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Garment prototyping based on scalable virtual female bodies

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Abstract

Purpose – The aim of the research is the development of 3D virtual models of lower female bodies from scanned data of different body types for computer-aided 3D product development of loose-fitting garments.

Design/methodology/approach – In order to develop reproducible construction of fashionable/functional outerwear (e.g. ladies' trousers) on the basis of generated scalable 3D virtual female models, 3D-CAD methods have to be developed. In doing so, the variable parameters are predefined and the block pattern of a trouser design can be modified by changing the parameters for the variety of trouser models. Two-dimensional (2D) pattern pieces are then automatically generated and modified if necessary. According to morphological changes, the whole process proceeds automatically up to 2D patterns and thus corresponds to a grading in 3D.

Findings – The generated 3D virtual model and trouser design corresponding to a basic design or block pattern can be offered to the garment industry. The task of the designer or stylist is only to define the intended pattern design on the created trouser shell. Therefore, the approach is also very feasible for pattern makers who are not skilled in computer technology. The goal of this research is to provide an indispensable basis for an effective new technology for the construction of fit-relevant, loose-fitting garments, and in doing so, further accelerate the textile chain.

Originality/value – This paper provides methods of creating 3D garment design as well as grading in 3D, based on scalable virtual models of female lower bodies, which are worked out using a new German size designation system. Since the data processed for the generation of virtual models derives from direct scan data from women (taking into account different body types), the targeted German population is reflected.

Keywords 3D virtual models, Computer aided 3D product development, Loose-fitting garment, 2D pattern, Grading in 3D, Garment industry, Prototypes

Paper type Research paper

1. Introduction

The requirements for the clothing industry have altered over the years. The production has to be changed from the standard mass production to the production of a rapidly changing, trendy range of products. Causations for this are market saturation, import pressure, and constantly changing consumer preferences. In addition to a variety of

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fashionable materials and styles, high functionality and the perfect fit of clothing are requisite (Yunchu and Weiyuan, 2007). Due to this enormous competitive pressure, it is imperative to reduce time and costs of product development in the clothing industry.

Traditional 2D computer-aided design (2D-CAD) concentrates on 2D pattern drafting and modification (Liu *et al.*, 2010). Garment prototyping is based on the development of a conceptual design. First, a basic block pattern is selected and then modified in accordance with the desired style. After cutting and sewing procedures, an iterative process is undertaken until the appropriate fit is achieved. Finally, a size range is produced through grading from the basic pattern (Bond, 2008). Consequently, the skill and experience of the designer plays an important role in achieving the desired product of good fit and high quality. The task of the designer is to transfer 3D body shape into 2D pattern pieces taking into account physical and fit-related design features. Since the link between the 3D human body and product development is interrupted, a good fit can only be achieved with numerous iterations, which is often a time- and labour-consuming process (Rödel and Morlok, 2011).

One of the most important factors for the apparel production and retail industry is to achieve well-fitting garments on 3D human body forms (Strydom and Klerk, 2006). Body measurements and shapes are fundamental necessities for pattern construction (Workman, 1991), which plays an important role in the garment fit. Two bodies with the identical measurements but different morphological shapes may have different patterns to get the well fit (Strydom and Klerk, 2006). Moreover, the clothing industry often produces clothing for idealized figure, which do not reflect all customer groups. As a result, the available pattern-making know-how is not adequate for the requirements of different customer groups. The existing systems are based on a limited number of 2D body measurements, and thus the complex body shape is insufficiently considered in the pattern-cutting system.

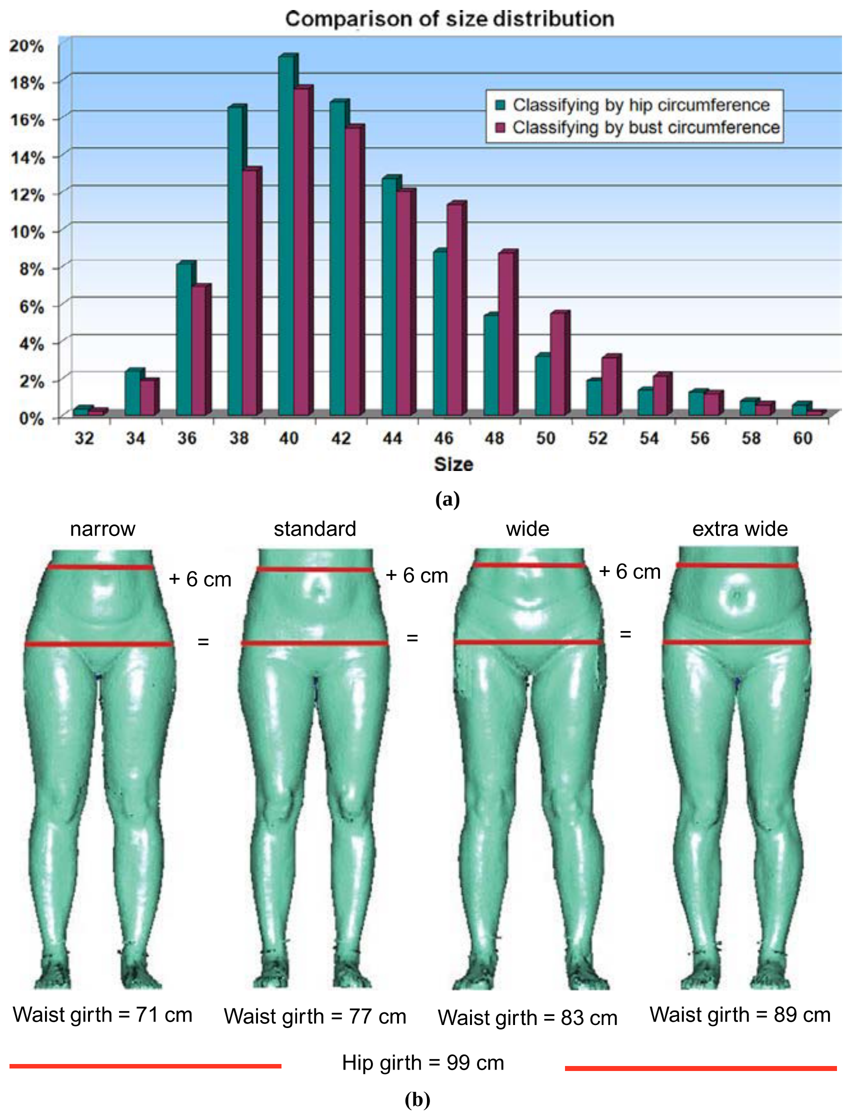
With the aid of 3D body scanners, fit-relevant information for garment design such as 3D body shape, body posture, body cross-sections, and curves and surfaces can be generated (Rödel and Morlok, 2011). In our research work, 3D body scan data are implemented for developing an innovative 3D construction method of loose-fitting clothing, especially trousers. The trouser construction is based on virtual lower bodies of women. The prerequisite for this is the evaluation and classification of female 3D scan data and the development of scalable 3D virtual models.

2. Approach

Classification of the scan data

Women's body types (Connell *et al.*, 2003; Detering and Haug, 2006; Morlock and Wendt, 2009; Schneider, 2007; Simmons, 2002) are defined in different forms relating to geometric or alphabetical shapes such as the rectangle, triangle, pear, inverted triangle, diamond, hourglass shapes, or A, H, and V shapes. The International Organization for Standardization (ISO) has proposed numerical size-designation system (Bougourd, 2007). In the German sizing system (DOB-Verband, 1994)[1], body types are assigned in accordance with the size of the hip as slim, standard and broad. Defining the body types in designating the garment sizing is vital so that consumers can choose the right fit for apparel. However, a size-designation system developed from body types that represent population is lacking.

In our research, the primary requirement for the generation of scalable virtual female models from scan data is size-related classification of these data, specified by our joint research partner, “the Hohenstein Institute for Textile Innovation” (HIT), Germany. According to a morphological analysis, hip circumference is feasible to use as the basis for the anthropometrical characterization of lower bodies (Rödel and Morlok, 2011). Figure 1(a) shows that clustering sizes by hip girth is more consistent than bust circumferences. As the classification of body sizes is no more relevant of breast



Source: Rödel and Morlok (2011)

Figure 1.
(a) Comparison of size distribution by hip and chest circumference;
(b) determination of waist types at constant hip girth

circumference in this research, the virtual models are considered just from the waist. Furthermore, as individual human body shapes within the same size can differ, it is essential to cluster the body shapes/types as well. The body types are thus distinguished according to four waist types (narrow, standard, wide, and extra wide) at the constant hip circumference with the interval of 6 cm between each type as shown in Figure 1(b).

Data selection of polygon models

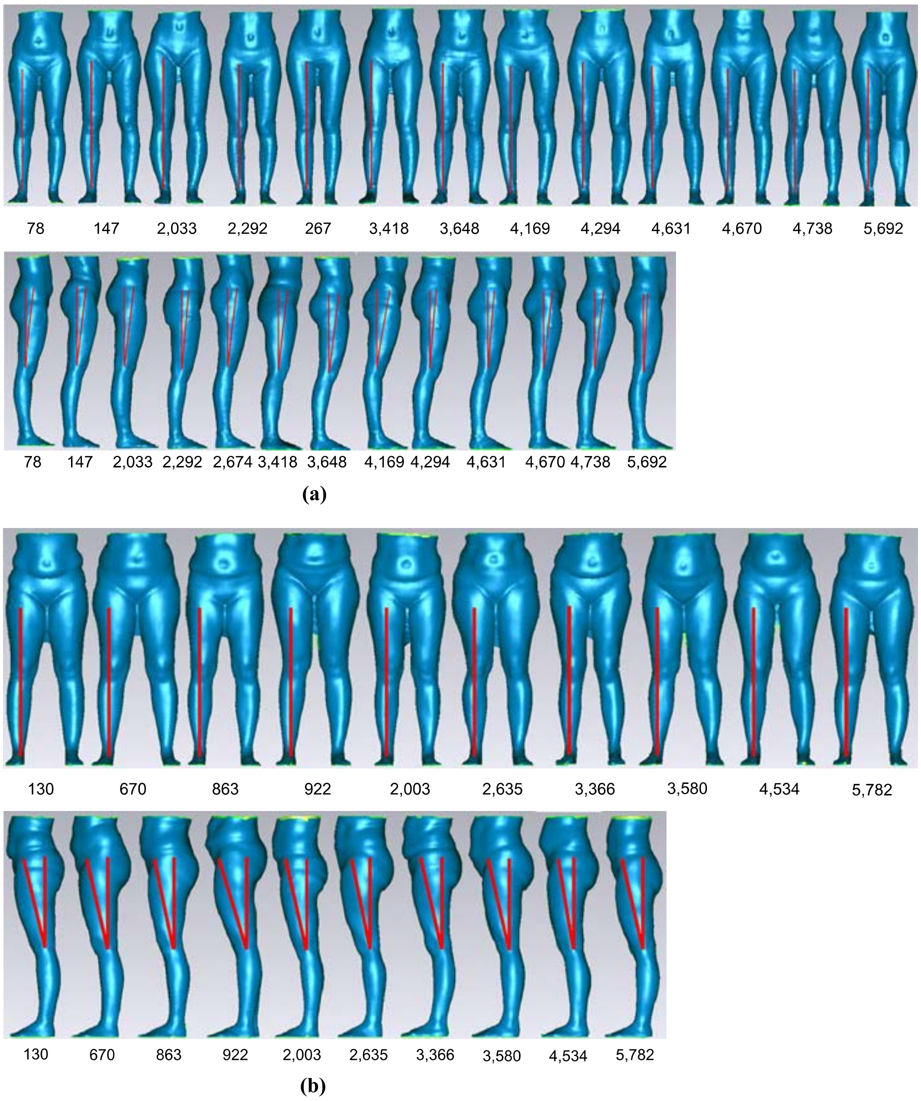
An essential prerequisite for 3D product development in the clothing industry is the implementation of anatomical geometric models in virtual form, which can then be utilized in 3D-CAD systems as design tools as well (Rödel and Krzywinski, 2004). Since human body structure is quite complex, mathematical consideration and graphical representation are crucial for a realistic description (Krzywinski, 2005). Presently, there is the potential to generate virtual human models based on measurements and specifications of a real person (Allen *et al.*, 2003; Magnenat-Thalmann, 2010; Wang, 2005).

The statistical analysis of the size distribution (Figure 1(a)) shows that the maximum statistical percentage is occupied by size 40. While the sizes 38, 40, and 42 cover most of the smaller sizes, the dominant sizes among larger sizes are 44, 46, and 48, respectively. Bearing in mind that and because of time limitations, the sizes of scan data processed in our research work are set at sizes 38-48 including four different waist types and normal body height, which corresponds to the length of inner leg defined in the size chart (HIT). Therefore, data was generated for 24 groups (six sizes including four waist types for each).

In the first step, individualized 3D scan data (point clouds) are transformed into polygon surfaces using reverse engineering software, Geomagic Studio (2010), which is based on the iterative closest point (ICP) algorithm. ICP algorithm is the registration method for the representation of point sets, line segment sets, curves, triangle sets, and surfaces (Besl and McKay, 1992; Gelfand *et al.*, 2003; Rusinkiewicz and Levoy, 2001).

To select the optimal data among the available data set for each size and type, the body dimensions of the data are compared with those from the standard size chart and the data are selected regarding the minimum deviation from size chart. As a result, a problem is presented because the surface of the resulting polygon model is lost after averaging process due to the different body posture. Thus, the optimal data with similar body postures, which fulfil the requirements of the virtual or physical model defined by HIT such as bowed leg or knock-knee and leg position in frontal and lateral view, are chosen. As an example, data analysis of sizes 40 (normal waist type) and 46 (normal waist type) with normal body height is shown in Figure 2.

Due to the fact that the scan data in shaded areas like the crotch of the body did not fulfil the required quality, those areas have to be modified. The selected data are then automatically averaged with the aid of the ICP algorithm to generate the representative or reference model (Figure 3). Subsequently, the body dimensions are verified. If necessary, body dimensions can be scaled according to size chart so that the exact dimensions can be attained. Since the average virtual model is developed form real human bodies, the resultant model is asymmetric. For this reason, the optimal side (left or right) is selected and mirrored to achieve the symmetrical model. Moreover, the hip region is also modified to realize the buttock profile. This resultant polygon model can be applied for virtual cloth simulation and as a reference model in verifying the generated parametric model (Figure 6(b)). For further implementation of the polygon



Notes: (a) Size 40-narrow waist type; (b) size 46-normal waist type

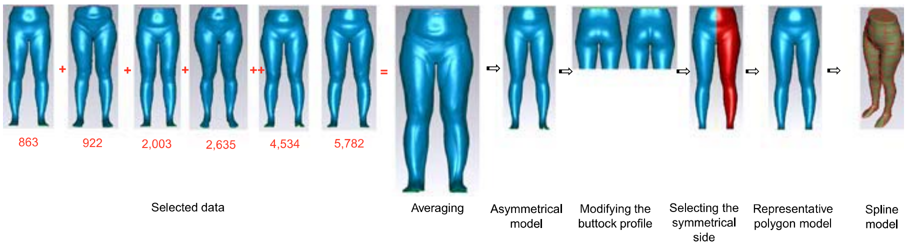
Figure 2.
Analysis of body posture in frontal and lateral view

model in 3D-CAD systems such as DC3D (Lectra, 2011), CATIA (Systèmes, 2011) for the trouser construction, it is vital to convert the polygon surfaces into B-spline surfaces (Figure 3).

Developing the parametric models

The next step is to generate the parametric 3D virtual models of various sizes and waist types. For this purpose, the half part of the spline-model is cut with horizontal planes (Figure 4(a)) at the required girths (primary and secondary body dimensions) to yield the symmetrical data. The horizontally-cut slices consist of two types of curves: the opened curve, e.g. the waist or hip girth and the closed curve, e.g. the thigh girth. All sectional curves are measured and created as length parameters so as to scale the girth of each body dimension in accordance with the size chart. For the opened curve, the end points are connected and the scaling point is set at one-third of this connected line from the back part (Figure 4(b), left). Contrary to the opened curve, the extreme points of the respective closed sectional curves are automatically set in *x* and *y* direction (Figure 4(b), right) with the aid of DC3D software (Lectra, 2011). These extreme points are then joined together so that the scaling point/centre is determined. For the sake of scaling the virtual models in longitudinal direction, all horizontal slices are projected at the crotch point (Figure 4(c)) and then duplicated in longitudinal direction (±) in a corresponding distance. In this case, it is only intended for longitudinal scaling, and not yet for adjusting the body posture in three coordinate directions (*x*, *y*, and *z*). For that reason, it is essential to duplicate the projected curves three dimensionally. All the dimensions and parameters regarding each body size and waist type are stored in Excel-sheets, so that the generated parametric virtual model can be scaled and modified to corresponding sizes and body postures.

The body shapes or cross-sectional diameters of the individuals could be different even within the same sizes or girth measurements. Furthermore, body proportions for a variety of sizes do not remain constant. In Figure 5, the cross-sectional curves at waist and hip areas of different sizes are described, from which it can be concluded that the body shapes of different sizes do not develop homogeneously. For the trouser construction, cross-sectional shapes of waist and hip girths are basic parameters to be involved (Rödel and Morlok, 2011). Thus, the basic sizes for the scaling of size ranges



Note: Size 46, normal waist type

Figure 3. Generation of the representative model

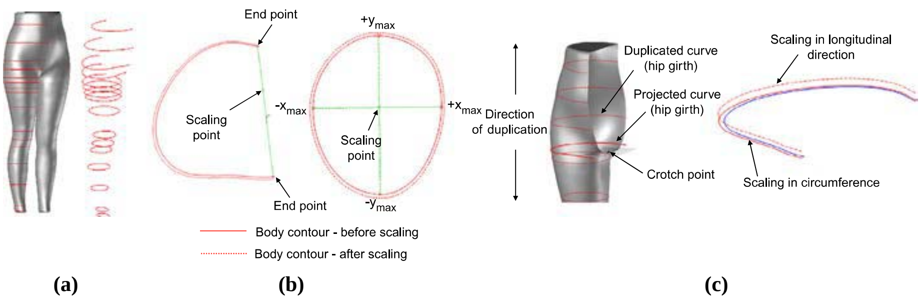
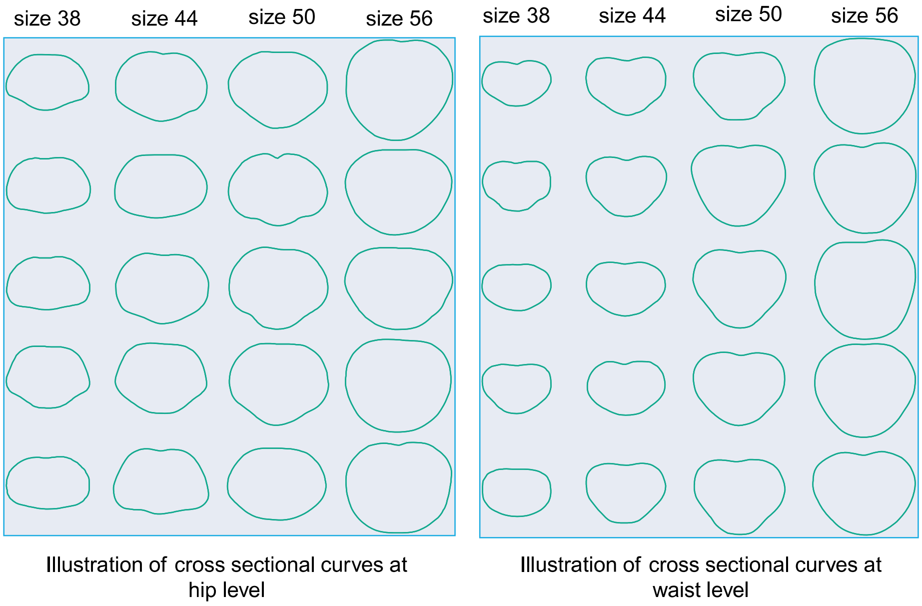


Figure 4. Generating the parametric virtual model



Source: Rödel and Morlok (2011)

Figure 5.
Morphological features of cross-sectional shapes at hip and waist level

including four waist types are divided into two groups, namely size 40, from which the size range 38-42 is derived and size 46 deriving size range 44-48.

After generating the skeleton of the virtual model, the surface is constructed and mirrored to obtain a symmetrical one (Figure 6(a)). Afterwards, the resultant data are

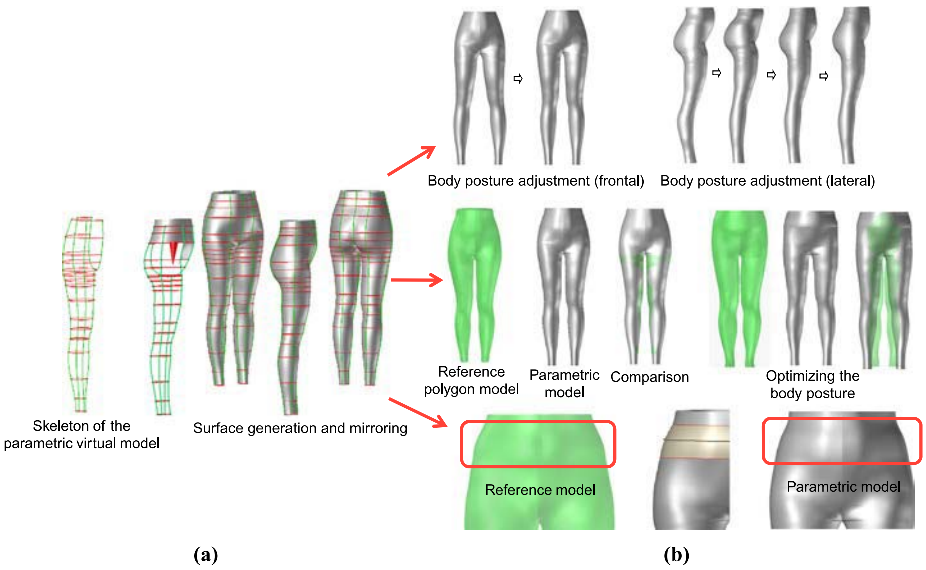


Figure 6.
(a) Parametric model;
(b) modification of body posture and body shape

verified through a comparison with the original reference polygon models (Figure 6(b)). If necessary, the body posture or leg position can be modified. In some cases, the leg position of the reference model is not ideal to set as standard posture, because the standing position of the test persons were not optimal during the data capturing time. Thus, it is unavoidable to optimize such body postures. The same verifications are also performed to assess the body posture in frontal and lateral view. In some data, especially in wide or extra wide waist types as well as in larger sizes, the morphological shape between the waist and hip girth has to be modified according to the reference model by varying the parameter of that area.

Prototyping of loose-fitting garment (trouser construction)

With the aid of 3D virtual fit simulation, it is possible to reduce garment sample making and minimize the associated personnel and material costs. For the simulation process, 2D pattern pieces must be correctly sewn in a virtual environment. In this way, the simulated clothing can be judged three dimensionally through 2D patterns virtually. If necessary, modifications or changes can be done in 2D systems (Magnenat-Thalmann, 2010).

In constructing close-fitting garments using appropriate 3D-CAD software, the intended design can be directly constructed on a virtual model and the corresponding cutting patterns are automatically flattened into the plane. Contrary to that, for the loose-fitting garment, it is necessary to develop 3D construction method for a virtual "second skin", which covers the body contour with the offsets or eases, in order to ensure the desired comfort and fulfil fashionable/functional demands.

Before constructing trouser patterns in 3D, it is requisite to simulate a two-dimensionally constructed trouser on the corresponding polygon model (Figure 7), so as to determine the offsets between the virtual model and trouser. In this step, the trouser is modified in 2D construction as long as the optimal fit result is achieved. Then, the virtually-simulated trouser and polygon model are transformed into B-spline surfaces for further application in CAD software. Those predefined offsets provide

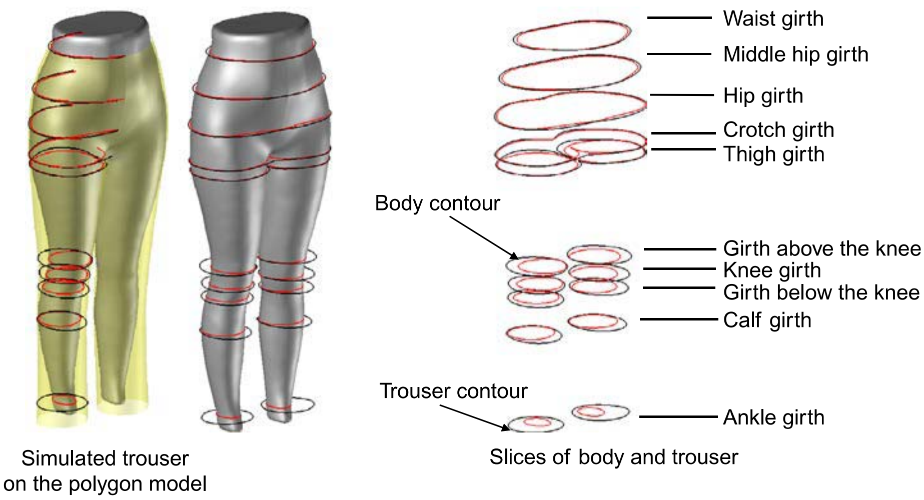


Figure 7. Fit simulation for determining the eases between virtual model and trouser

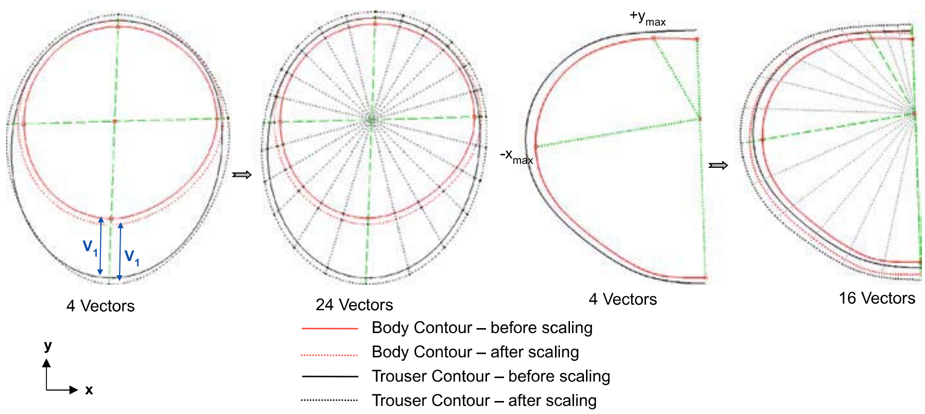
the frame-work for constructing the trouser. Subsequently, the shell of the simulated trouser is cut at the same level as the virtual model (Figure 7), in which only primary dimensions are demonstrated. The construction of the sectional curves is analogous to virtual model.

In order to develop the trouser construction, the connected lines of the extreme points of the closed curves of the body contour are extended with the intention that intersection points give rise at the trouser contour (Figure 8(a), left). The resultant offset between the body and trouser is defined as distance parameter, V_1. Afterwards the body dimension is scaled according to the standard size chart. After scaling the body contour, it is illustrated with a dotted contour. This allows the offset between the body and trouser to remain constant ($V_1 = V_1'$). Through the connection of the resultant end points of the extended lines, the trouser contour is created. To achieve the trouser contour exactly, more vectors must be generated (Figure 8(a), right). For the opened curve, the extreme points are also automatically developed on the respective sectional slices. Afterwards, the end points and the extreme points are connected with the scaling point (Figure 8(b)). The remaining procedures are accomplished analogous to those of closed curves. In this way the trouser contour for each section curve is generated. All the distance parameters created for each curve are stored in Excel-sheets, so that the trouser shell can be modified for a variety of trousers in coupling with parameters.

For the purpose of developing the trouser surface, the side seam lines as well as crease lines for the front and back parts are constructed. The offsets or eases are then varied by coupling with parameters relating to a desired trouser shape (Figure 9). The generated virtual model and trouser design that corresponds to a 3D block pattern can be offered to the garment industry. The task of the designer or stylist is only to define the intended pattern design on the created trouser shell. Therefore, our methodology is very feasible also for pattern design makers who are not very skilled in computer technologies.

Defining the pattern design

The boundaries of the trouser are successively activated so that the specific area such as the front or the back part is defined including the darts. To flatten the 3D garment patterns into 2D planes, those defined 3D patterns are triangulated (Figure 10(a)).



(a) Calf girth **(b)** Half of the waist girth

Figure 8.
Creation of trouser contour

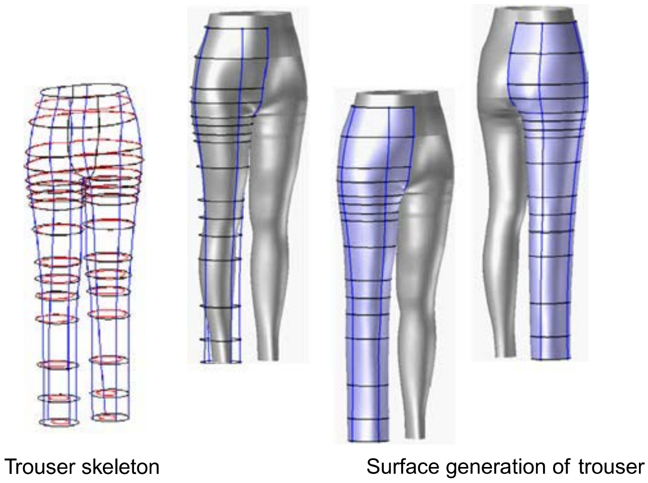


Figure 9.
Trouser construction

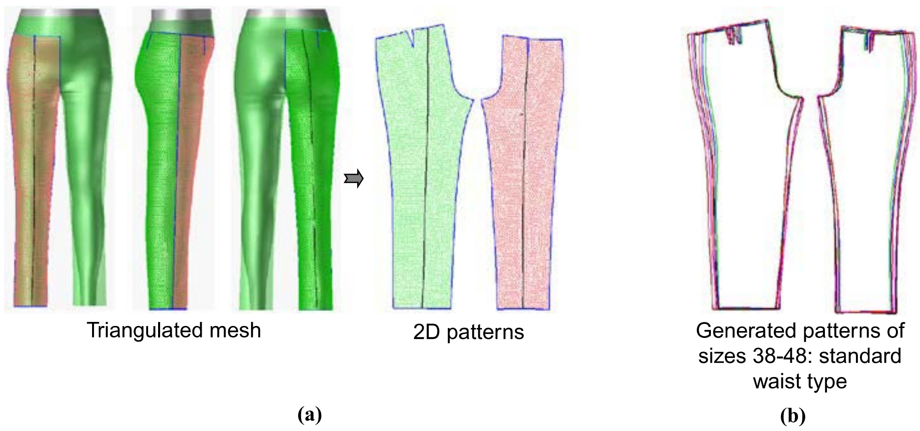


Figure 10.
(a) Automatic generation of 3D-surface into 2D-cutting patterns; (b) grading nest

This triangulation or meshing provides the approximation of the constructed trouser surface based on Mosaic algorithm (Lomov *et al.*, 2007; Weeën, 1991), which computes the surface with flat triangles. As the trouser surface is not a ruled surface, the flattening process takes into account the curvature of the body with minor distortions of the triangles of the mesh. According to morphological changes, the whole process proceeds automatically up to 2D patterns and thus corresponds to a grading in 3D.

Morphological grading in 3D

After accomplishing the 3D pattern design and meshing, the virtual models of the basic sizes 40 and 46 are scaled to the nearest sizes (38, 42 and 44, 48) including four various waist types in coupling with excel-sheets, in which the parameters of respective sizes and waist types are stored. Finally, the corresponding 2D trouser block patterns are automatically developed according to the morphological changes without user intervention.

An example of automatically generated grading nest of normal waist type is shown in Figure 10(b). It must be noted that the dart positions of the two scaling groups are slightly offset owing to the different morphologies around the waist and hip area. Ultimately, fit tests for standard and individual sizes have been carried out based on prototypes and the results are good evaluated.

Trouser modelling

We constructed our block pattern or basic trouser with a large number of vectors (Figure 8) for each sectional curves, thus achieving the exact trouser hull. But, this approach is not user-friendly because it takes considerable time to change the offsets to attain the optimal trouser shell of different trouser models. Therefore, it could make sense to simplify the basic trouser construction, so that variety of trouser models can be created in a short time. In doing so, the number of the sectional curves and vectors of block pattern should be limited. Figure 11 shows the primary dimensions of the trouser and the number of vectors reduced (e.g. knee girth) used in trouser modification, which should be varied according to various trouser models.

Through changing the offset parameters, coupled with the Excel-sheets where all parameters for each model type are separately stored, the trouser shell is modified regarding the different varieties of trousers. In Figure 12, some examples of constructed models (right) deriving from the block pattern (left) are demonstrated.

3. Conclusion

Up to now, garment pattern-making could only be accomplished through the empirical experience of the designer due to the lack of a correlation between virtual model and garment pattern. This deficiency could be overcome through the direct construction on the virtual mannequin so as to rationalize the product development significantly. The research can provide an indispensable basis for an effective, new technology for the fit-relevant construction of loose-fitting garments, and thus further accelerate the textile chain. Based on the results of the research, optimal cloth fitting corresponding

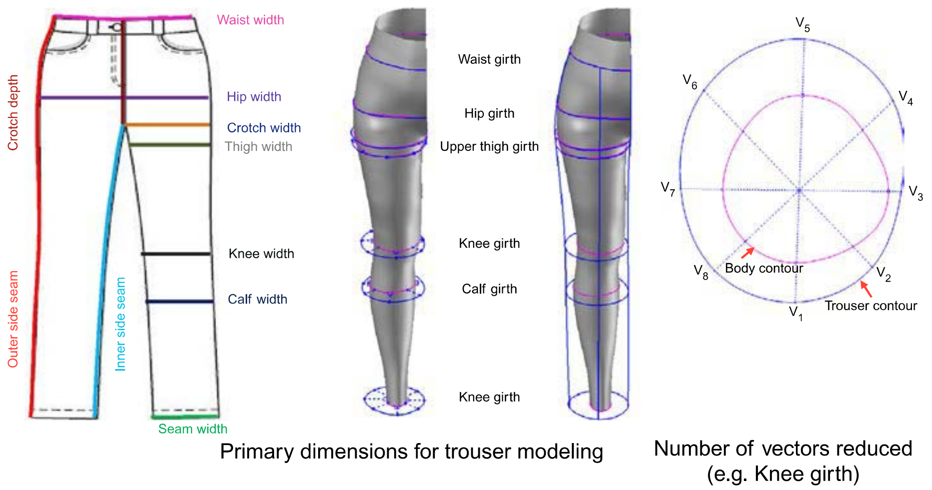


Figure 11.
Primary dimensions and offsets considered in trouser modelling

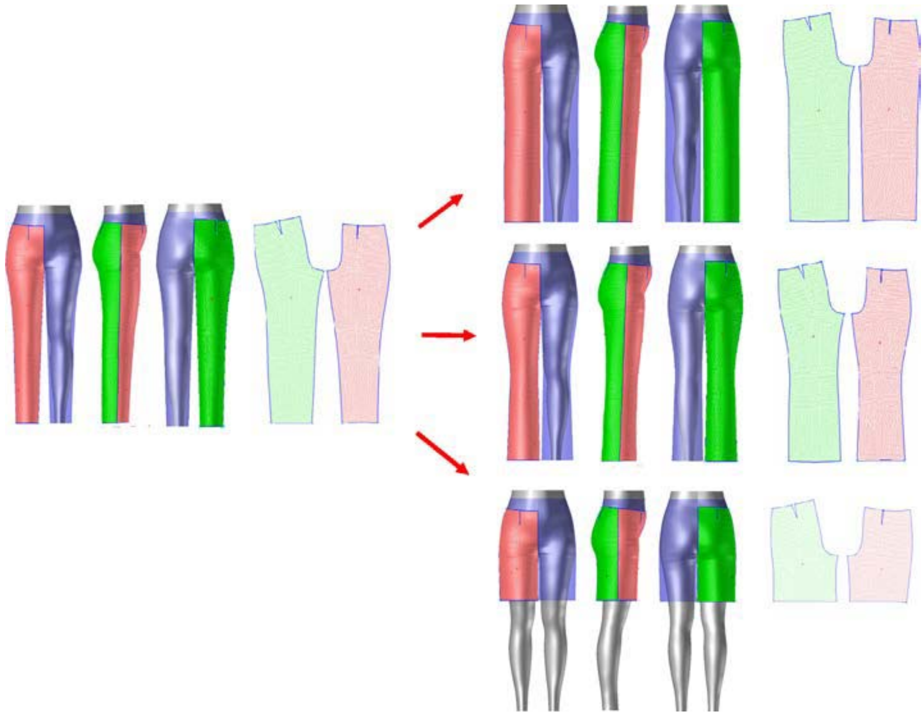


Figure 12.
Trouser modification

to the different body types for the targeted groups is possible. This may lead to an increase of customer satisfaction, a higher purchase frequency, and thus contribute significantly to ensure market success. As product development remains one of the most cost-intensive processes, the targeted mission of our technology would save 60 per cent of the current time necessary for labour.

Note

1. Women's outer garments.

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