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Evaluation of a Garment Fit Model Using AHP

Abstract
Garment fit on a body model is an important factor for designing comfortable, functional and well fitting garments. Nowadays the virtual prototyping of garments provides high potential for design, product development and marketing processes. Previous examinations of garment fit to the body in a real and virtual environment were merely focused on expert evaluation by way of a descriptive comparison of proper and improper areas for fitting. Therefore the problem area in our research was to examine the fit of a skirt on a live model and on virtual models such as parametric and scanned body models in order to propose which virtual human body is the most suitable where garment fit is concerned. The paper also discusses the fit of a skirt on an individual part of the human body with respect to predefined areas. A numerical study with a questionnaire survey database was conducted with the aim of selecting the best model to assess the fit of a skirt to the human body, and the Analytic Hierarchy Process (AHP) was used to evaluate the questionnaire results. The results obtained confirm that the design is most important factor when evaluating a skirt's fit to the body. Furthermore results confirmed that the hips and abdomen areas were the most important for evaluators when assessing as kirt's fit to the body.

Key words: *garment fit, parametric model, 3D scanned model, analytic hierarchy process (APH).*

Introduction

Fitting a garment to body contours is one of the key properties besides the design and quality of the fabric used and evaluated by the end-user. As a garment is composed of different materials, the final garment fit depends on the interaction of its parts as well as on the body silhouette, pattern construction and fashion trends. There are many definitions of the garment fit [1], some of which define garment fit as:

- 'Fit is defined as the ability to be the right shape and size' - *The Oxford Dictionary* [2].
- 'Clothing which fits, provides a neat and smooth appearance and will allow maximum comfort and mobility for the wearer' - Shen and Huck [3].

Irrespective of definition, garment fit to the body is generally discussed from an aesthetic and functional point of view. From the aesthetic point of view, garments fulfil the fit criteria according to the wishes of fashion trends. From the functional point of view, clothing fit is mostly observed with respect to clothing comfort [1, 4 - 6].

Evaluation of garment fit to the body could be done on a live, scanned or parametric human body model. However, the assessment of garment fit to the body should be the same for a real and virtual garment [7]. A live model can be any human being irrespective of gender, age, and body construction. In a virtual environment the body can be presented as a parametric and scanned body model on the basis of body measurements and silhouette of a live human being. A scanned body is obtained by using 3D body scanners and presents exactly the same 3D form as a real human body. 3D body scanning has some limitations that are the subjects of many researches nowadays [8 - 11]. A parametric human is a digital human body model generally based on user-specified body size inputs and it is mostly integrated into CAD systems for garments such as Gerber [12], Lectra [13], Assyst-Bullmer [14] and Optitex [15].

In general, garment fit depends of the human body position, body measurements and properties of materials applied and clothing design [3, 16]. The clothing fit to the body could be evaluated subjectively and objectively. Normally, in a real environment, the clothing fit is assessed subjectively on a live model or dress forms (dummy) using several methodologies and standards for subjective evaluation of the clothing fit to the body [1]. Advantages and disadvantages of fitting standards for live and dress forms are listed in ***Table 1*** [1].

Moreover different procedures have been developed in order to set the subjective evaluation of clothing on a live model. Huck et al. developed an exercise protocol and wearer acceptability scale of garment fitting which might be required in a work environment where garments shape chancing and stretching in different positions [17]. The fit evaluation scale [18] contains 25 items in three categories: overall fit, bodice front fit and bodice back fit. For each item, nine responses were possible, ranging from 'much too tight' to 'much too loose', evaluated for men`s jackets [17]. A five-point scale was developed for expressing agreement and disagreement regarding garment fit to the body [19]. The company Cadmodelling

Table 1. *Advantages and disadvantages of fitting standards.*

Fitting standard	Advantage	Disadvantage
Live model	Real body shape	Subjective and qualitative
	Real movement	Psychological interruption
Dress form	Static and convenient to use	Subjective and qualitative
	High repeatability	Personal assessment of tension

Ergonomics s.r.l. developed an apparel fit dummy Formax®, which is based on international scans and represents proper fit verification tools ensuring accurate fitting and quality control tests of a garment [20].

In this context, researchers in the field of clothing engineering are focusing more and more attention on the development of the virtual prototyping of garments. Research works addressing the garment fit of sportswear for professional purposes to the parametric body model and scanned 3D body model show significant differences between virtual garments' fits to body models and the successfulness of virtual prototyping using the scanned 3D body model [8, 9]. Previous examinations of garment fit to the body in a real and virtual environment were similarly based and merely focused on an expert's view regarding the descriptive comparison of proper and improper fitting areas [21, 22]. The comparisons were made only for some critical areas on the garment, respectively.

Furthermore evaluation of the garment fit to the body in a virtual environment is an important communication message, and in the future it will be an irreplaceable part of new advanced technology for design studios, for manufacturers to develop garment prototypes and for retailers for the presentation of garment models to customers. Garment fit to the body is and will be the most important consideration for customers in making apparel purchasing decisions [23].

Since besides a living human body parametric and scanned models are available in a virtual environmental, we focused our research on investigation of which human body is the most suitable where garment fit is concerned. We used the Analytic Hierarchy Process (AHP) [24] in order to find the right answer, which is a multi-criteria decision making method that was originally developed by Prof. Thomas L. Saaty [25]. It is a method to derive ratio scales from paired comparisons, and it is used for analysing complex decisions based on mathematics and psychology. The input can be obtained from actual measurement or from subjective opinion such as satisfaction, feelings and preference. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. Basically the method uses the following structure: problem modelling, weight valuation,

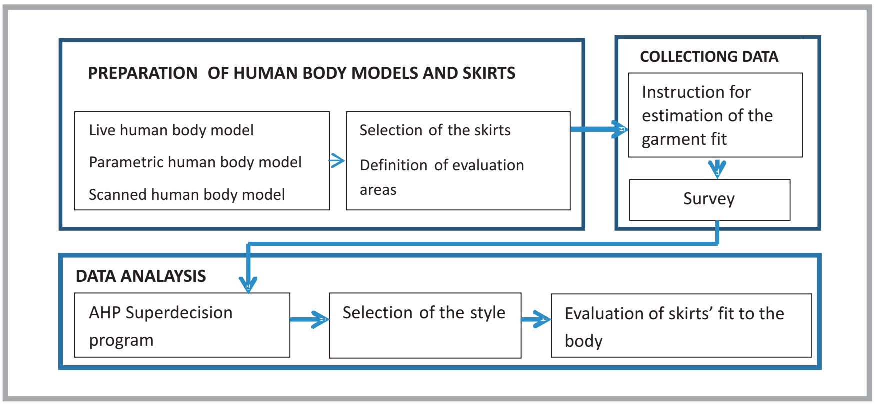
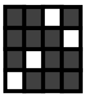
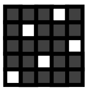


Figure 1. *Research model for garment fit.*

Table 2. *Skirt styles with corresponding basic characteristics of fabrics used.*

Fabric code	Type of weave	Fabric composition, %	Yarn density, yarns/cm		Yarn liner density, tex		Surface mass, g/m²
			Warp	Weft	Warp	Weft	
F1	 Twill	85% linen 15% polyamide	42	23.5	2.5	40	113
F2	 Satin	98% cotton 2% elastomer	84	33.5	12	15	164

weight aggregation and sensitivity analysis. The AHP procedure has been mainly used for industrial engineering applications and decision making processes such as integrated manufacturing systems, technology investment decisions, flexible manufacturing systems, and selecting optimal parameters in engineering problems [26 - 35]. There have been many studies in literature concerning decision making in many different sectors and areas, but until now there have been no studies on the evaluation of clothing fit to the body using the AHP process.

Therefore AHP was selected as a new and promising tool to find the most proper model for evaluating garment fit to the body. More over for the first time this study presents differences between live, parametric and scanned human bodies, and underlines the importance of the virtual presentation of garments. The paper also discusses garment fit on individual parts of the human body with respect to predefined areas.

Experimental part

The study focused on which model is the most suitable for presentation of a skirt's fit to the body. For the research a live body model in a real environment as well as parametric and scanned 3D body models in a virtual environment were used. The fit was studied using classical women´s skirts with body measurement for body size 42. A numerical study with a questionnaire survey database was conducted and the Analytic Hierarchy Process (AHP) [25] used to evaluate the results. The research model designed is presented in ***Figure 1***.

Styles and materials

Three women's skirt styles were designed and produced from fabrics suitable for upper garments for assessing the skirts' fit and establishing the most suitable model for presentation of garment fit to the body, ***Table 2***. Skirt styles 1 and 2 were made in the same design but from different fabrics, while skirt style 3 was made from the same fabrics as for Style 1, but its design was different, ***Table 3***.

The patterns were made using the OptiTex CAD system [16] and sewing of the skirts was performed in real garment production. The real/live model was a woman of middle age. A parametric 3D body model was obtained using the OptiTex PDS program [15] based on body measurements of a real woman determined by a 3D body scanner.

Table 3. Skirt styles with corresponding fabrics.

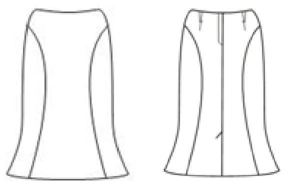
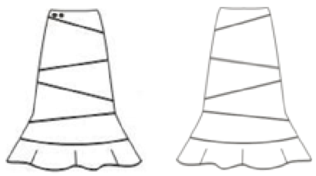
Sketch of styles developed	Style code	Fabric code
 Front Back	Style 1	F1
	Style 2	F2
 Front Back	Style 3	F1

Table 4. Mechanical properties of fabrics applied.

Fabric code	Extension at a load of 98.1 Nm^{-1}, %		Bending rigidity, μNm		Shear rigidity, Nm^{-1}	Surface thickness, mm
	Warp	Weft	Warp	Weft		
F1	2.6	2.2	3.0	16.2	11.5	0.179
F2	1.9	3.5	9.4	4.7	48.2	0.145

A scanned 3D body model was obtained using aVitus Smart 3D body scanner and ScanWorx V 2.7.2 software package. The process of generation of the scanned 3D female body model involved body reconstruction as the 3D scanner cannot produce sufficient scan data, which results in a defective body model. For this reason, reconstruction of the scanned 3D female body model was performed by using Atos [36], Blender [37], Rhino 4 [38], Netfabb [39] and MeshLab programmes [40]. The 3D body models scanned and reconstructed were imported into the OptiTexPDS programme for simulation of virtual women's skirts.

Fabric properties for virtual simulation for both parametric and scanned models based on measurements of mechanical properties of the fabrics by using the FAST measuring system [41], ***Table 4***.

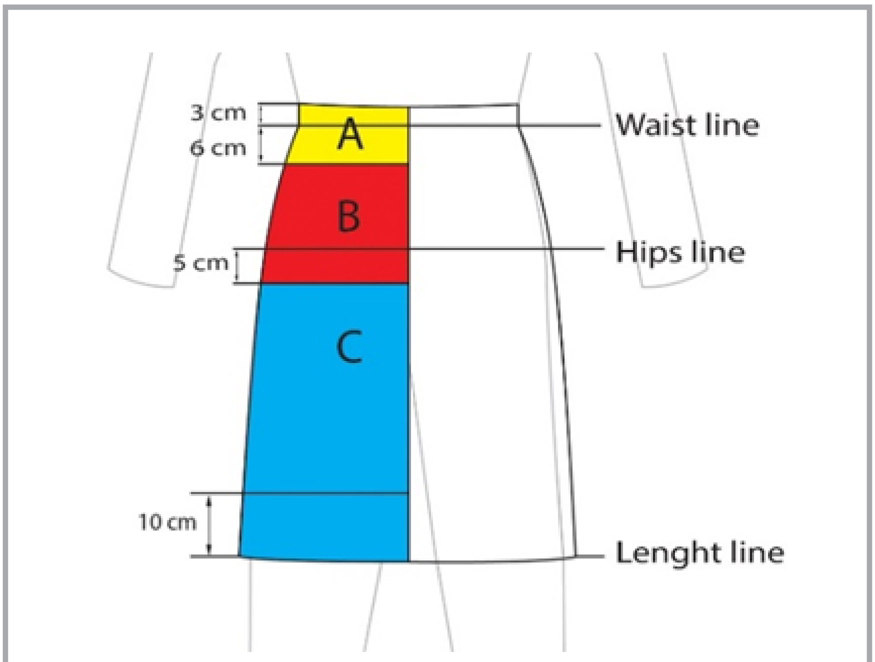


Figure 2. Evaluation areas of a skirt.

The appropriate appearance (colour, texture) of the virtual textiles, respectively, was achieved by scanning the textiles.

Definition of evaluation areas

For evaluation of the fit of real and virtual skirts to the human body, three specific areas (A, B and C) were defined valid for all skirt styles (***Figure 2***) according to the front, side and back view.

Selection of the evaluation areas resulting from construction rules for the pattern making of skirts was under taken Body measurements of the waist, hips and length line are the basic ones needed for constructing the pattern and defining the allowance for comfort of a skirt. The width of the evaluation areas was determined on the basis of previous experiments on the requirements of users for subjective evaluation of a skirt's appearance on the human body. Thus, irrespective of the skirt`s design, the users always estimated the appearance in the area around the waist, hips, abdomen and length. Waist area A is around the waist line and includes 3 cm up to the waist line and 5 cm below. The hips and abdomen area B was defined between evaluation areas A and C. The length of area C was defined from 5 cm below the hip line until the length of the skirt. Evaluators paid particular attention to the area around the length of the skirt from 10 cm up to the edge.

The evaluators took into account the following instructions for the front, back and side views for estimation of garment fit in predefined areas: in the waist area they observed if the level of the skirt waist is on the line of the waist of the human body, on the hips and abdomen

Table 5. Fundamental scale for making judgments [25].

Insensitivity of importance	Definition
1	Equal
2	Between Equal and Moderate
3	Moderate
4	Between Moderate and Strong
5	Strong
6	Between Strong and Very Strong
7	Very Strong
8	Between Very Strong and Extreme
9	Extreme

level the transverse or longitudinal folds, and in the length area the wrinkling and straight line of the skirt's length.

Garment fit evaluation procedure

The Analytic Hierarchy Process (AHP) is a decision technique to solve complex and unstructured problems with multiple attributes [25, 33]. Matrices of pairwise comparisons are formed either by providing judgments to estimate dominance using absolute numbers from the 1 to 9 fundamental scale of the AHP, or by directly constructing pairwise dominance ratios using actual measurements [25]. The AHP establishes priorities from paired comparison judgments of the elements of the decision with respect to each of their parent criteria. As an evaluation scale, Saaty's scale of 1 - 9 will be used, as shown in ***Table 5.***

The results were evaluated according to the main criteria defined: "Selecting the best model to assess a skirt's fit to the human body". The skirts' fit were subjectively assessed by 63 estimators, textile experts working in different textile areas. The skirts on human bodies were presented to the evaluators using the projection of graphics; the evaluators had been informed about the evaluation procedure in detail. On the other hand, the Analytic Hierarchy Process (AHP) is a multi-criteria decision making method for deriving ratio scales from paired comparisons that can be used for analysing complex decisions. The AHP procedure's internal decision making mechanism and its function operate without the influence of a human being, and therefore it can be stated as an objective method. Our method for

Figure 3. *Fitting results for skirt style 1.*

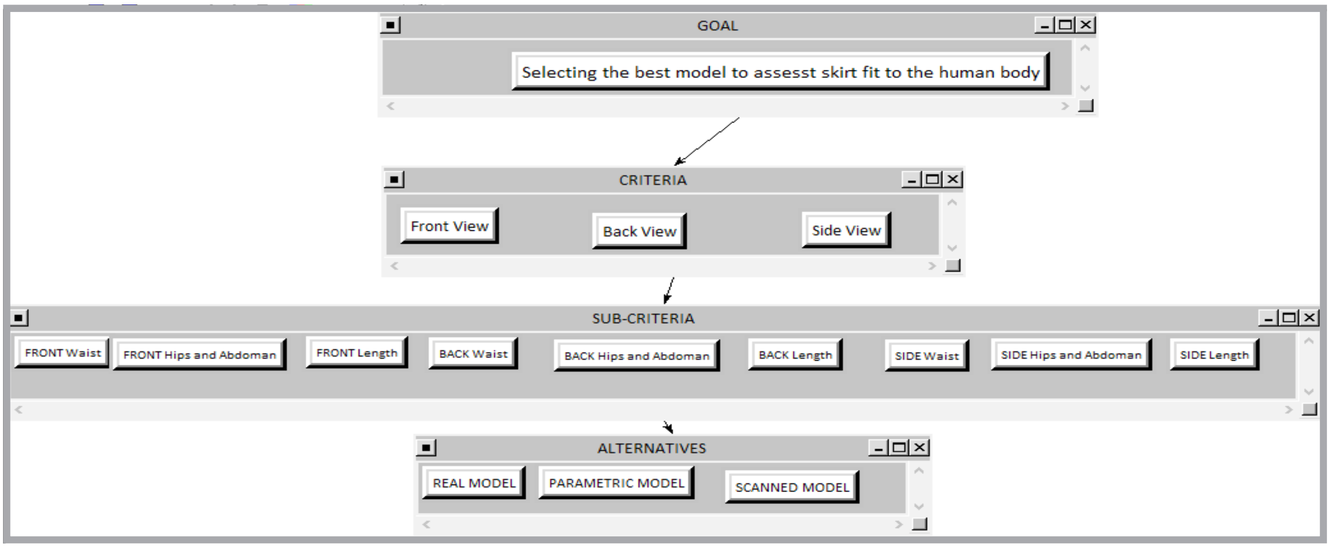


Figure 4. *Hierarchical model from the Superdecision program.*

PART I: EVALUATION OF CRITERIA

1 = Equal, 3 = Slightly more important, 5 = More important,
7 = Too much important, 9 = Extremely more important.

1. When you consider comparing the retailers according to their succeed, which "MAIN CRITERIA" is more important than the other?

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Front																		**Back**
Front																		**Side**
Back																		**Side**

2. Which of the following criteria is more important when "FRONT" is considered?

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Waist																		**Hips and abdomen**
Waist																		**Length**
Hips and abdomen																		**Length**

3. Which of the following criteria is more important when "BACK" is considered?

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Waist																		**Hips and abdomen**
Waist																		**Length**
Hips and abdomen																		**Length**

4. Which of the following criteria is more important when "SIDE" is considered?

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Waist																		**Hips and abdomen**
Waist																		**Length**
Hips and abdomen																		**Length**

Figure 5. *Evaluation questionnaire.*

evaluation of garment fit using the AHP canthus be evaluated as a hybrid subjective/objective method.

Results

In this study, research results to determine the model for evaluation of garment fit on real and virtual body models (3D scanned and parametric models) are given in the form of a graphical representation of the skirt's fit to the body, a Hierarchical model designed using the Superdecision program and analysis of the body models used.

All skirt styles were presented to the evaluators from the front, back and side views, as presented in ***Figure 3***.

The Procedure Analytic Hierarchy Process (AHP) was used for evaluation in order to determine the most proper model for presentation and for studying garment fit to the body. The Hierarchical model from the Superdecision program for selecting the best fit among theskirts evaluated is presented in ***Figure 4***, from which it can be seen that the main aim of the study was to select the best model to assess the skirts' fit to the human body. The front, back and side views were compared by considering the waist, hip and abdomen areas, as well as the length of the skirt. Real parametric and scanned body models were evaluated as alternatives.

The main goal of the research "Selecting the best model to assess a skirt's fit to the human body" was defined according to three types of fitted garment views on the body: the front, back and side view. Each main criterion was then divided into three sub-criteria: the area in the surroundings of the waist (evaluation area A), the area in the surroundings of the hips and abdomen (evaluation area B) and the area in the surroundings of the length of the skirt (evaluation area C), Figure 1. The skirt's fitto the body was evaluated for all three models (real, parametric and scanned) with a pairwise comparison matrix. ***Figure 5*** shows a part of the questionnaire for evaluators.

Figure 6 shows the results of models calculated using the Superdecision program for selection of the best body model for all skirts. The calculation was based on 63 completed surveys.

When the selection was evaluated by Styles 1 and 2, made using the same design and different fabric properties, the scanned model comes first (Style 1 39.5%, Style 2 37.8%), next the parametric (Style 1 32.1%, Style 2 36.1%) and last is the real model (Style 1 28.4%, Style 2 25.6%). From the results obtained, it can be concluded that for the evaluators design is a very important parameter when evaluating the appearance of garments. For skirt Style 3, which was

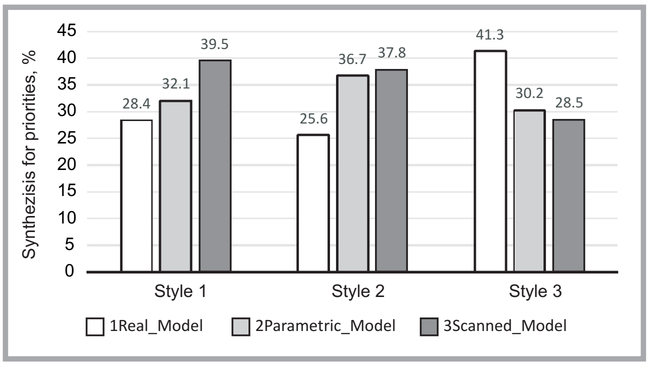


Figure 6. *Selected body models for skirt fit evaluation according to textile experts' decision.*

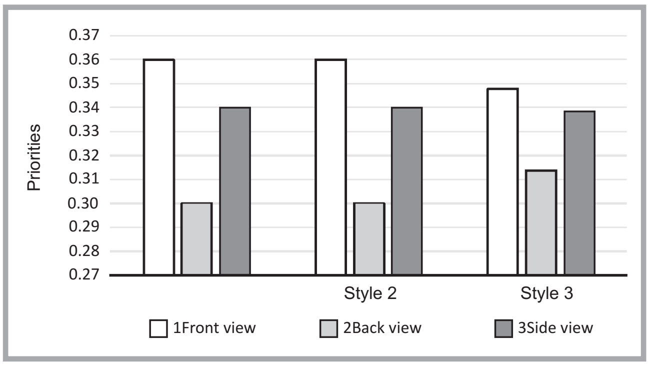


Figure 8. *Priorities for criteria defined according to the type of observation.*

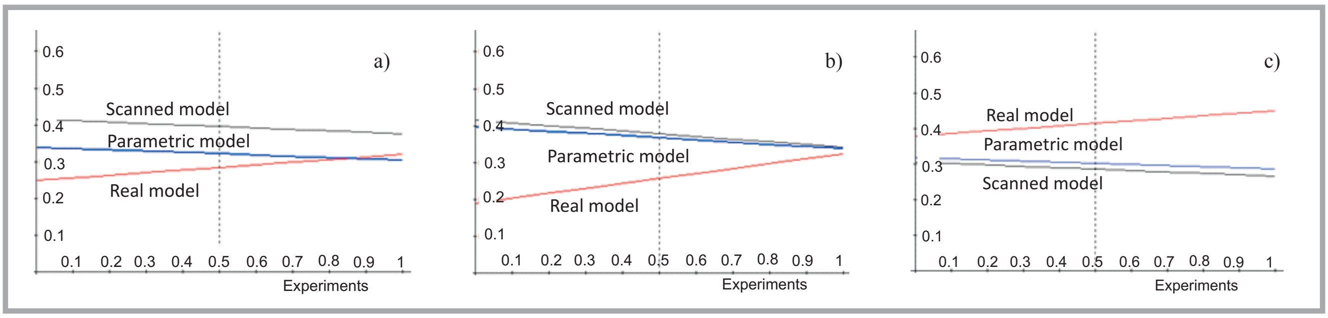


Figure 7. *Sensitivity analysis of all three body models; a) Style 1, b) Style 2, c) Style 3.*

made from the some fabric as Style 1 but with a different design, first selected was the real model with 43.1%, next the parametric model with 30.2%, and last the scanned model with 28.5%. From results it can be concluded that when assessing the skirts' fit for evaluators the fabric properties were less important than the design. When we compare all three body models for evaluating the skirts' fit, the users firstly chose the real and scanned models. It is understandable that the real body model with real clothing is still the most important for evaluating a skirt's fit for the user. On the other hand, the scanned body of a real person with a virtual skirt also became interesting for the users. Because of numerous advantages of virtual representation of the human body and garments, it can be expected that for evaluating garment fit, virtual objects will supplement real ones in the future. However, the silhouette of a parametric body model only approximates that of a real body model. Namely the adjusted dimensions of the parametric virtual body model were proportional, and therefore do not provide a satisfactory real image of the body's figure. Consequently a skirt's fit to the body cannot be perfectly represented; therefore the parametric model was never selected as a priority model for skirt fit assessment.

Figure 7 shows sensitivity analyses of the results. The priority of the criteria is plotted on the x axis and the priorities of the alternatives are on the y axis. For skirt Style 1, the scanned body model was always selected as the first alternative, but there is a difference between the parametric and real models at around 0.8. This means that if the priority of the sub-criteria is greater than 0.8, the real body model is preferred as second instead of the parametric body, model meaning that all other sub-criteria have to be 0.2, which is not probable. (***Figure 7***, Style 1). Moreover no intersection can be seen in ***Figure 7*** between the scanned, parametric and real body models for skirt Styles 2 and 3. As we can see for skirt Style 2, the scanned model was always selected as the first method, the parametric model second, and the real body was selected as the last method irrespective of the sub-criteria. In comparison to skirt Style 2, for skirt Style 3 the real model was always first, followed by the parametric and scanned body models. Therefore from the results of the sensitivity analyses it can be seen that all the evaluation results were implementable and reliable.

Figure 8 shows the selection priorities for evaluation of the garment fit according to the main criteria: front, back and side views of skirts. For Styles 1 and 2 the results were exactly the same. Regardless of the skirt design, kind of fabric construction, properties and body model used, the front view was selected as the most important for evaluators, followed by the side and back views.

Figure 9 shows the results of selected priorities for defined evaluation areas (***Figure 1***) on all body models used.

The hip and abdomen area (evaluation area B) was the most important for evaluation of the skirt's fit to the body, followed by the waist area (evaluation area A) and then the length of the skirt (evaluation area B). The sequence of selected priorities of evaluation areas obtained is reasonable. In general, in everyday life, when the skirt's fit to the body is assessed more attention is given to the hip and waist fit than to the length of the skirt. The results obtained confirm that the hip and abdomen area of skirts fitted to the body is most important when evaluating skirts' fit.

Conclusions

Virtual garment simulation has received significant attention in the past decade, and the fashion and garment industry has been attracted to use this tools in the actual product development process to strengthen collaboration along the supply chain and shorten the product time. The study presented is the first attempt to evaluate differences in garment fit among live, scanned and parametric body models in order to select the most suitable human body. With the use of the APH method, it was concluded

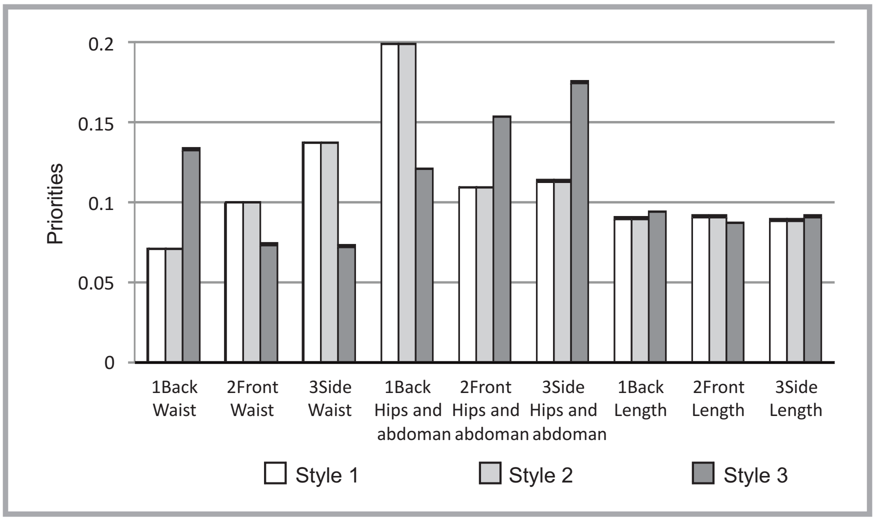


Figure 9. *Priorities for defined evaluation area.*

that for the evaluators design is a very important parameter when evaluating the appearance of garments. Moreover when assessing a skirt's fit, for evaluators the fabric properties were less important than the design. Furthermore the sensitivity analyses proved that all the evaluation results were implementable and reliable. Results also showed that for evaluators front views of skirts were the most important regardless of the design and fabric properties. Furthermore results confirmed that the hip and abdomen area was the most important when evaluating a skirt's fit to the body. The result salso confirm that the hip and abdomen area of skirts fitted to the body is the most important when evaluating a skirt's fit.

Since this is the first attempt at the selection of the most proper human body models for evaluating garment fit, in the future the research model will be improved by new body models in different postures. Also more attention will be paid to the definition of evaluation areas in order to improve communication between the garment producers, retailers and customers.

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