Analysis of 3D Construction of Tight Fit Clothing Based on Parametric and Scanned Body Models

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Abstract

The contribution presents the study related to the use of parametric and 3D scanned computer body models for designing and constructing the skin-tight garments. A number of methods and systems have already been developed that allow an efficient 3D design of garment patterns in a virtual environment using the computer-based body models. Such systems usually offer solutions for creating the models of garments to be manufactured from elastic materials, which come close to the body. Here, the designer designs the garment and also constructs a 3D model of the garment on the surface of the virtual model of the body. After finishing the computer design of the surfaces that simulate 3D patterns, the transformation of three-dimensional to two-dimensional patterns is performed. As a prototype of the garment, on which the study was conducted, the model of a wet diving suit was chosen. Using the 3D simulation method on the parametric and scanned body model, we have analysed the fit of designed prototypes in static and dynamic body postures.

Keywords: 3D body scanning, CAD system, parametric body model, tight fit clothing, diving suit

1. Introduction

Virtual garment simulation is the result of a large combination of techniques that have dramatically evolved during the last two decades. Besides the mechanical models used for existing mechanical engineering for simulating deformable structures, many new challenges arise from versatile nature of textile fabrics. Therefore, garment simulation is based on the development of the efficient mechanical simulation models, which support the reproduction of the specific non-linear mechanical properties of textile materials. In addition, the garments interact strongly with the body, as well as with other garments layers. This requires the development of the advanced methods efficiently detecting the geometrical contacts constraining the behaviour of the fabric and integrated them into the mechanical model [1- 3].

Tight fit clothing items represent a specific group of products intended for wearing tight to the body. Special requirements are to be considered when dealing with suits intended for professional sports activities. A group of researchers have been dealing with a similar problem related to the development of a jumpsuit for professional ski jumpers [4]. The jumpsuit pattern design was performed according to the FIS requirements by using the ski jumper body measures. One of commercial CAD/PDS systems was used to design the jumpsuit patterns. Both parametric and reconstructed scanned body models were used for the complete virtual prototyping process, including constructing of patterns, virtual try-on, tension analysis and visualisation of designed jumpsuit. The research confirmed the need for using the scanned 3D body models instead of parametric models in order to assure the accurate shape of the body. Performed research solving the issue of parametric body adjustment according to individual measurements also showed some disadvantages in adjustment, especially adjustment of body posture, spine curvature and shoulders rotation which is particularly important for specific tight-fit garment applications [5]. When analysing clothing construction according to individual measurements it is best to use scanned body models to gain accurate body shape on which computer 3D prototype will be joined in simulation process [6]. Similar approaches have been used in a number of other research works [7-9].

When using 3D flattening method for 3D construction of tight-fit clothing it is necessary to take inconsideration physical and mechanical properties of the material from which the clothing will be made. It requires comprehensive knowledge of fabric behaviour, its tensile and shear properties, its behaviour on the body as well as constructional and functional requirements imposed on the clothing. This approach is quite demanding and time consuming and commercial software tools available today cannot be used without difficulties. However, results of cutting patterns constructed and manufactured prototype showed good clothing fit which makes the method adequate for tight-fit clothing construction [10].

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This paper presents two aspects of 3D flattening model application [11], using selected wet diving suit model for construction of cutting pattern. The special diving suit above all protects the human body from hypothermia and various forms of injury Depending on the water temperature and the depth of the dive, diving suits are produced using different thickness of the material [12]. Wet suits are made of polychloroprene, material with excellent insulation and physical characteristics. This material, known under the trade name Neoprene, is further processed by "incorporating" the air bubbles, which assure additional isolation properties. When the suit gets wet, the water penetrates into the pores of the material and is then heated by the body temperature of a diver. Therefore, the size and cutting pattern of the diving suit should be completely adapted to the measures and shape of the diver's body. If the suit is too large, the water cannot penetrate between the body and suit and heating will not be possible. On the other hand, if the suit is too little, it can be expected that circulation decrease in the limbs and consequently hypothermia will occur [12].

2. Methods

2.1. 3D scanning of the diver and computer-based processing of the body model

In order to achieve best fit of skin tight garments taking into account the individual anthropometric characteristics of the body and to ensure at the same time the comfort in different dynamic postures, it is necessary to determine the specific body measurements that define the body shape, profile curves and dimensions of the segments of the body surface. The use of a 3D scanners and accompanying computer program allows to obtain a very precise 3D body model in static and dynamic postures. An important advantage of this technology is the possibility of analysing the shape and determining the curve dimensions. Also, the parts of the surface and the volume of individual body segments can be determined, Fig. 1.

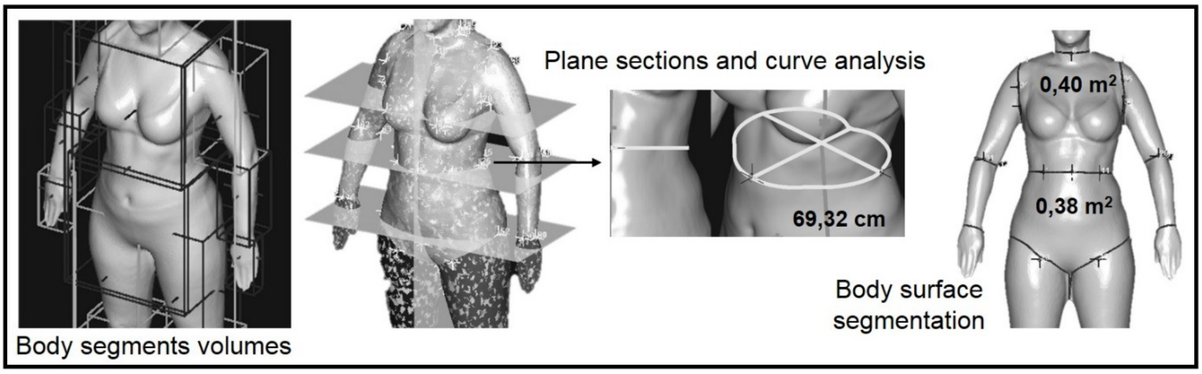

Fig. 1. Measurement of body curves and surface segments

Measurement and analysis of the body shape of a female test subject using the 3D laser scanner Vitus Smart and accompanying computer program Anthroscan 3.0.4 was carried out within this research. With regard to the problems of designing tight fit clothing and determining the necessary body measures, caused by the fact that the bodies may be of different shapes and proportions, application of such technology significantly simplifies the design of such clothing. In order to ensure a high level of a fit of a garment, a certain additional number of measurement points and curves on target segments of the body was defined in addition to the usual anthropometric body measures, which are typical for the construction of the conventional clothing. The female diver was scanned in basic upright standing body posture according to the standard ISO 20685 and additionally in five selected dynamic postures, in order to analyse changes in the length of the characteristic segments of the body, important for the design and functionality of the model of a garment.

The scanned body model was processed in order to close its surface with a goal to obtain a single-layered polygonal model, suitable for importing into a CAD system for computer-aided garment construction.

2.2. 3D flattening method for designing the female diving suit

The construction of a female diving suit was derived by applying the 3D flattening method [11], which involves the construction of a garment model by drawing and creating pattern lines directly on the surface of a computer body model and separation of discrete 3D surfaces as well as transformation into 2D cutting parts, Fig. 2.

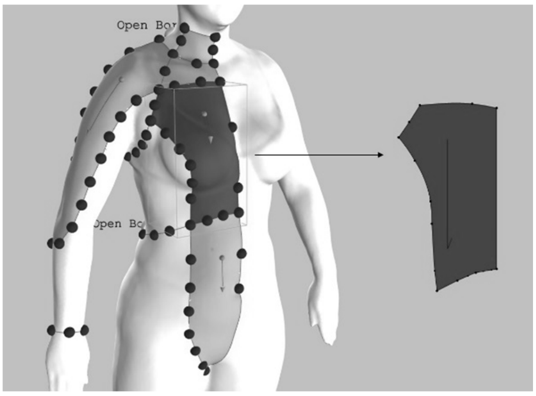

Fig. 2. Computer-based 3D construction of clothing pattern

Within this research, we have constructed a one model of a female diving suit using the scanned/processed 3D body model and additionally using the parametric 3D body model, adapted taking into account the measures of the scanned female diver. In the construction process it is necessary to think about the functionality of the garment model with respect to the ability of the applied method in terms of precise positioning of characteristic anthropometric points on the body. In addition, the pattern lines are important for they ensure the mobility of the kinematic points of the body, the support in the critical stress areas, and thus the fit of the garment in static and dynamic conditions. In order to determine the differences in accuracy of patters, obtained by applying the parameter and the scanned body model, the values of selected area or patterns, as well as the dimensions of pattern segments were analysed.

For both constructed models of female diving suits, we have performed 3D computer simulations, in order to analyse the garment fit on body models in static and dynamic postures. For dynamic postures, we have selected different arms movements: arms spread across, arms spread above the body and arms spread in the front of the body where the changes of body measurements and segment areas of the back were investigated. Furthermore, the analysis of elastic strain of the garment at the shoulder and at the back of the scapula was performed. Selected dynamic postures were defined according to recomendation of professional awarded diver.

3. Results and discussion

3.1. Results of 3D body scanning of the female diver and computer-based processing of the body model

Fig. 3 shows the results of the 3D scanning of the female diver in the standard static posture and a set of five selected dynamic postures. The first three dynamic postures refer to the mobility of the upper extremities and present the terminal positions of the arms at characteristic body movements when diving. The fourth posture refers to the length of elongation of the body, especially in the area of the rear part of coccyx, at maximum flexion of the torso. The fifth posture refers to the mobility of the lower extremities, resp. the flexion of 90˚ in the hip and knee, wherein we analyse the elongation length on the back line of the leg and the change in length in the area of the knee joint.

Automatic determination of the anthropometric points and measurement of body dimensions with 154 identified body measurements was carried out using the computer body model in a static upright posture.

For the analysis of changes of body dimensions in the defined postures, we have selected two typical measures in the area of the back: shoulder width, defined by the length between the acromium points and width of the back at the armpit level, Fig. 4. The professional divers and diving suits manufacturers have characterized the selected measures as the areas with the most prominent issues related to the changes of body dimensions. When moving the hands forward a shift of shoulders forward and stretching of the width of the back occur, Fig. 4. Therefore, also the garment moves with the body causing the pressure on the body and hindering hand dexterity. When lifting the arms above the head, which is a characteristic posture in diving, the acromium points approach, which decreases the shoulder width, Fig. 4. Due to compression, the garment is separated from the body and wrinkles and buckling appear. This can be stated as a critical area because of the possibility of penetration of water in the space between the body and the garment.

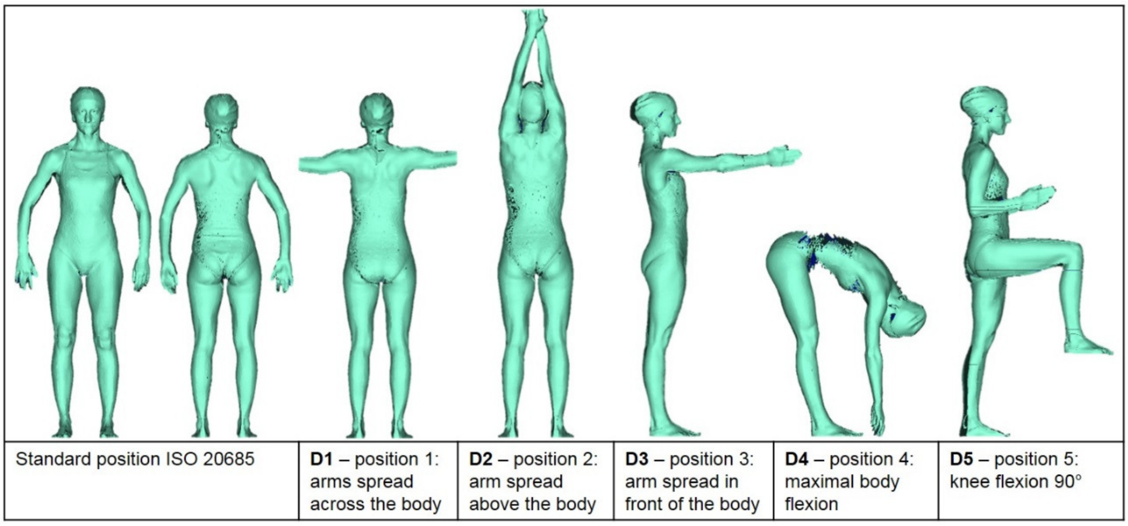

Fig. 3. Results of 3D body scanning in one static and five dynamic positions

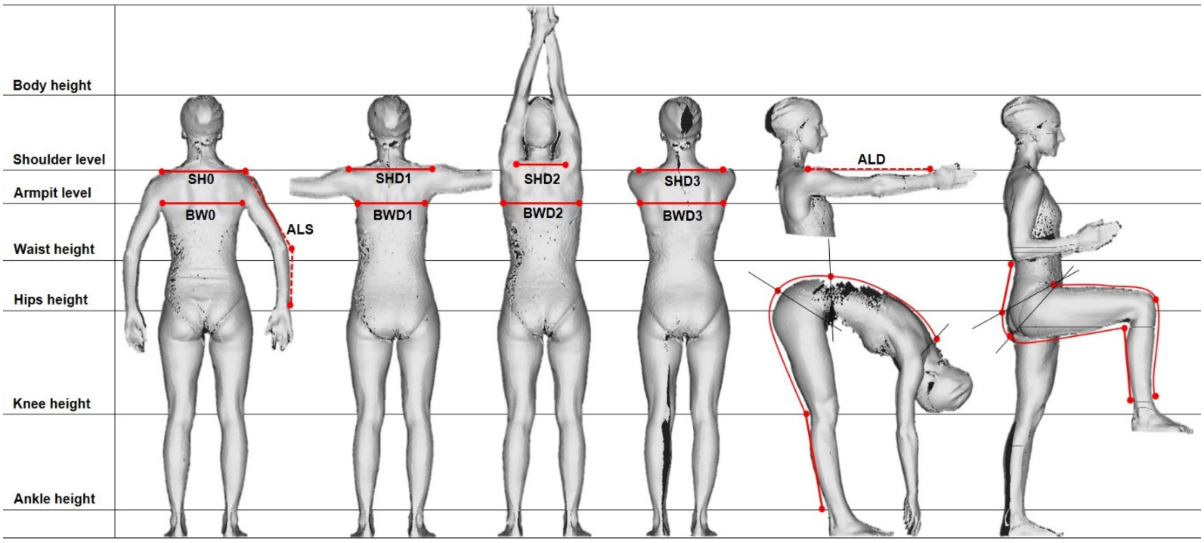

Fig. 4. Position of taken measurements

The scanned body model of the female diver was processed using appropriate software in terms of closing the surface and creating a single-layered polygonal model. Next, it was converted into a format, suitable for import into a CAD system for construction and simulation of garments, Fig. 5.

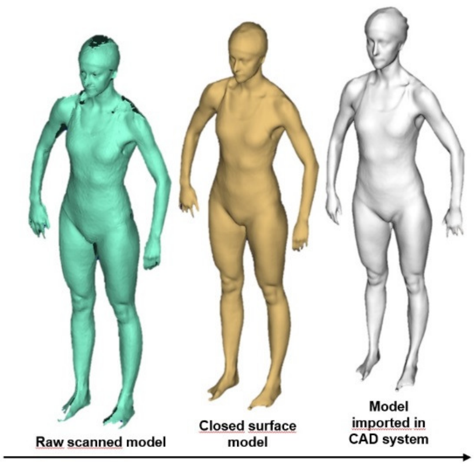

Fig. 5. Scanned body model in three different forms: raw scanned model, closed surface model and model imported in CAD system

The set of 25 body measurements, Tab. 1, was selected for adjusting the parametric body model of the test subject. The measurements file, resp. .ord file was created in order to automatically adjust the body dimensions. Before reading the measurements file, the custom parameters that determine the shape and posture of the body were interactively adjusted. Such measurements have been adapted by visual definition of the expression of a target characteristic between the defined limits. In this sense, the parametric body model has been first adjusted according to the shape of breasts and buttock, as well as taking into account the curvature of the spine in the thoracic and rump area. After that, loading of .ord file followed and consequently automatic adjustments of other body measurements.
Fig. 6 shows the comparison of the scanned and custom parametric body model depicting the position of the body measures with implemented adjustments according to measures of the respondent.

Tab. 1. Table of measurements for adjusting the parametric body model

No.	Measurement	[cm]	No.	Measurement	[cm]
1.	Body height	166,7	14.	Neck height	143,4
2.	Body width	31,3	15.	Body depth	19,3
3.	Waist circumference	65,0	16.	Breast circumference	81,0
4.	Neck circumference	29,5	17.	Hips circumference	90,5
5.	Breast height	120,3	18.	Cross shoulders	43,3
6.	Hips height	83,9	19.	Waist height	105,1
7.	Knee height	44,7	20.	Crotch height	76,0
8.	Ankle height	7,3	21.	Calf height	
9.	Knee circumference	30,1	22.	Thigh circumference	51,4
10.	Ankle circumference	18,7	23.	Calf circumference	30,6
11.	Elbow circumference	20,4	24.	Upperarm circumference	23,8
12.	Arms lenght	53,1	25.	Wrist circumference	13,6
13.	Waist to hips	21,8			

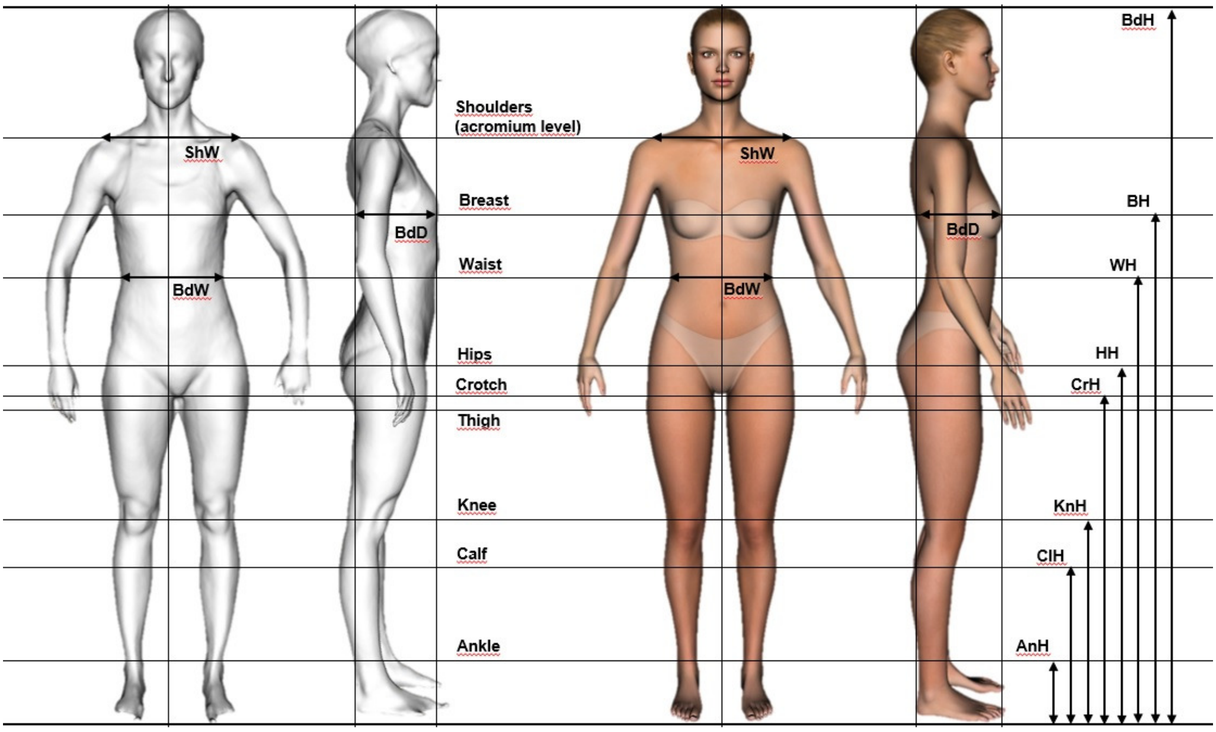

Fig. 6. The scanned body model and custom parametric body model showing the position of the body measures

3.2. The results of the application of a 3D flattening method in prototyping of a female diving suit model

The complete computer development of the diving suit prototype models was carried out using the 2D/3D CAD system Optitex. As a starting point for computer-based design, we have used the 3D scanned and adjusted parametric body model of the same female diver. Design of the prototype was carried out with the purpose of testing the applicability of the 3D flattening method on different body models of the same person and to define the optimal methodology for 3D virtual prototyping of garments.

On the 3D model of the body were in the beginning of the garment design process primarily defined positions of the characteristic anthropometric and kinematic points on the body between which at a later stage curves were created in order to separate the segments of the surface and extract the patterns. In view of the style selected and the type of a garment for a specific purpose, as well as taking into account high criteria in terms of fit, which requires also undisturbed mobility of the body, especially the upper extremities, the sleeve was realized in the raglan embodiment in order to avoid transverse cutting through the acromium point as the centre of rotation and mobility in the shoulders area. On the sides of the model, we have added an insert with a triangular ending in armpits area for ensuring the required width in this area and preventing tightening of the sleeve when a person is in motion. On the front sleeve, we have created a dividing line in the area around the elbow. By the transformation from 3D to 2D shape, a dart will be opened in that position creating the sleeve slightly bent at the elbow area, Fig. 7. The lower part of the suit is designed with a minimum number of distribution lines, and the line of the dart at the knee area was added in order to create and ensure mobility of the knee joint, Fig. 7.

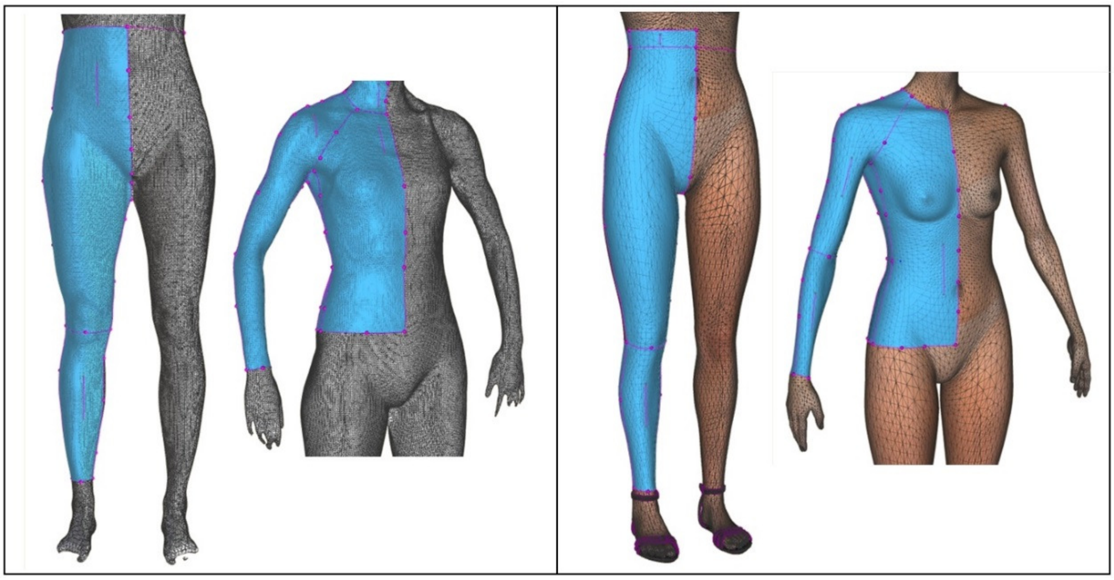

Fig. 7. 3D design of a diving suit model by applying scanned body model (left) and custom parametric body model (right)

Since the parametric model of the body does not allow the adjustment of the dimensions of the head circumference, which is a key measure in the design of a headgear, the hood was designed only on the scanned body model, Fig. 8, and was applied to both suit models, with a minor adjustment of the dimension of a neckline for connecting with the upper part designed on the parametric model of the body. After creating all the necessary points and pattern lines on the scanned and custom parametric body model, we have defined separate detachable surfaces, on which we have determined the direction of the base line in the 3D space. Extraction of all separated 3D surfaces and transformation to 2D cutting parts was derived using the method of 3D flattening.

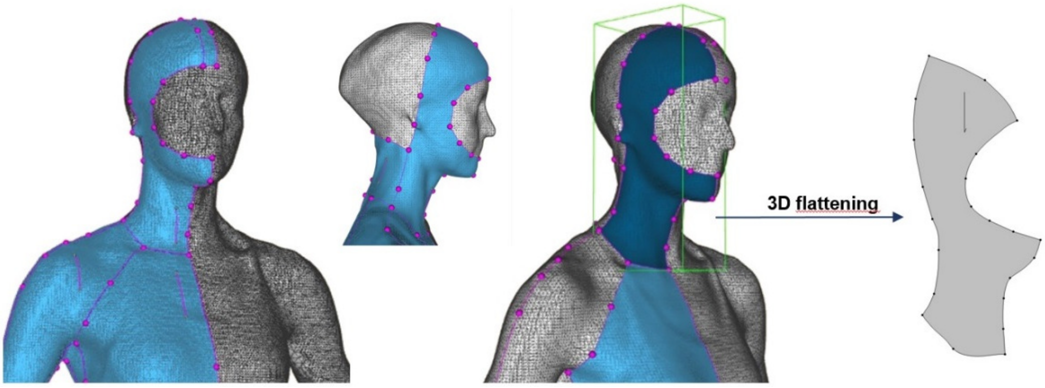

Fig. 8. 3D design of a hood of the model on the scanned body model depicting the transformation of a pattern from 3D to 2D surface

Extracted 2D cutting parts have to be elaborated in terms of smoothing the distribution segments, due to irregularities in the surface of the body caused by the 3D flattening, which influences the shape and smoothness of the curves. In order to determine deviations between the patterns, obtained by the method of flattening the 3D scanned body model and custom parametric model, a comparison was carried out by folding the contour of patterns. Here, the differences in the sizes and shapes of individual pattern segments, can be seen, Fig. 9. In addition, surface areas for all patterns have been determined, Tab. 2. The total area values of the diving suit model were also calculated. Furthermore, we have examined the differences in the areas of individual patterns. However, we have not found significant differences in the total surface areas of patterns separated from the scanned and parametric body model.

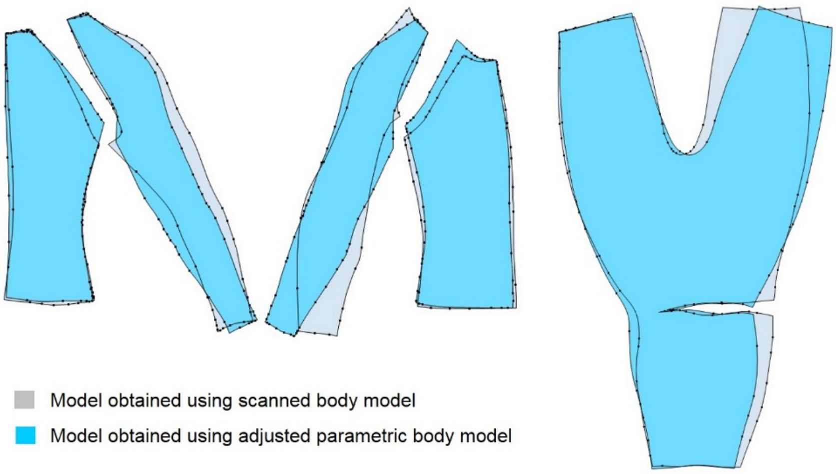

Fig. 9. Comparison of diving duit patterns designed by using 3D flattening methods on scanned and parametric body model

Tab. 2. Comparison of cutting parts surface areas with representation of scanned body surface area value

Surface area [cm^2]	Model 1 (obtained from scanned body model)	Model 1 (obtained from parametric body model)	
FP	782	746	
FS	592	605	
BP	688	678	
BS	616	606	
SI	129	134	
TRS	3533	3579	
∑	**6340 x 2 = 12680**	**6348 x 2 = 12696**	**13200 cm^2**

3.3. Results of 3D simulation of model prototypes

In order to verify the patterns, separated by the method of 3D flattening, 3D simulations have been carried out of both diving suit models on the scanned and custom parametric body model. Predetermined simulation of all the parameters relating to the positioning of each part of the pattern in relation to the body model and defining connecting segments and their characteristics in the simulation process has been carried out in the beginning. Physical and mechanical properties of neoprene material, specific for manufacturing of the diving suits have been applied to the patterns. With regard to the specific stretchability of the neoprene material, model simulations showed too high ease allowance of the patterns. Therefore, in the next step we have performed the scaling of patterns in the transverse direction, in accordance with extensibility of the material, Fig. 10. Value of 5-15 % shrinckage was applied depending on position and pattern segment on the clothing model.

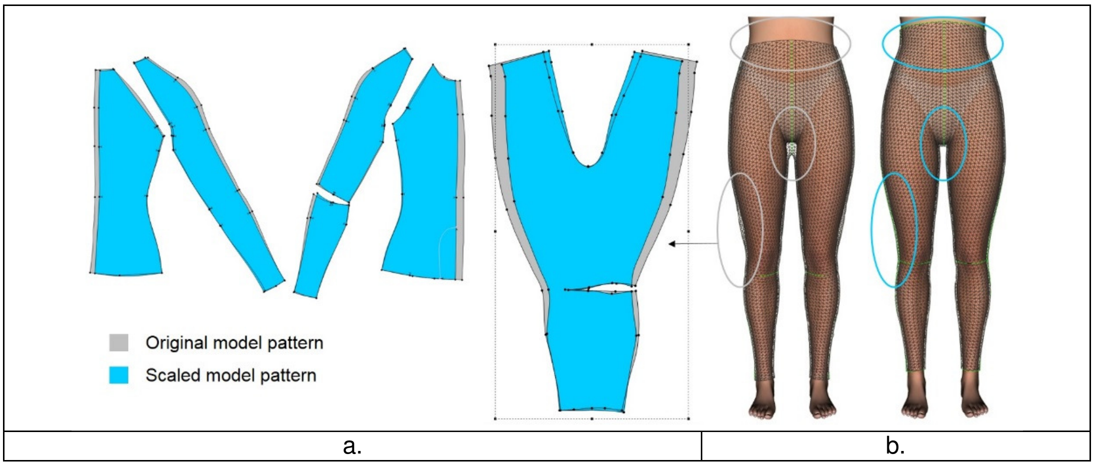

Fig. 10. a. Comparison of 2D patterns before and after scaling in the transverse direction; b. 3D prototype simulation with indicated loose ease allowance zones

The results of visualization of simulated prototypes of both models after scaling, confirmed appropriate fit of a garment patterns, Fig. 11, Fig. 12. In terms of process optimization and applicability of the method in real production condition we have evaluated additional criteria, such as the number of required additional interactive corrections on 2D patterns, position and correctness of pattern connection segments and symmetry of pattern parts. Better optimization and applicability was evaluated for the flattening method on a custom parametric body model.

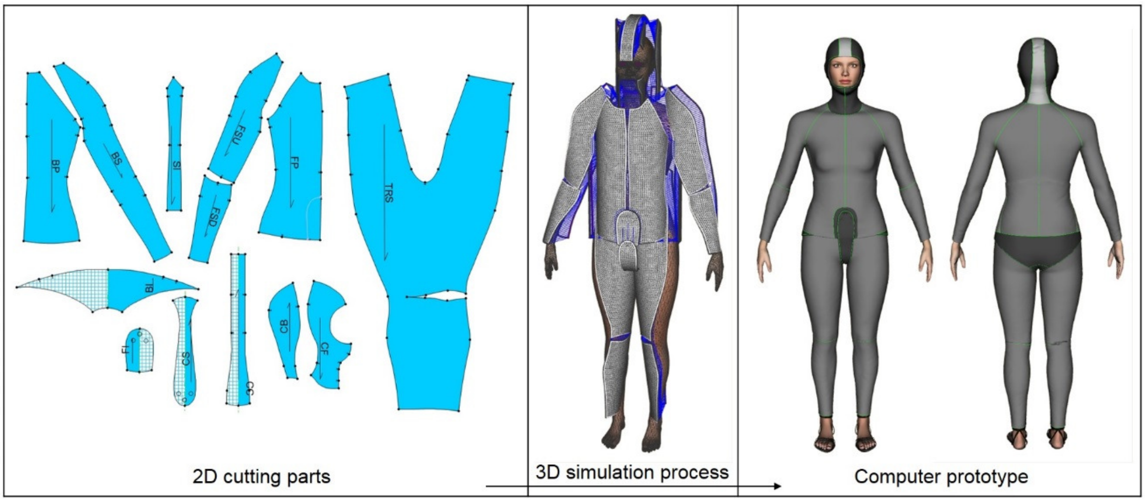

Fig. 11. 3D simulation process of diving suit pattern obtained using the custom parametric body model

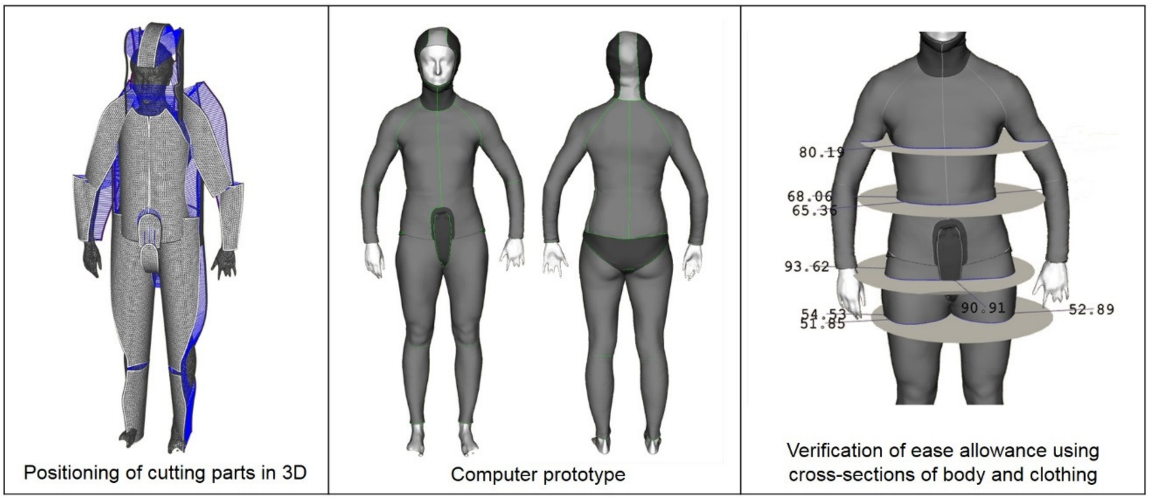

Fig. 12. 3D simulation process of diving suit pattern obtained using scanned body model and verification of ease allowance using transversal cross-section of body and garment

3.4. Results of the fit analysis of a diving suit in static and dynamic posture

We have performed the computational analysis of the stretching of material for both 3D prototypes of a diving suit on the basis of assessing the simulated deformations of the garment on the characteristic areas of the body, and in accordance with the applied values of the parameters of physical and mechanical properties of a material. In a static posture of the body, we have determined for both two designed prototypes the values of stretching the material in individual zones within the limits that ensure satisfactory fit of a diving suit, Fig. 13.

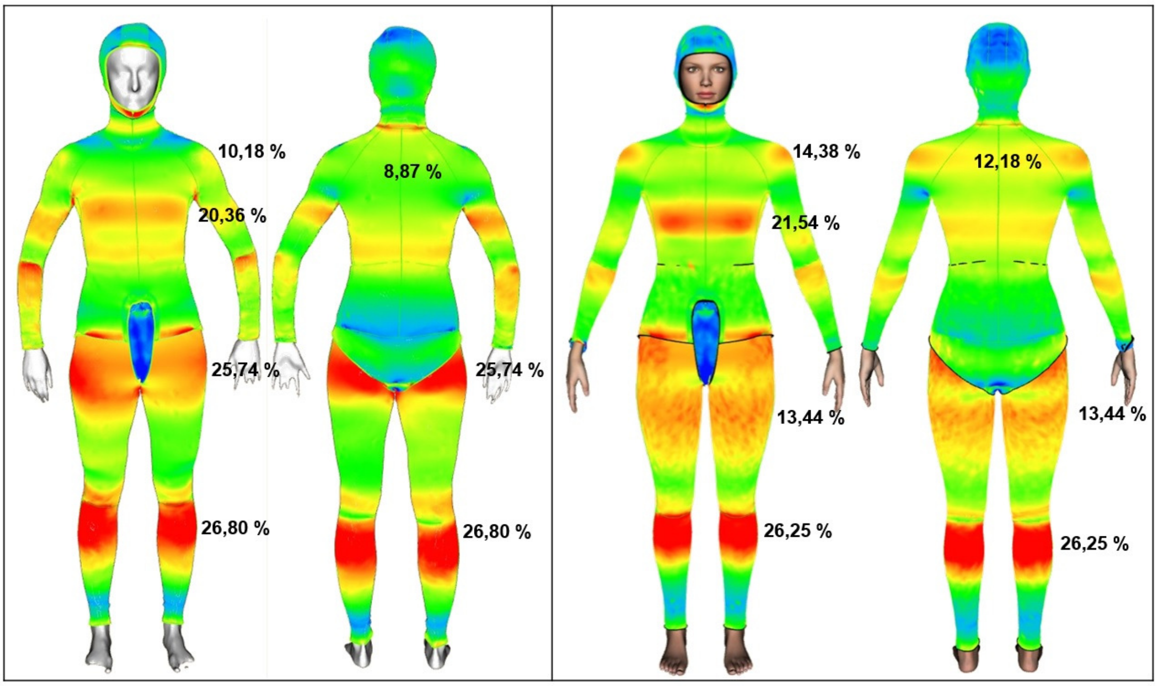

Fig. 13. Computational analysis of the material stretching on 3D prototypes in static position

Due to the limitations in the application of parametric and scanned body models for performing a 3D simulation of a prototype and analysis of stretching in dynamic body postures, we have performed the 3D simulation and computational analysis of stretching only in a dynamic posture with arms spread across. Thereby, critical zone on the shoulders area was determined, due to the unwanted wrinkles that are apearing during the rising arm movement. In that sence, corrections of curved pattern segment sin shoulders area were performed and wrinkles were removed, Fig. 14. After corrections, stretch analysis of diving suit model on back, in dynamic position of arm spread across showed satisfactory fit, Fig. 15.

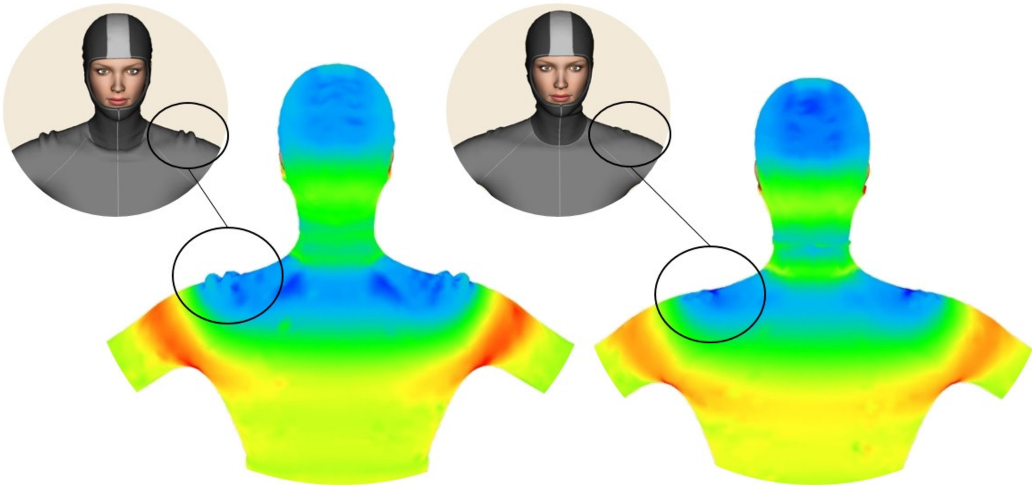

Fig. 14. Prototype simulation in dynamic position – before and after shoulder curve adjustment

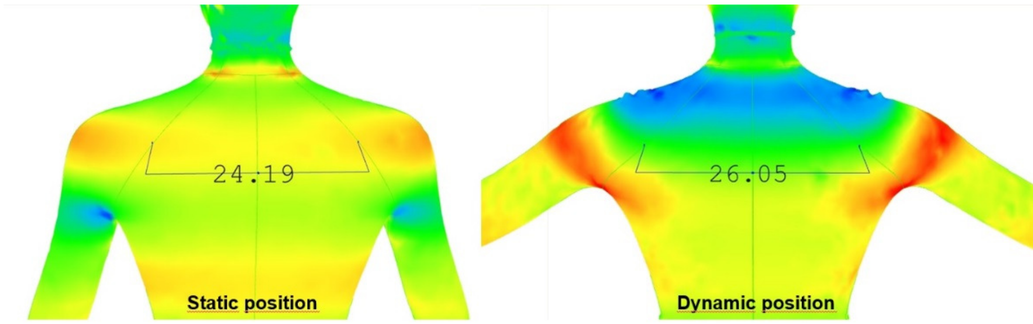

Fig. 15. Computational analysis of the material stretching on 3D prototypes in dynamic position

Final computer-based 3D prototype of diving suit with applied textures and logo is shown in Fig. 16a. For the verification of the whole development process of a computer-based design of a diving suit model, we have produced the real physical prototype, Fig. 16b. The diving suit prototype was tested by the female sportsperson in real conditions of use. In view of the pre-assessment of the patterns and after completing a 3D simulation using the custom parameter and computer-processed 3D scanned body model, the custom parametric body model was chosen for production of the real diving suit prototype.

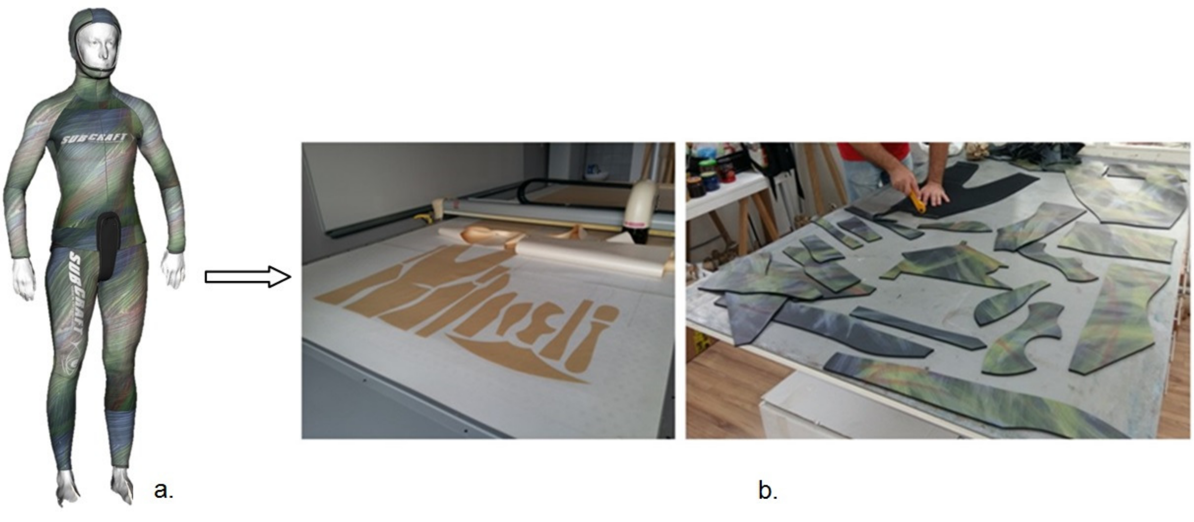

Fig. 16. a. Computer-based 3D prototype; b. production of real diving suit prototype

According to the results of evaluation of the real prototype in terms of wear, by a professional female sportsperson, it can be estimated that the diving suit assures an appropriate fit. Therefore, the methods can be verified as applicable for virtual prototyping and production of tight-fit garments with high demands on fit and functionality, Fig. 17.

a. b. c. d. e. f.

Fig. 17. Verification of real diving suit model prototype by professional female diver, in dynamic body positions: a. Standard ISO 20685; b. D1 position; c. D2 position; d. D3 position; e. D4 position; f. D5 position

4. Conclusions

Purpose of the research was to evaluate validity of 3D scanned and custom parametric body model application, as a starting point for construction of tight-fit clothing where it is necessary to fulfill high demands for clothing fit and functionality. Furthermore, goal was to evaluate precision and overall quality of clothing pattern obtained using 3D flattening method on scanned and custom parametric body model.

Based on the presented results, it is determined that parametric body model in CAD system has limited number of body measurements that can be adjusted and it does not provide complete adjustment according to test subject, but is symmetrical and easier to use. Processed scanned body model represents the identical replica of body surface. However, it is difficult to use scanned body model for 3D construction considering that it is not completely symmetric and is constructed of high density polygonal mesh that defines precise body surface but requires high computational cost. Reduction of polygonal mesh density leads to deviations from real body shape and surface. Parametric body model in CAD system can be customized to match complete surface area value of scanned body model, regardless minor deviations in shape of individual body segments. Model cutting parts analysis also showed positive assesment of 3D flattening method application for obtaining precise cutting parts from custome parametric model and cutting parts of that suit model were used for real prototype production. Finally, material stretch analysis on computer prototype and verification of real garment prototype by professional female diver, confirmed that method enables development of functional model of tight-fit clothing.

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