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3D Virtual Prototyping of Garments: Approaches, Developments and Challenges

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Abstract

The paper deals with the 3D virtual prototyping of garments since they represent an important tool for booth textile and garment designers. It offers simple introduction of changes while developing a model in comparison to conventional techniques, quick response to the costumer's demands and wishes regardless of their location. Moreover, 3D virtual prototyping of garments can successfully replace prototyping processes when the specific garments are designed e.g. garments for people with the non-standard body figure, wheelchair users, sportswear etc. The advantages and disadvantages of virtual prototyping of garments, used processes and methods, as well as the suggestions for new research opportunities on the field of virtual simulation of garments and textile materials are presented.

Keywords: 3D Virtual Prototyping; Ski-jumper Suit; Garments for People with Paraplegia

1 Introduction

Development of new computer technologies, which are closely linked to all of textile fields, ranging from designing and construction of fabrics, to custom made clothes and from virtual fashion shows to e-trading, has been a driving force for this type of progress over the last years. Nowadays, the textile and garment manufacturing companies use virtual reality computer tools to produce digital prototypes of textile forms in order to decrease the manufacturing process and material costs.

Garment virtual prototyping is a technique in the process of garment development. The main purpose of virtual prototyping is to construct a clothing model, which would then be adjusted to the customers' demands and wishes. During the virtual prototyping, process customers and developers of the model are familiarized in details using different computer technologies regardless of their location. Thus, virtual prototyping presents one of the most important links in the chain of manufacturing the garments or other textile products.

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In this article the approaches, developments and challenges used for virtual prototyping of garments simulation are presented. At the beginning, the theoretical backgrounds of computer simulation of textile materials and fabric parameters needed for computer simulation are shortly presented. Further, the paper is focused on presenting the virtual prototyping of regular garments, garments for special applications, such as suits for professional sportsmen and people with the special needs. The advantages and disadvantages of virtual prototyping of garments, used processes and methods, as well as the suggestions for new research opportunities in the filled of virtual simulation of garments and textile materials are presented.

2 Computer-Based Simulation of Textile Materials and Garments

Virtual garment simulation is result of a large combination of techniques that have evolved during the last decade. A number of simulation methods have been presented having different goals, such as accurate physical simulation of cloth draping over objects, realistic clothing of virtual 3D character models or generation of fast visually-pleasing cloth animation for applications needing (soft) real-time performance [1, 2]. Fabric modelling presents an important field in garment virtual prototyping because the realistic behaviour of a garment in virtual environments mainly depends on developed computer-based fabric models. Moreover, with computer fabric models, the researcher can study mechanical and physical properties of the fabric in virtual environments. This mean an opportunity for the development of textile materials depending on suitable testing methods. Fabric modelling techniques within the computer graphic community are classified into three categories [3-5]: geometrical, physical, and hybrid models.

Geometrical models were the first techniques to be used in computer graphics for fabric simulation. The main interest of the used geometrical models for fabric simulation application is to have a computationally efficient and highly controllable model, which can perform the simulation well within certain predefined fabric behaviour. Using the geometrical models only the geometric shapes are displayed, and no material properties of the objects are taken into consideration. In addition, it is very difficult to represent with the geometrical models some special deformations, such as wrinkles and various sizes of folds [4]. The physical-based models for modelling the fabric deformation are based on the structures and properties of cloth materials [3]. The hybrid models are constructed by the combination of the physical and geometrical-based methods, therefore they present great challenges with consequences for development of computer technologies in modelling deformations of highly flexible and complex materials, such as a piece of fabric [6].

2.1 Fabric Parameters for Computer Simulation

For computer simulation, the fabric should be described with a set of parameters, such as the imposed deformations, constraints, or force patterns to define the fabric behaviour that occur in some applications. The mechanical behaviour of fabric is inherent to the nature and depends on fabric compositions, raw materials of yarns and finishing process during the manufacturing. The properties of the fabric have very deformable characteristics, therefore for computer simulation should be taken into account [7]: elasticity, which characterizes the internal forces resulting from a given geometrical deformation, viscosity, which includes the internal forces resulting from a given deformation speed, plasticity, which describes how the properties evolve according to the deformation history and resilience, which defines the limit, at which the structure will break.

3 Virtual Prototyping of Garments

3.1 General Approach for Virtual Prototyping of Garments

The general process of 3D virtual prototyping is presented in Fig. 1.

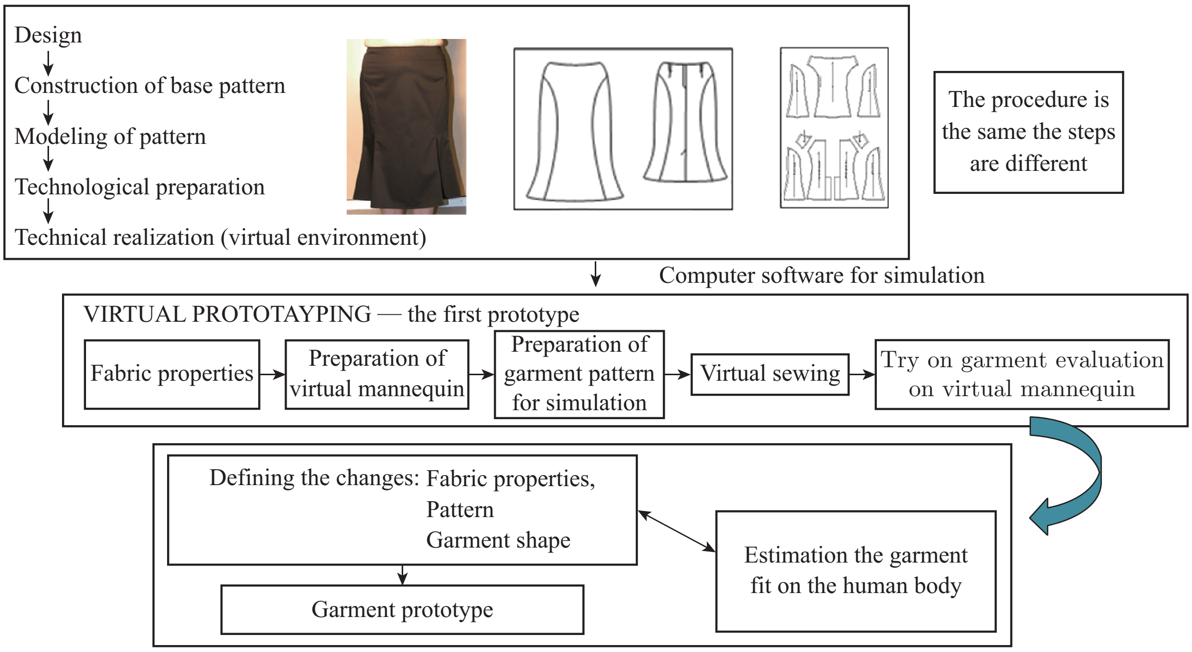


Fig. 1: Representation of a 3D virtual prototyping process [8]

Clothing fit to the body is and will be the most important consideration for the customers in making apparel purchasing decisions. Moreover, the evaluation of clothing fit to the body of a virtual prototyping model in a virtual environment is an important communication message, and in the future, it will be the irreplaceable part of new advanced technologies for design studios, for manufactures to develop the garment prototypes and retailers for presenting the garment models to the customers. The evaluation process of garment fit for virtual simulated and real prototype of woman's skirt and jacket can be the same and provided by the following procedure [8]:

- Selection of the jacket or skirt style.
- Selection of the evaluation area on the jacket or skirt (Fig. 2).
- Assessment of a jacket and skirt fit to the body model using the following criteria grades: 1 (good), 0 (satisfactory) and −1 (inappropriate).

For assessing the woman's jackets and skirts parametric and scanned digital body models, as well as a real female body were used. The parametric model was selected from the base of different virtual parametric models of the human body, offered by the program OptiTex [9]. Parametric

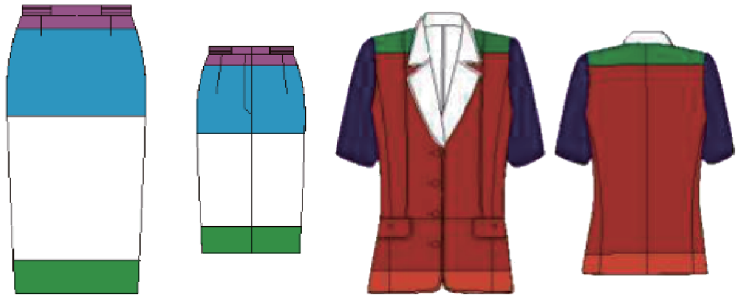
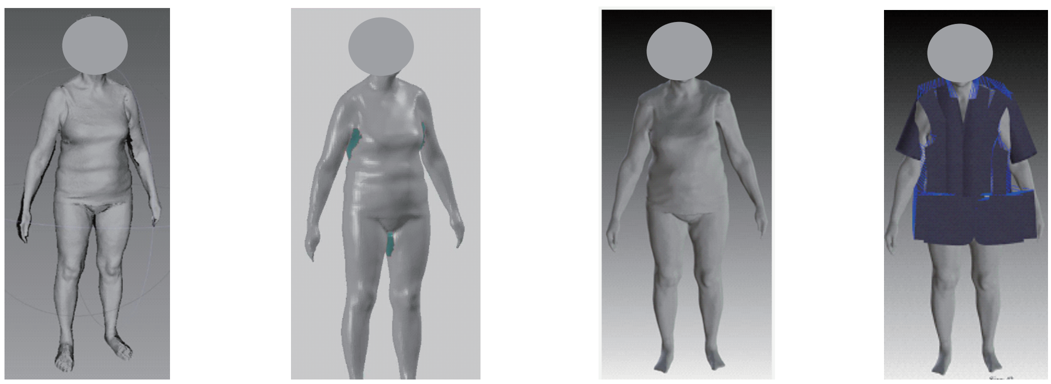


Fig. 2: The evaluation areas of skirt and jacket (front and back views) [8]

model has defined basic and the supplementary body measurements according to the real body measurement for woman's body size 42. For virtual simulation the fabrics properties were defined with the following characteristics: tensile, bending, shear, and surface thickness using the FAST measuring system in order to obtain their realistic behavior in a virtual environment [10].

Virtual body scan was obtained with a 3D scanner Vitus Smart 3D at the Faculty of Textile Technology, University of Zagreb, Croatia. The scanned human body was suitable for further analysis after the reconstruction phase performed with the following computer programs: MeshLab, Blender and Atos [11]. The final 3D body model was imported into the OptiTex PDS program for the simulation of virtual garments, Fig. 3 [8].

Example of the real and virtual prototypes of the jacket and skirt is presented in Fig. 4.



(a) After scanning (b) After reconstruction (c) Imported in OptiTex PDS (d) Virtual simulation of a garment

Fig. 3: The process for preparing the scanned body model [9]

Based on evaluation of textile experts it can be concluded:

- Differences in the jacket's and skirt's fit to the scanned body model depend on the construction of the jacket and characteristics of the body model.
- The scanned body model was perfectly compatible with the real body. This showed also the assessment of the jacket's and skirt's fit to the real and scanned 3D body models.
- The parametric body model only approximates the real body model. Namely, the adjusted dimensions of the virtual body model were proportional, therefore, do not provide satisfactory real image of the body figure.

(a) (b) (c) (a) (b) (c)

Fig. 4: Fit results for the jackets and skirts on (a) real, (b) scanned and (c) parametric human body

- Virtual prototyping of garments still cannot fully replace conventional prototyping. There are many unresolved technical solutions for simulations that are related to the parametric body figure and their presentation in a virtual environment, the properties of textile materials and preparation procedures for simulation.

- Estimation of a garment fit to the body is very difficult, because we cannot eliminate the subjective effect of individual evaluators.

3.2 The Ski-Jumpsuit

The ski-jumping is one of the most successful sport disciplines nowadays in Slovenia. Apart to very good developed jumping techniques the successfulness of sportsmen depend also on jumpsuits. The size and shape of the ski-jumper suit should be adapted to the individual body measurements of each jumper according to the requirements of FIS (Fédereation Internationale de Ski). FIS requirements vary annually or even more frequently in order to ensure the highest security level for ski-jumpers. For easy and proper development of the ski-jumper's suits according to the FIS requirements to human body silhouette the virtual prototyping process is a very promising techniques [12, 13].

The development of the ski-jumpsuits in the virtual environmental was based on two virtual body models (parametric and scanned) and further compared with the real one. For all models the same patterns and fabrics were used. The virtual prototyping of ski-jumper suits had the following phases: pattern construction of ski jump suits, testing the mechanical properties of fabric, adopting the 3D parametric model according to human body dimensions, scanning the human body, virtual simulation and evaluation of the fit of ski-jumper suits to the body (scanned, parametric and real), Fig. 5. For virtual prototyping of ski-jumper suits the Optitex program was used.

(a) (b) (c) (d)

Fig. 5: Ski-jumper suit; (a) virtual prototype on parametric human body model; (b) virtual prototype on scanned human body model, (c) prototype of a ski-jumpsuit; (d) professional ski-jumpsuit

When evaluating the fit of the jumpsuit the estimation of the neckline, shoulder area and armpit front and back, as well as form of the sleeves, trousers and waist area were carried out.

The neckline on the virtual model is after simulation extended when compared with the real prototype. Difference arises because of the draping of the laminate in the neck area on a parametric virtual mannequin. The real jumpsuit has the neckline made with non-elastic band, Fig. 5(d).

When comparing the simulated jumpsuit on the scanned human body model and real jumpsuits in the waist area, an additional fold in the area of waist and buttock area appears, Figs. 5(b) and 5(c), while it is not visible when simulating the ski jumper suit on a parametric 3D body model, Fig. 5(a). The appearance of the bottom part of the simulated ski-jumper-suit on a parametric body is smooth and gives us the filling of tension and discomfort, Fig. 5(a). Further, the real jumpsuit and simulated jumpsuit on a scanned 3D body model of the ski jumper expresses non-stretched trousers and assures felling of a good comfort, Figs. 5(b) and 5(c).

The form and fit of the sleeves are very similar on all of prototypes with the exception regarding the shoulder and armpit area, because of the anomalies of the parametric mannequin. Additional folds on sleeves appear in elbow area. These are visible on real and simulated jumpsuit on scanned 3D body model, while they are not visible on a parametric body model because of the stretched arms.

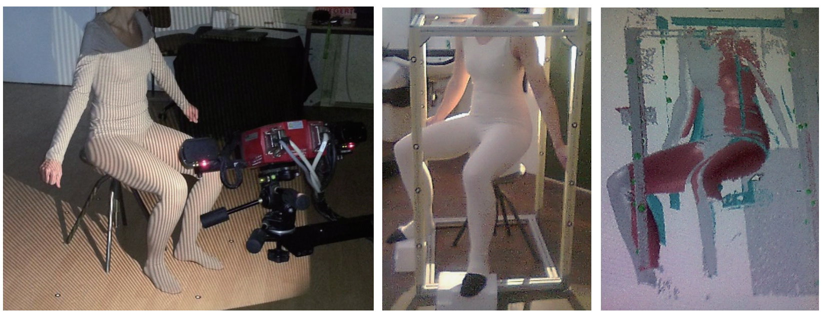
The comparison among the ski-jumpsuit on the parametric 3D body model and scanned 3D body model resulted in the following conclusions:

- The best matching have prototypes of the ski jumper-suits on a scanned and real human body. The appeared differences between them are because of determination of mechanical properties of the laminated fabric and seam properties in a virtual environmental.

- Parametric body model does not present a precise simulation of real human body. For ski-jumpers it is very important that the suits fit completely to the body according to the FIS requirements.

3.3 The Garments for People with Paraplegia

The sitting position in everyday life is very common. Those garments worn by those disabled persons who are bound to a sitting position throughout life are especially important. These include paraplegics whose restricted movements are due to paralysis of the lower limbs and restrict them to a wheelchair. Garments for a sitting position must be adapted to the particular needs, body dimensions and postures of each individual in such a way to provide ergonomic comfort in a sitting position. In addition, they must meet functional requirements during wearing and that do not cause additional health problems to paraplegics, e.g. skin irritations, pressure sores, obstruction of the blood flow etc. Moreover, the garment for paraplegic people should assist them to improve their quality of life and due to their higher self-images, their garments should have good aesthetic and fashionable appearance for integrating them within the society [14]. Commercial 3D CAD systems for virtual prototyping are limited to a standing posture of a 3D human body model. Its body shape could be adapted to healthy individual's body measures and therefore useless if there is a need to construct individualized garments for people with limited body abilities, caused by several forms of injuries, diseases, and amputations. For this reason, research regarding the scanning of humans was performed in a sitting position by using the 3D human body laser scanner Vitus Smart XXL and two general-purpose optical scanners (GOM Atos II 400 and Artec™ Eva 3D hand scanner) [15, 16]. Fully mobile individuals were involved in this study to avoid unnecessary burdening of paraplegics in this stage of the research. A scan time of the whole body with Vitus Smart XXL was approximately 10 seconds, while when scanning with optical scanners a scan time was approximately 4 minutes. Namely, scanning of the subjects with these scanners was performed from different angles and heights in order to digitize a complete body and each scan was polygonised into an independent mesh. In addition, when scanning with GOM Atos II 400 optical scanner a special frame with handles was developed, which was marked with reference points to facilitate the scanned data processing into a common coordinate system, Fig. 6(a). The sensor unit projects four times indented fringe patterns onto the scanned subject, which are then recorded by two cameras. Each single measurement it generates up to 4 million data points. The scanner records only those points visible by both cameras in a single scan. The scanning was performed by using the measuring volume of 1200×960×960 mm (LxWxH). Measuring point distance was 0.94 mm and 6 mm projector lens and 8 mm camera lens were used.



(a) GOM ATOS II 400 optical scanner

(b) Artec Eva 3D hand scanner

Fig. 6: Scanning of humans in a sitting position

Scanning with Artec™ Eva 3D hand scanner is similar to recording a movie with a video camera, Fig. 6(b). Compared with the Atos scanner, Artec does not require marking with reference points for alignment of the scans; they can be significant points on the body. These main problems related to the scanning procedure regardless the type of a scanner were indicated: (a) body movements regardless of the scanning time, which can't be avoided, and (b) scanning of the areas below the knees, armpits and crotch. The research works showed the great potential of the used general-purpose 3D optical scanners for digitizing of the human body in a sitting position, because a greater surface area of the body can be scanned compared to the conventional human body 3D laser scanner.

Based on the gained experiences and knowledge on poor balance of paraplegics when sitting, the chair for scanning of the paraplegics was developed in order to digitize them with Artec Eva 3D optical hand scanner [17]. The developed chair is vertically adjustable and has handles for legs, arms and head that can be adapted to different body heights and widths. The chair can be disassembled in order to be transferred to any scanning place, Fig. 7. By using the handles, a person keeps the body in the same posture during the whole scanning procedure. During the scanning using Artec Eva 3D optical hand scanner the chair was revolving to digitize the whole body as one scan.

Fig. 7: The chair for scanning of paraplegics with Artec Eva 3D optical hand scanner

Research regarding the development of the adapted garments for paraplegics by using the virtual prototyping was carried on the scanned 3D body models of paraplegics [17]. It was based on interviewing and discussions with a group of paraplegics and individual discussions. Results showed that the adapted clothes for them should be designed according to the individual's requested needs and wishes regarding the ergonomic and functional clothes that do not cause additional health problems to them, and have good aesthetic appearance. Men pointed out that they had most of the problems with pants and jackets, while women exposed the need for adapted dress and blouse. For each type of the garment, general specific requirements for a sitting posture were researched, whilst during the development of garment for a particular paraplegic person, its specific requirements with respect to its health problems were also taken into account. The development of the ergonomic garments pattern designs for a sitting position was based on body dimensions measured on scanned 3D body models of paraplegics and by using the virtual prototyping. The real prototypes of the garments were sewn without their trial fit on real persons, which is also a purpose of virtual prototyping. Clothes were given then to paraplegics for testing. Their positive satisfaction with the developed adapted clothes to a sitting posture and their needs showed that virtual prototyping is extremely suitable for the development of made-to-measure garments also for the wheelchair users. The examples of virtual 3D simulations of the adopted garments to a sitting posture on scanned 3D body models and garments' real prototypes are shown in Fig. 8.

Fig. 8: Virtual 3D simulations of the adopted garments to a sitting position on a scanned 3D body models and garments' real prototypes

3.4 Sport Suits for People with Special Needs

The next approach on the virtual prototyping for people with special needs involves an adaptive 3D body model to different body postures that was built based on designed kinematic skeleton construction [18, 19]. The developed kinematic skeleton was intended for adoption of the static 3D body model. Hierarchical skeleton was constructed using the Blender program and the tool "Armature Modifier". It had 20 bones and 15 joints in a standing posture, which enabled the change of body postures, Fig. 9. Within this research, the suitability of the developed adaptive 3D body model for virtual prototyping of garments for people with limited lower limbs ability was presented by using the OptiTex 3D and Marvelous Designer software systems. The right picture on the Fig. 9 presents a standard sitting posture of the wheelchair user (P1).

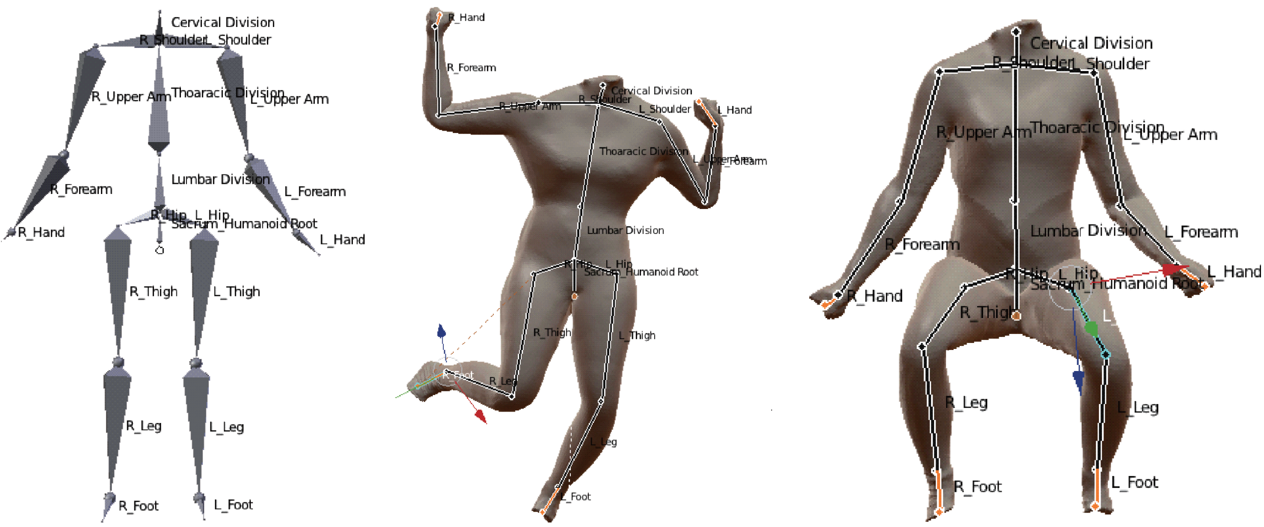


Fig. 9: Kinematic skeleton construction and adapted 3D body model postures (on right: posture 1 – P1)

Figure 10 presents examples of use of adaptive 3D body models to a wheelchair-racer (posture 2 – P2) and a wheelchair tennis player (posture 3 – P3) for virtual prototyping and engineering of the sports garments for people with special needs, which should provide high comfort and allow unrestricted movements during sports activities [19].

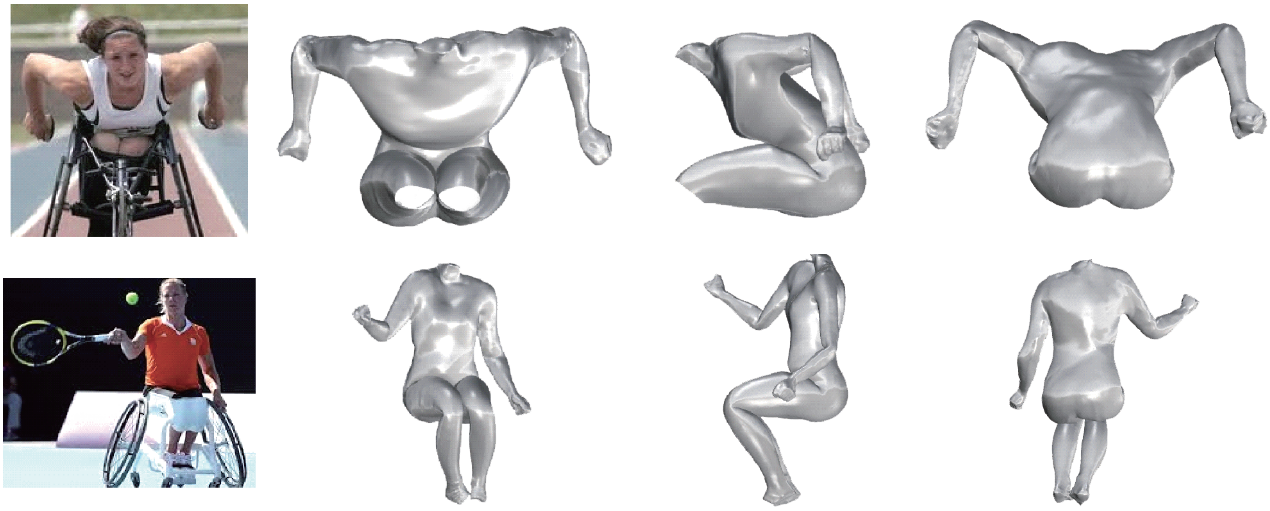


Fig. 10: The adapted 3D body model postures in a sitting position

The sport T-shirts' fitting to the 3D body models by using the visualisation tool of the OptiTex 3D system (tension and stretch deformations in both course and wale directions) were examined depending on the fabrics mechanical characteristics (code KF1 and KF2) and garment pattern designs (inserted sleeve and raglan sleeve). The basic properties of used knitted-fabrics are represented in Table 1, their mechanical properties in Table 2 and T-shirt pattern designs in Fig. 11.

The knitted-fabrics' mechanical parameters (extensibility, bending rigidity, shear rigidity, compression) were determined by using the FAST measuring system. Necessary extensibility for the

Table 1: Basic properties of the knitted-fabrics

Fabric code	Raw material	Knited-fabric density		Fabric weight gm^{-2}
		Wales d.	Courses d.	
KF1	85% PA 6, 15% Dorlastan	22	80	50
KF2	73% PA 6, 27% Lycra	22	156	95

Table 2: Mechanical properties of the knitted-fabrics, measured by FAST measuring system

Measured properties	Direction	Unit	Knitted-fabric	
			KF1	KF2
Extensibility	Wales	%	/	/
	Courses	%	/	/
Bending rigidity	Wales	μNm	0.3	1.6
	Courses	μNm	0.6	1.2
Shear rigidity	/	Nm^{-1}	17	46
Surface thickness	/	mm	0.054	0.047
Surface mass	/	gm^{-2}	50	95

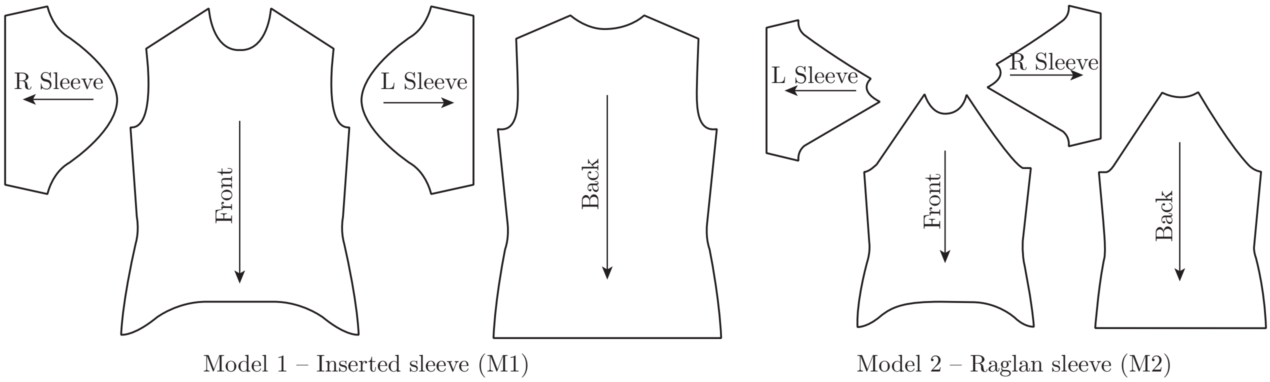


Fig. 11: Sport shirt 2D pattern design

garment simulation was measured at tensile load of 98.07 Nm^{-1}. Since the knitted-fabrics' extensibility exceeded the measuring range of 20%, the knitted fabrics' stretch of 23% was used from the fabrics' list of the OptiTex program for a similar knitted fabric.

The fitting of two sport shirts pattern designs (M1, M2) to a sitting 3D body model in different postures (P1, P2, P3) was investigated with respect to the mechanical properties of the used knitted-fabrics. In addition, garment fit was investigated by using the Tension Map of the OptiTex PDS in order to estimate the fit on different 3D body models due to fabric's mechanical characteristics.

Fig. 12 presents the influence of the mechanical properties of the knitted fabrics on fit of the

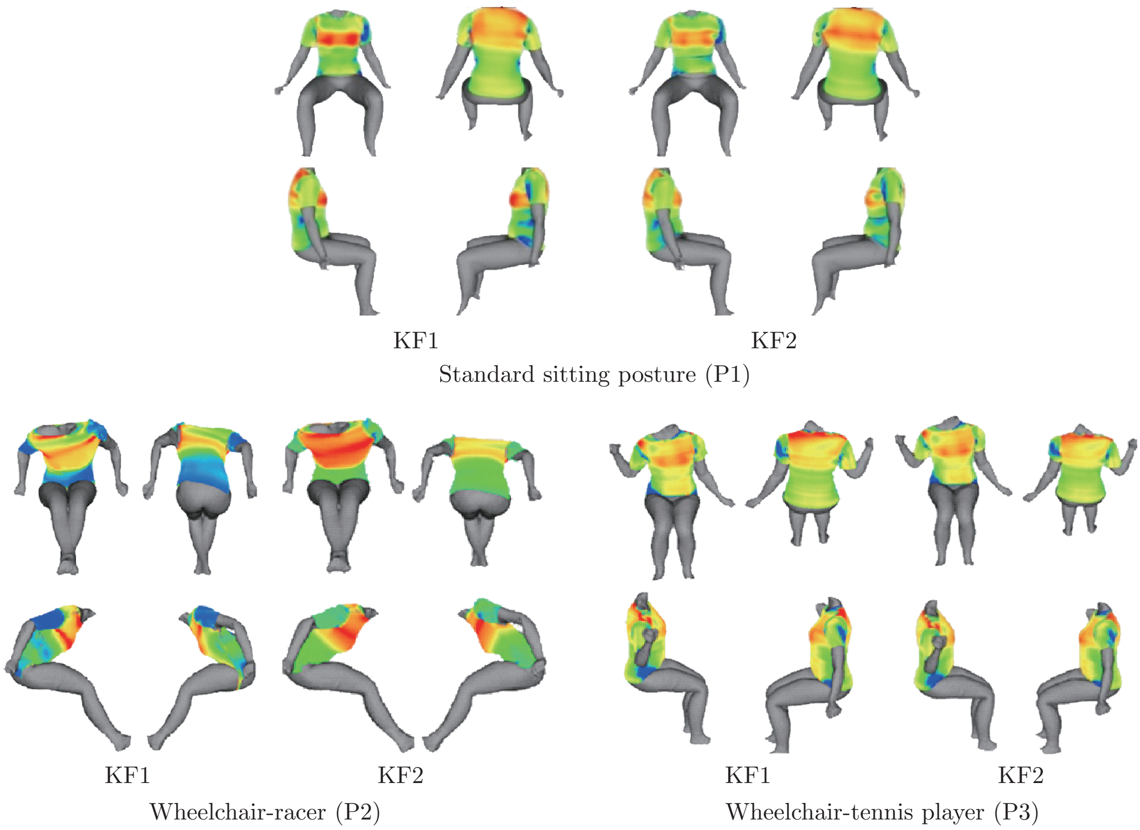


Fig. 12: Influence of the mechanical properties of the knitted-fabrics on the T-shirt fitting (M1) on a sitting 3D body model in different postures

T-shirt (M1) regarding the sitting 3D body model in different postures. The fit of a T-shirt model with the raglan sleeves on the adapted 3D body model of a wheelchair-racer and wheelchair-tennis player is presented. Fig. 13 for the knitted fabric KF1.

Fig. 13: Fit of a T-shirt model with the raglan sleeves on the adapted 3D body models for the knitted fabric KF1

There are some obvious differences in tension maps of both garments on 3D body models in different postures. They are caused by the differences in structural and physical/mechanical properties of the applied knitted-fabric, and also by garment pattern design and 3D body model complexity. The results of this investigation showed that we can analyse the impact of textile materials' parameters on behaviour/tension loads of virtual garments also when using sitting and adapted 3D body models and, consequently, to develop the well-fitted garments for the non-standard body figures and postures. Furthermore, this can serve as a basis for engineered projection/planning of textile fabrics and garments to be produced.

4 Conclusions

Advanced computer-based garment simulation techniques already represent an important tool for textile and garment designers, since they offer numerous advantages, such as quick and simple introduction of changes while developing a garment model in comparison with conventional techniques. The primary advantage of virtual prototyping is that we can design garments while directly monitoring their fit to the silhouette of a specific person without his or her physical presence. Thanks to latest developments, this technology will be widely used in the near future for implementation in daily tasks. This will have an immense effect on different modules in the clothing industry with its related branches and can be seen as a way to move a very traditional industry to a higher level. Computer-based prototyping has a great potential in modern clothing industry because it allows rapid development of 3D virtual garment prototypes. In a small number of process steps, we may change patterns, colors, fabric types and other parameters that influence the appearance and behavior of clothing products.

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