girth g_i on each plane intersecting the human body, figure 2.

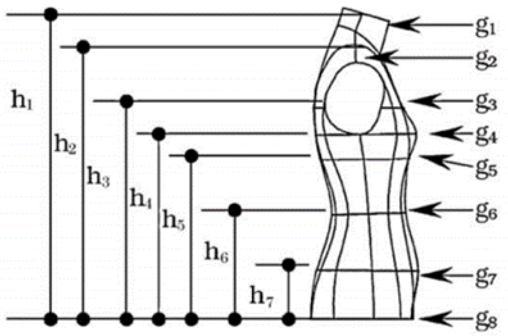

Figure 2. Human body model and segmented semantic features [6]

To obtain a human body model that fully and accurately represents the acquired data of the human body surface, many researchers have proposed different modeling methods to achieve this goal. According to Jun Zhang [7], modeling the human body usually follows the following directions: implicit surfaces, curves, and B-spline surfaces.

3.2. Method for creating implicit surfaces.

Implicit surfaces have been used in the design and animation of 3D objects because they have many useful advantages over traditional parametric surfaces. Use implicit surfaces to create smooth and deformable 3D models. Implicit surface C is to use an equation F(x,y,z) with defined conditions to represent the surface. A point in space (x,y,z) that satisfies the equation F(x,y,z) = 0 will be located on the implicit surface C, otherwise point (x,y,z) will be located outside the surface implicit surface C.

Velho et al [8] determined the mathematical form of surface shapes using implicit surface generation and its applications to geometric modeling, visualization, and animation. Using a method combining implicit surface and spline techniques, I. Douros et al [9] created a model from a mixed surface with many segments, but smooth and closed, for physical surface reconstruction of the model. Using several small B-spline surfaces is significantly better than wrapping one large surface around the object. With the shape extrapolation method, Stefanie et al [10] also created a human body model that satisfies the measurement conditions.

The algorithms of most existing modeling methods are numerous and complex, they are mainly classified into three types according to the optical properties, geometrical, and topological of the human body [11].

3.3. Parametric curved surface modeling method

Geometric models in 3D space are widely used in computer graphics [12], playing an important role in the garment industry and fashion design. Among the 3D geometric models used to represent the surface of an object on the computer, the parametric curved surface model has been researched by many scientists to apply to human body modeling that needs to be created according to different size parameters.

With the method of creating surfaces from curves, an algorithm is used to create a surface from a curve and combined with an existing curve algorithm from points to create a surface from points. Gather B-spline curves and use them to quickly create surfaces. Shih-Wen Hsiao et al [13] proposed a surface reconstruction method for 3D mannequins based on characteristic curves. From the mannequin scanning data, the shape of the entire 3D mannequin is reconstructed using B-spline curves. The continuity between connected surfaces is adjusted by tangent vector regulation methods based on the minimum energy required to improve the quality of the surfaces.

The human body segmentation method to create surfaces, Mustafa Kasap et al [14] created a human body model for real-time applications. Based on a sample model, different body sizes are created according to anthropometric measurement standards. These standards are used to segment the body model into regions that can be deformed by the corresponding measurement parameter. Anthropometric points and anthropometric lines are used to describe and represent the complex, smooth outer surface of the human body [15]. Methods for estimating human body segmentation parameter values include approaches based on geometric models of the human body, methods for automatic shape detection, segmentation, and size calculation. anthropometry [16]. To divide the human body, Charlie C.L Wang et al [17] used the method of automatically locating three main feature points on both sides of the armpit and crotch point to divide the entire human body into six parts with fixed topology: head, body, left arm, right arm, left leg and right leg, figure 3.

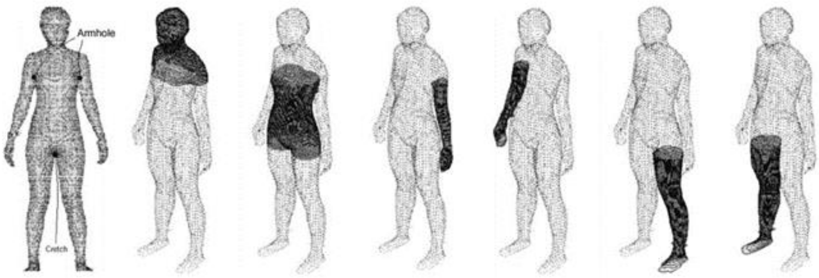

Figure 3. Three main features and six semantic parts [17]

Using the parametric design method, Sungmin [18] automatically analyzed the human body surface shape and divided the complex surface shapes of different human bodies consistently, reducing the shape analysis time surface of 3D body scan data. Using a segmented generic model and the points arranged in slices, Thibault et al [19] adjusted the size of each limb on the body and fit each slice on the data. Based on silhouette segmentation, the Shape-from-Silhouette (SfS) method allows 3D reconstruction of body segments separately to reconstruct dynamic and difficult-to-shoot objects [20], bringing results in better human body shape estimation, especially in concave areas.

From semantic parameters, a 3D human body shape can be created. Chih-Hsing Chu et al [21] used a model-based method to reconstruct the human body with the same topology (mesh connection), facilitating the automatic design of form freedom of body-centered products. Also from linear anthropometric parameters, Bon et al [22] used the method of parametric modeling of 3D human body shapes with the following stages: building basic shape training data human body shape, static analysis of human body shape, and body model building.

Human body models can also be created using the control slice method and control algorithms [3]. The 3D model of the human body is divided from the neck to the thighs into many horizontal and parallel slices, figure 4 and measured with a slide ruler. Each cross-sectional shape is subdivided, and the radius is obtained by image analysis.

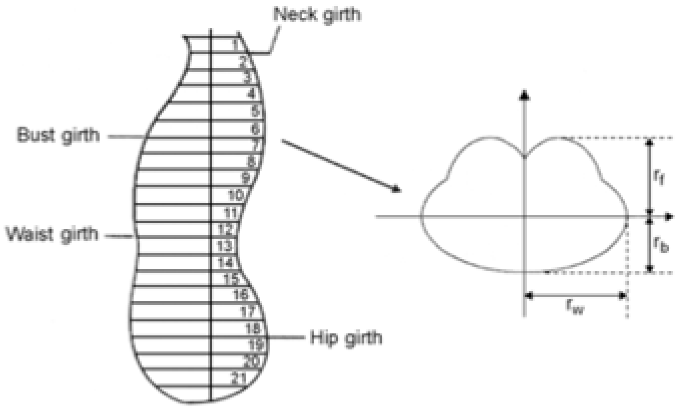

Figure 4. Basic and chest cross-section [3]

Peng Sixiang et al [23] also created a 3D model of the human body by using control algorithms and control cross-sections taken from anthropometric surveys. From the scanned human body data, determine anthropometric points according to ISO standard: 8559, 14 cross-sections based on anthropometric points and dimensions commonly used to measure clothing size, figure 5. For each cross-section, set control points to control and determine the shape of the slice curve, thereby creating a set of body model shapes.

Figure 5. Parametric mannequin shape controlled by cross-sections [23]

Static mannequin model characteristic curves can also be dynamically adjusted [24], from which the mannequin model surface is reconstructed according to the user's specific requirements to create a model realistic 3D mannequin that conforms to the application needs of mass-produced clothing.

A human body model that is suitable for the size of the clothing can be created using the body shape deformation method [25]. From the 3D scan data, the anatomical body planes and coordinate axes are determined, figure 6. Measure the distance from the origin to the contour in the y, +z, and −z directions for each cross-section of the shirt and body, figure 7. Then, deform the body by varying the distances obtained on each cross-section to create a body model that is suitable for the desired shirt size.

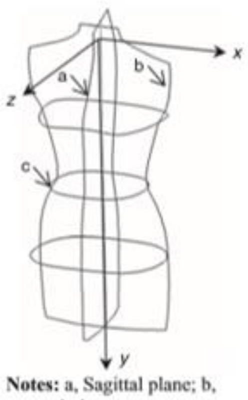

Figure 6. Anatomical body planes [25]

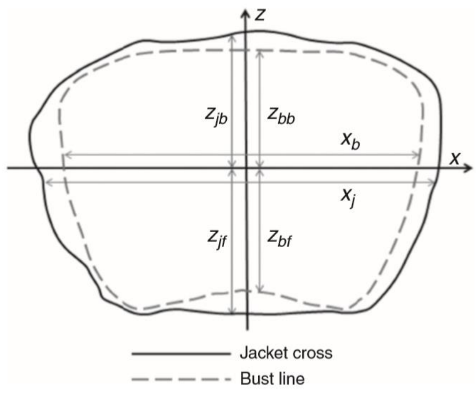

Figure 7. Distance measurement [25]

Sybille et al [26] developed a virtual female mannequin with variable shape, allowing the body size and shape to be reduced or enlarged. By locating cutting planes and characteristic points on the body to determine body size lines: chest diameter, waist curve, or measured length. Further curves are defined to allow precise alignment of the body shape. Calculated spline surfaces for skinny, normal, and fat bodies, figures 8 and 9.

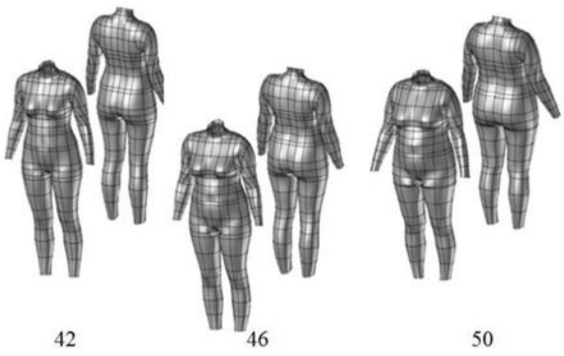

Figure 8. Computational model for the whole body [26].

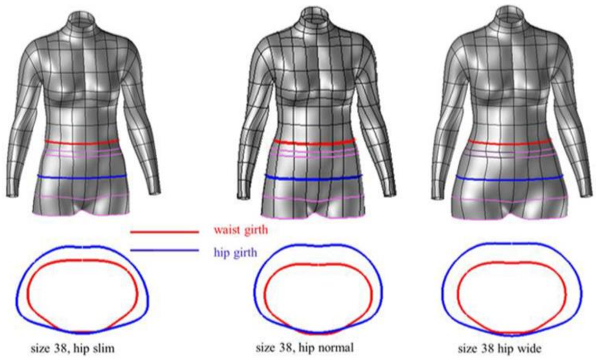

Figure 9. Computed models for different hip shapes [26].

Dongliang Zhang et al [27] also created a 3D parametric model of the human body and represented the model using a triangular mesh. By using the cross-sectional plane method to section the body from head to toe, the cross-sections pass through characteristic points. Main features include neck, shoulders, elbows, wrists, chest, waist, hips, knees, ankles…

Liwen Gu et al [28] reconstructed a custom 3D human body model based on a visual body image by establishing a cross-sectional contour template of the body in the modeling software 3D open-source Blender, then reconstructed the body and tested the method with evaluation. The results are highly accurate body models but lack constraints for creating bodies of the required size and shape. This method only uses representative anthropometric data, so the body shape does not respond to the requirements of clothing design. The modeling of human body morphology by Agnieszka et al [5] is based on the model surface being determined by using multiple curved surfaces obtained from scanning the human body. To parametrically model the human body morphology, the positions of the main contours are defined to set the model's parameter control data such as waist, hip... These parameters represent the position of each part of the human body depending on the height h concerning the shape of the scanned human body, figure 10. To preserve the form and beauty of the human body, sub-contours must be created. These sub-contours are located between the primary contours to represent the body surface and are controlled by height h, figure 11. This model serves the design of ready-to-wear garments, but it is not yet suitable to produce tight-fitting clothes and each size change requires a new digital model of the human body.

Figure 10. Morphological model of primary contours [5]

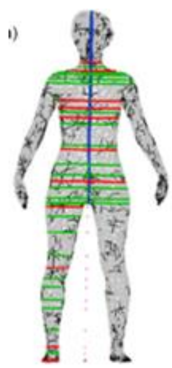

Figure 11. Morphological model of primary and sub-contours [5]

Charlie C.L. Wang [29] parameterized the human body model by exploiting semantic features from 3D human body scanning data. Feature points are identified and connected by parametric curves, which approximate the shape of the human body surface. Construct body surface feature wireframes from curves and wireframes are modified by control points. The patch pieces are used to create a continuous mesh surface that interpolates the curves on the feature wireframe and creates a smooth continuous surface, figure 12. This method allows the creation of a new human body according to size-determined or designed human body parameters.

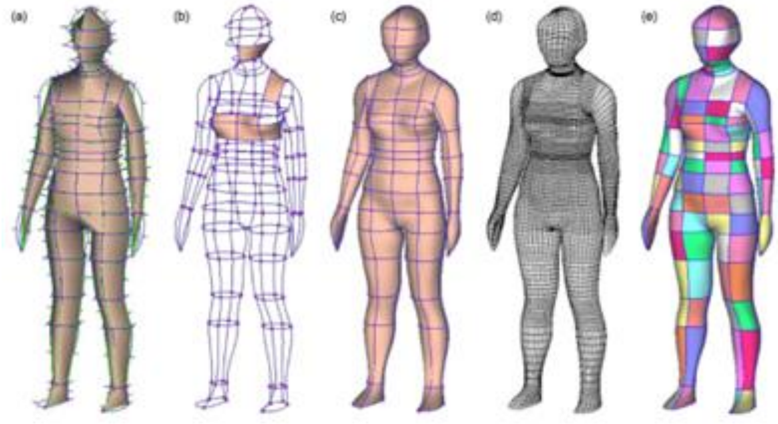

Figure 12. Interpolated characteristic patches [29]
(a) Structure associated with normal; (b)Curves and patches on the body; (c) Characteristic patches are created; (d)Mesh structure of patches; (e) Sample to verify characteristic patches

Using the method of creating surfaces from human body wireframes, Sun Mi Park et al [30] used a multi-purpose body form to develop garments by introducing skin surface and the ease of standard body form, figure 13. Free deformation method to create a virtual model based on an average wireframe, figure 14.

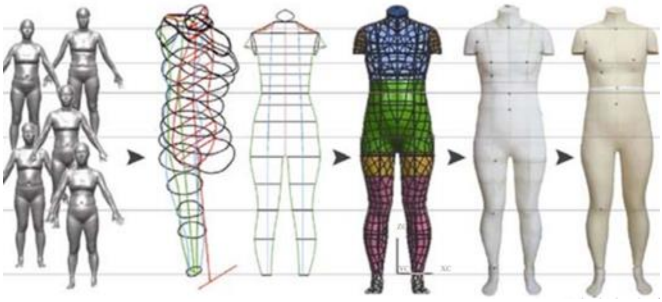

Figure 13. Process of developing a standard body shape [30]

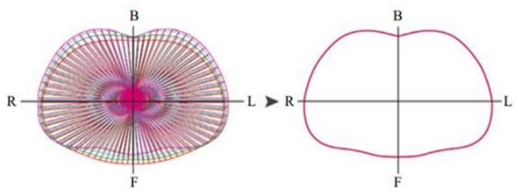

Figure 14. Example of creating an average cross-section [30]

Shuxia Wang et al [31] also constructed the human body skeleton by adding and adjusting the position of joints. The authors automatically extracted semantic feature cross-sections and main points on the cross-section to control the cross-section. Then, interpolate the main points to fit the boundary curve of the cross-section for each body part, using the drag parameter to represent simple deformation of the body shape and connect the body parts.

Also, in this direction of research, Jituo Li et al [32] created a body frame and were able to control the parametric structure for 3D models of the human body. First, the body parametric wireframe model is constructed based on the anatomical points of the human body and curves along the body frame. Then, deform the slice surface to create a human body model with a surface that approximates the high-resolution scanning surface, figure 15.

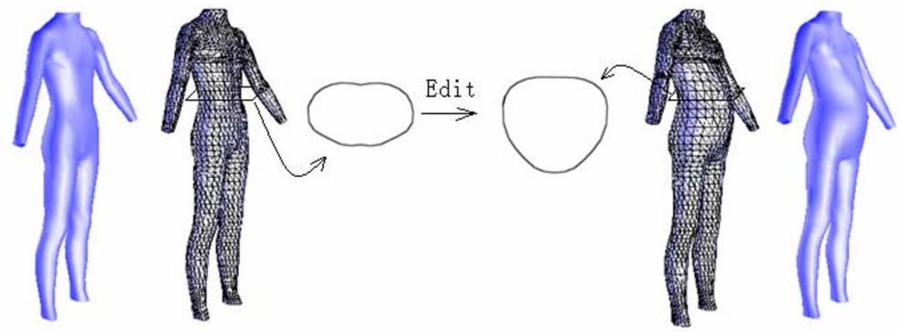

Figure 15. Deformation of slice surface [32]

Péter et al [33] have been modeled based on object-oriented parametric properties that describe the human body with appropriate accuracy. To establish a 3D human body model, feature points are obtained through body measurements [34]. The measurement data points are marked on the human body model and divided the body into the neck, body, hips, and legs and divided along the longitude and latitude lines to perform measurement data standardization, and a mesh is formed. The mesh nodes are measurement points of the human body surface. This method shows that the characteristic curves of the 3D human body model reflect the characteristics of the human body model but are not enough to represent all the morphology of the human model.

A human body model can be generated using a representative body model method from an existing commercial scan database [35]. This model was created by implementing preprocessing steps and evaluating the accuracy and generality of the new model. The back-propagation artificial neural network (BP-ANN) model is used to predict body dimensions related to pattern generation by inputting the main human body dimensions [36]. When wanting to show the impact of body shape on clothing fit [37] it is necessary to change the parametric representation available in the 3D software package, using manual and digital body measurements of real people.

To integrate research results into garment design applications, Seung-Yeob Baek et al [38] approach was to develop a parametric human body shape modeling process. Based on a 3D scanning database and statistical analysis, human body sizes are studied. A GUI graphical user interface was used to select reference points, curves, perimeters of slices, and define constraints for the model.

To reconstruct a simulation model of the human body to limit errors in the 3D scanning process due to small movements of the body such as breathing and shaking, Do Thi Thuy et al [39] used real mannequins to conduct experiments. The process of reconstructing a 3D mannequin simulation model is carried out through the following steps:

- Collect data on 3D female body mannequins

+ Identify anthropometric points on the mannequin to ensure the accuracy and consistency of data obtained between scans.

+ 3D scanning of mannequins with a handheld scanner under normal environmental conditions.

+ Process scan data on Rapidform XOR3 software.

- Reconstruct a 3D mannequin geometric model of the female body

+ Identify 6 primary slices on the mannequin as horizontal slices, parallel to each other and passing through anthropometric points on the mannequin. These are important slices, ensuring the main dimensions of the mannequin are modeled accurately.

+ Identify sub-slices on the mannequin as horizontal slices, located between and parallel to the primary slices. The sub-slices ensure the size, shape, and curvature of the body in the parts between the primary slices. Horizontal sub-slices will be taken on both sides of the main slice passing through the two nipple points. Sub-slices spaced 5mm apart can ensure the accuracy of the obtained model, figure 16.

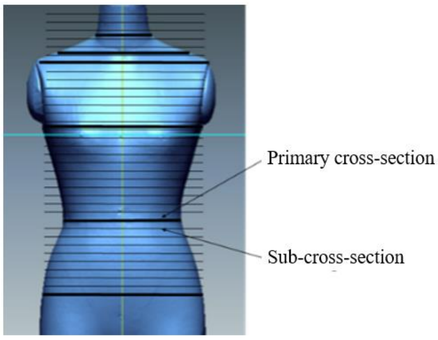

Figure 16. Primary and sub-cross-sections [39]

+ Construct mannequin model surfaces using the boundary curve interpolation method.

Depending on the position of the cross-section when cutting the scan data, different shapes of boundary curves will be obtained. Create a 3D mannequin model surface from the boundary curves obtained using the boundary curve interpolation method, figure 17.

- Evaluate the accuracy of the mannequin model by comparing the dimensions of the created mannequin model with the 3D scanning data obtained. The dimensions that need to be compared and evaluated are the dimensions measured from the center of the slice to points on the slice's boundary, and the length of the slice's boundary [39]. To obtain a boundary curve, use horizontal slices to slice the 3D scan data. The intersection of each slice with the outer surface of the 3D scan data is a boundary curve. To reconstruct the mannequin geometry accurately, it is necessary to design a spline curve that resembles the boundary curve of the scan data. The spline curve passes sequentially through points located on the boundary of the scan data. When the number of points increases to 180 points, the spline curve will have a shape closer to the boundary curve of the scanned data [39].

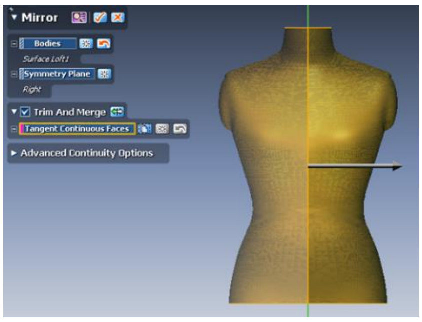

Figure 17. Creating the surface of a female body mannequin model [39]

Some research works by authors La Thi Ngoc Anh [40], Dinh Mai Huong [41], Phan Thanh Thao et al [42] have used 3D scanning data to recreate 3D model's human body. 3D scanned objects have been researched, measured, and selected to fit standard sizes. The result of model building is a 3D dataset that reconstructs a human body model.

IV. CONCLUSION

Model construction methods are based on 3D scanning data of the human body. These data are used to reconstruct human body models or construct human body models with desired dimensions.

In the garment industry, a virtual human body shape is necessary during the garment development process, especially the prototype development or computer fit assessment stages. Therefore, garment enterprises need to accommodate different sizes of human body shapes to design their garments to respond to the needs and desires of their target customers. These virtual human body models will help designers achieve their desired goals and avoid having to store too many physical body models.

The research in this article has been presented and evaluated on the construction of 3D human body models. Some main methods have been summarized: implicit surface generation method, and parametric curved surface modeling method. Computer-aided 3D human body surface generation is an area that has received a lot of attention and needs a lot of research. The overview of these studies is by no means complete. However, this article may provide some help to researchers to see past developments and future research directions on human body modeling methods 3D on the computer.

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