

Development of an Automated Product Development Process for Tailored Bras Using Breast-Specific Measurements from 3D Body Scans in Conjunction with an Interactive Pattern Construction

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Abstract

The process for the production of customized bras is really challenging. Although the need is very clear, the lingerie industry is currently facing a lack of data, knowledge and expertise for the realization of an automated process chain. Different studies and surveys have shown, that the majority of women wear the incorrect bra size. In addition to aesthetic problems, health risks such as headaches, back problems or digestive problems of the wearers can result from this. An important prerequisite for improvements is the basic knowledge about the female breast, both in terms of body measurements and different breast shapes. The current size systematic for bras only defines a bra size by the relation between bust girth and under bust girth and standardized cup forms do not justice to the high variability of the human body. As the bra type shapes the female breast, basic knowledge about the relation of measurements and shapes from the clothed and the unclothed breast is missing.

In the present project, studies are conducted to explore the female breast and to derive new breast-specific body measurements, different breast shapes and deformation knowledge using existing bras. Furthermore, an innovative process is being developed that leads from 3D scanning to individual and interactive pattern construction, which allows an automatic pattern creation based on individual body measurements and the influence of different material parameters.

In the course of the presentation, the current project status will be shown and the future developments and project steps will be introduced.

Keywords: 3d body scanning, interactive pattern, fashion on demand, automated measurement of body data, construction under consideration of material parameters, breast volume and shape

1. Introduction

According to the currently valid standard, the cup size is defined by the difference between under bust width and bust width. However, the individual shape of the female breast cannot be described sufficiently by this. Complementary to this, the need for individually tailored clothing is constantly increasing. The majority of women wear the wrong bra size and optimized solutions are needed in the development and manufacturing process that considers the strong variations and shapes of the female body in an individual way in contrast to the current size system, which only insufficiently describes the female breast. This results in the high number of women who wear the wrong bra size, which leads to the optical and health problems mentioned above. Furthermore, in previous studies concerning this area, the measurement of the female breast was generally made with a scan bra, which means that the natural shape was not considered in the construction. [1]

The aim of the project is therefore to develop an automated product development process for customized bras with an optimal fit. By using non-contact digital acquisition of the measurements of the potential customer and suitable software, underwear is to be developed and manufactured to fit exactly and without the need for trial fitting. Contrary to the existing sizing system, parameters such as breast width or breast volume provide the basis for the product development process. Especially the breast volume as a measurement is very important and is used as a parameter for cup size determination. Therefore, it was necessary to develop a new scan process that allows to determine the natural shape of the female breast as well as the volume. Using 3D software, the customer can be realistically presented with the optimal shape of the finished cup on her personal scanatar, i.e. her personal digital image in 3D. Optical changes as well as checking the fit means of target-performance comparisons replace costly try-ins and the production of sample parts. The virtual optic and garment fit review significantly shortens the production process.

In addition to the exact breast shape and volume, the material parameters are also incorporated into the interactive design. These play an important role in the construction because, depending on the placement of the seams, the parameters of the material used have a very large effect on the shape of the breast while wearing the bra.

Initially, the different methods for contactless measurement and evaluation of body data with a focus on the female breast area will be studied, in particular with the associated special features and challenges. These are, for example, possible hidden areas and naturally shapes, which can be widely different for each body. This is followed by measurement options including the necessary scan positions to take the defined measurements and points in the female breast area, which are later necessary for the construction of the bra. Finally, the chapter on pattern development for the still ongoing project follows, for which different pattern systems were analyzed. In the subchapters of this section the shapes of an optimal female breast will be defined first and serve as a guideline for the shape to be achieved by the bra. This results in requirements for the materials in the different bra zones, depending on the placement of the seam. Finally, the development of an automatic pattern construction for bras is discussed in more detail.

2. Contactless measuring methods of female breast area and its challenges

In the context of serial measurements, from which data are currently available that can be used for the task, the measurement was previously performed with a standard bra which is soft, cup- and wire-free. On the one hand, this bra leads to a comparability of the measured measurements, on the other hand it leads to a change in the natural shape of the breast. Therefore, this approach is not suitable for the task and the requirements of the present project application. So, one of the challenges is 3D scanning of the breast, which must also be performed without a bra to reproduce the natural breast shape.

Another challenge is the definition of a new scanning process which considers the specific measurements of the female breast. With a new scanning position, a new type of measurement system is being developed and at the same time it allows the exact and personal determination of the breast volume as well as the determination of the ideal cup shape. Test subjects are scanned with the newly developed procedure and body data and breast volume are analyzed. Through the additional application of marker points, as seen on the avatars in figure 1, the measuring point of the upper breast attachment point, which is optically only inadequately assignable on the scan, can also be clearly determined.

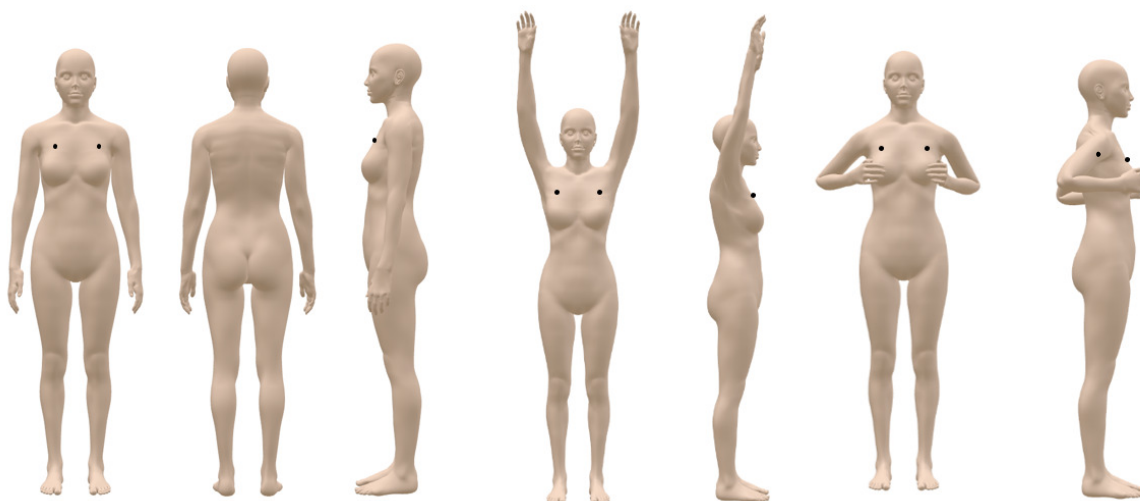


Figure 1 Scan Positions: Relaxed, Arms Up and Breast Up

In addition, the body measurements to be taken are often so small that the usage of a high-precision scanner is necessary in this project.

As part of the project, 500 women of different ages will be measured, some of whom belong to the Reutlingen University and others who come from outside.

3. Measuring possibilities, lines and points in the female breast area

By covering the breast area with the bra, only a few breast-specific dimensions and anatomical reference points are visible. Accordingly, there are usually only a few dimensions that describe size and shape from serial measurements, like bust girth and underbust girth to define cup size. The definition of the measurement points is based on the body points that could be of interest for the development of the customized patterns, as shown in figure 2.

First, the measuring points on the body were determined on which the breast measurements are based. At the same time, the points were selected in such a way that they could be identified clearly and reproducibly on the scan.

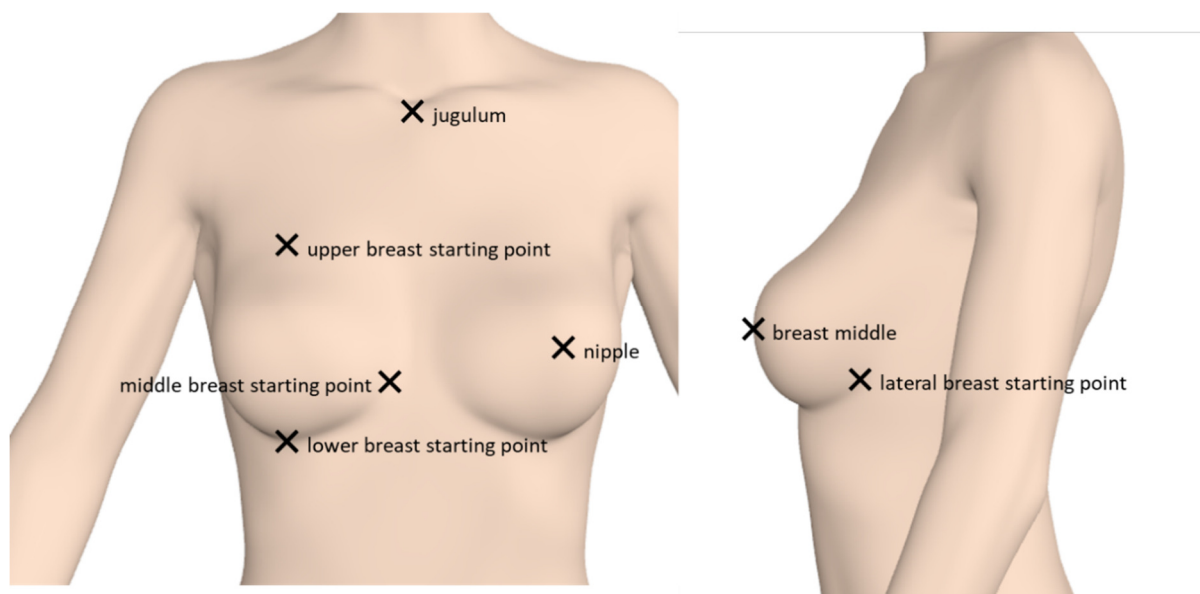


Figure 2 Defined measurement points in female breast area

Additional markers are used to identify special body parts in the breast area of the woman. These ensure that the body part is reliably determined at the right place, as different body areas can also be found by palpation.

4. Pattern development

The focus in the creation of the basic pattern was here on the usage of as many individual breast measurements as possible as well as in the parametrization, since the pattern construction is to be developed as an interactive process. In the research different pattern construction principles for bras were examined and also the different possibilities of seam placement in the construction of the basic pattern were considered. In any case, it is important to note that the design process, which is to be fully automatic and interactive later on, should contain as little to no parameters based on experience or correction factors as possible.

It has been discovered, that the placement of the cup seam from the lower breast attachment point to the middle of the breast ensures that the lower breast volume is raised. Placing the cup seam from the lateral to the middle breast attachment point ensures that the middle of the breast is visually raised and provides additional stability in the horizontal center of the breast. Thus, the angle of approx. 20° in the middle of the breast, which is considered to be the ideal aesthetic in european countries, can be visually modeled through the seam. [7][8]

In the context of this research it is important to develop a pattern system that is not based on the rules of conventional construction but with the focus on parameterization. Figure 3 shows the different effects of the placement of the seam in the basic construction on the shape of the breast. [3]

Due to different seam placements, different modulations of the breast are possible, so the optimum shape of the breast can be achieved by combining seam and material. [6]

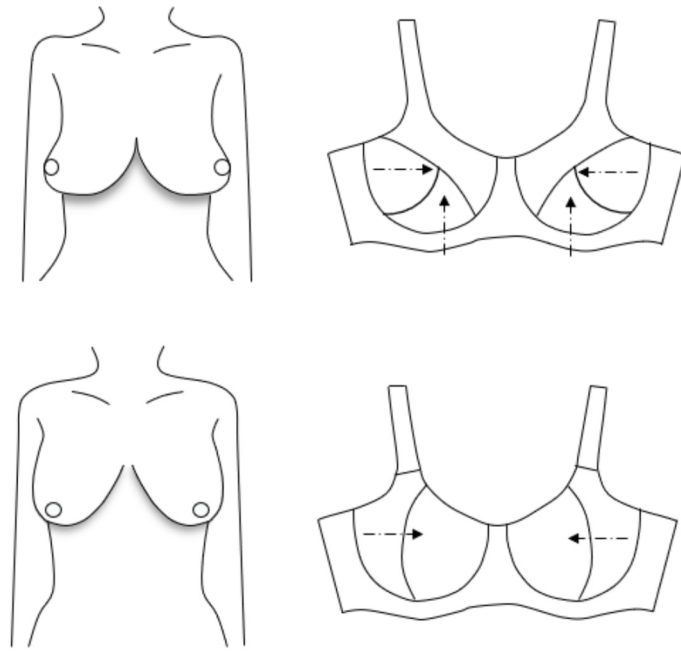


Figure 3 different Seam Placements

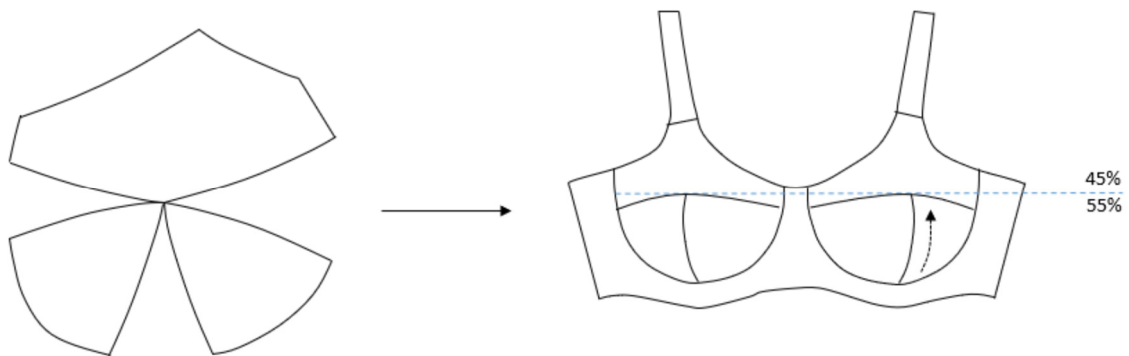


Figure 4 Breast shaping through seam placement

Furthermore, the shape of the female breast and the characteristics of the used materials are analyzed for the development of a modular design system. For this purpose, the material parameters are included in the construction and their effects need to be defined in detail. The modular design system itself is programmed with the program Rhino5 with the plugin Grasshopper and will be described further.

4.1. Breast Shape

Due to cultural diversity, the form of the female breast, which is considered ideal, can differ as well. Research has shown as a general beauty ideal that 45% of the breast volume should be above and 55% volume below the middle of the breast. Likewise, the breast nipple should be facing up about 20 degrees and the upper half of the breast runs optimally straight or concave, whereas the lower half of the breast should rather follow a soft, convex curve. It should be noted, the ideal form of the cup depends on current beauty ideals, individual aesthetic perception and, last but not least, cultural and social influence. Unlike in the USA, where breast volume has a significant influence on aesthetic perception, in Europe it is the shape that determines whether a breast is perceived as "beautiful". [2][4][5]

The optimal shape was developed in 3D as a result, shown in figure 5, and the classification of the cup shape is based on the breast volume instead of the traditional standard sizes, which are considered to be not sufficient.

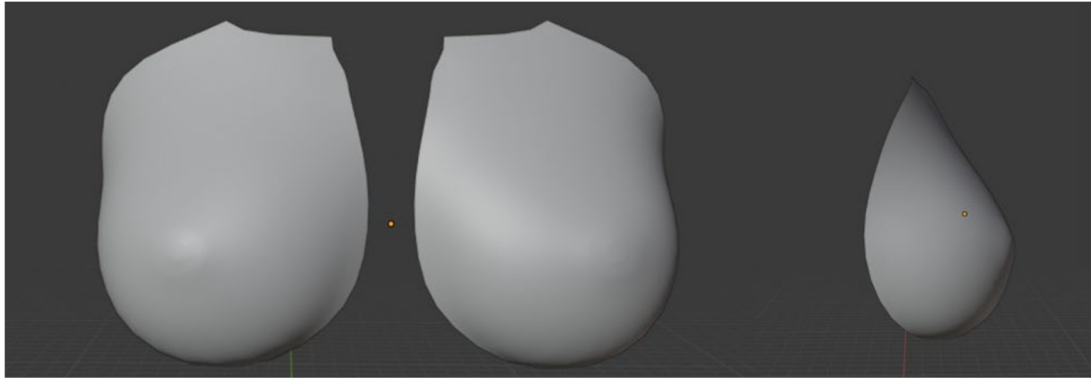


Figure 5 Optimal Breast Shape

In order to place this optimal cup shape on the scan body, the ideal measurements of the breast were researched, which thus help to evaluate the individual measurements with regard to the automatic selection of cup shape and basic pattern. In the next step it is necessary to define the breast of the scan in a 3D program as a vertex group, so only the breast itself is changed, not the body as a whole. This is important because the optimal cup is placed on this vertex group and then shrink-wrapped into the desired shape by moving the vertices of the scanned breast to the optimal cup. This applied shape shows the desired ideal shape that the customer's breast will achieve by wearing the bra with optimal support function and with this procedure the customer can already visualize the result before production.

To give an illustration of this step, an avatar with a naturally shaped breast, which tends to ptosis, was first created. The breast volume is 400 cm³, as in the optimal shape shown in figure 5, and is then shrunk to the optimal shape using the explained shrinkwrap procedure. The result of the application of the optimal cup is shown in Figure 6. This optimal breast- and body shape is then used as the avatar for the simulation and digital design of the bra.

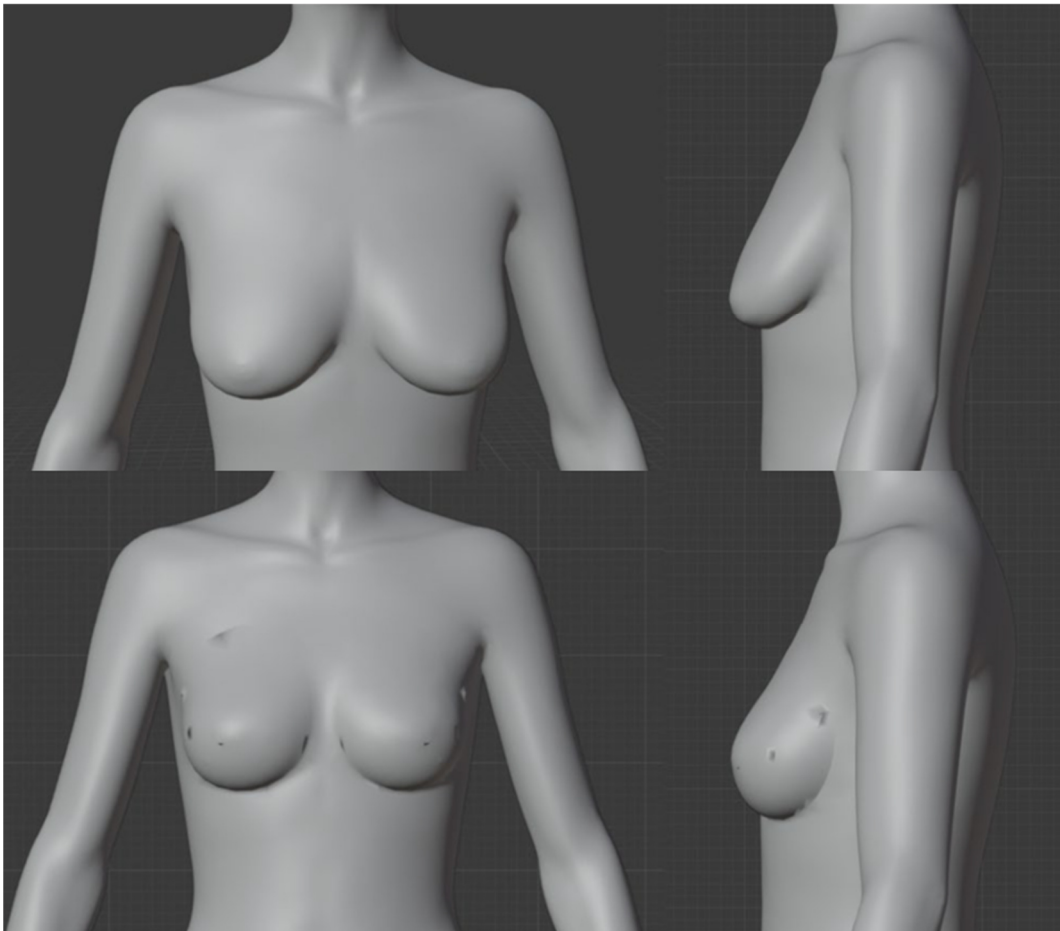


Figure 6 Shrinkwrap Procedure

4.2. Material requirements

The definition of material properties does not exclusively serve the purpose of improved fit and increased wearer comfort. The material properties should also be selected so they can be optimally integrated into the basic pattern and provide a realistic, digital image of the finished bra when simulated. This is the only way to ensure the exact fit of the automatically generated pattern. Materials used for the production of lingerie were tested for their properties and this includes the material composition and the following material tests: Mass per unit area, bending stiffness and fabric thickness. These values are decisive for the development, since these parameters allow an almost realistic simulation of the tailored pattern. Furthermore, the values of the stretching force and the stretch in percent are tested, since these values are important for the integration of the material into the pattern, since this is supposed to achieve an optimal support of the breast.

The following chart shows the composition of the so far tested materials, which are suitable for a production of bras. Here it is important to note that, depending on the placement of the cup seam, a suitable material must be selected, because a material with a very high elasticity causes an optical reduction of the volume, which is thus shifted to the lower breast area when it is inserted in the zone above the breast. As a result, it is important to test and specify different materials for the modular system in advance, since the material must have different parameters and properties depending on requirements.

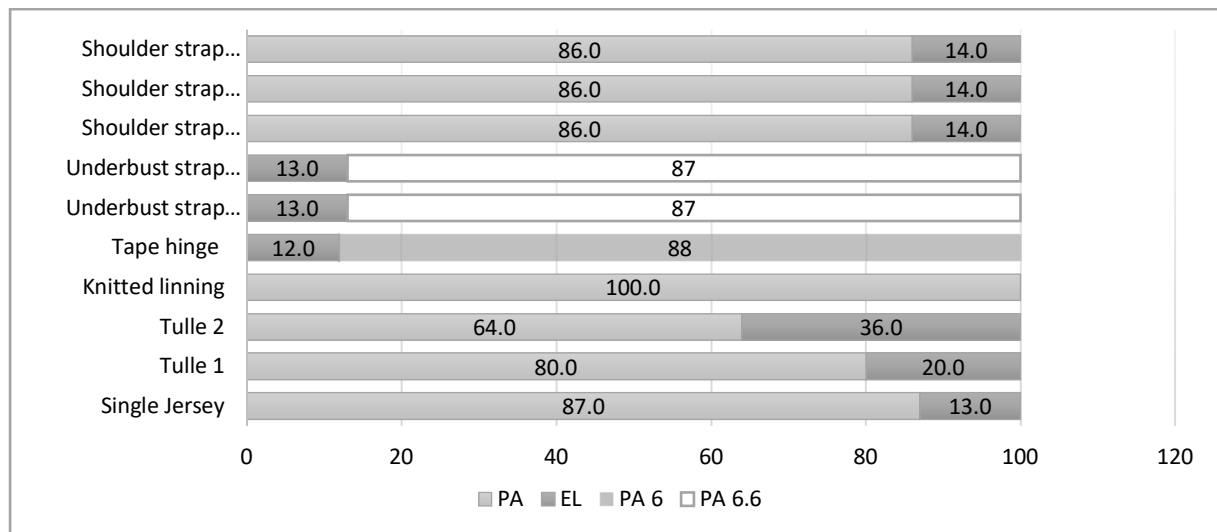


Table 1 tested Materials

The following illustration visualizes the impact of the material, depending on its use in one of the material zones. Here it is important to decide on the basis of the shape of the breast on what is necessary to achieve the optimal shape. In case of a breast with a ptosis tendency, it is highly recommended to use a material with a high elongation force for the lower half of the breast, so that the breast volume is raised. In the case of a breast where it is not necessary to lift the volume, it is possible to use a material with a high elasticity and low elongation in the lower half of the breast, so that the natural volume is preserved.

The same applies to the use of materials in the upper part of the breast. For a breast with ptosis tendency, it is best to use a material with high elasticity and low stretch in the upper part of the breast, so that the volume can be modeled. On the other hand, for one of the upper breasts in Figure 7, a material with high elasticity can be used to reduce the volume and optically move it to the lower breast area.

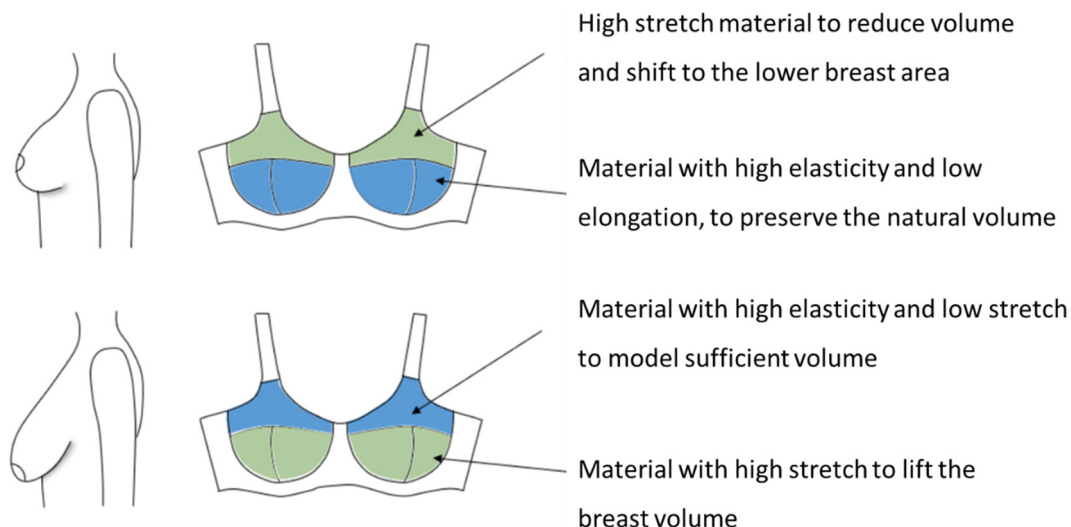


Figure 7 Material Zones Impact

4.3. Interactive pattern style development

A pattern construction with no or hardly any parameters based on experience or correction factors is important to ensure that the dimensional adjustment in the interactive pattern construction is as exact as possible. In order to achieve this, it is necessary to combine the pattern construction systems examined in the research and seam placement options for creating a final basic pattern. In addition, the properties of the tested materials should be included as parameters in the construction. In contrast to the conventional pattern construction, the new construction manual is prepared in such a way that the respective X and Y coordinates of the construction points are given and each line and curve is described by mathematical formulas. Furthermore, different seam placements allow different modeling of the breast so the optimal shape of the breast can be achieved by combining seam and material. The seam placement can be integrated into the interactive pattern construction by shifting the lines without increased work volume. Due to the fact that the female probands in this study are scanned without a bra, the natural shape of the breast can be captured and on the basis of this, the placement of the seams can be decided in order to achieve an optimal shape of the breast in the bra.

All in all, a basic pattern was developed which covers the breast optimally and can be adapted to individual breast measurements. In initial tests to test the process, the basic bra pattern was checked for its fit on an existing avatar. This avatar from the CAD program V-Stitcher is specially optimized in its body shape for bra simulations and was measured by hand, so that it could be imported into the interactive pattern construction as a test. [6]



Figure 8 Basic Pattern

For the development of the interactive pattern design, different CAD systems were first tested for their suitability, e.g. Blender, Assyst Vidya, Grafis, etc. It turned out that for the development of the interactive pattern design the software Rhinoceros with the associated plug-in Grasshopper is most suitable for the requirements of our project. This is a program, which allows the parametric design of 2D surfaces, but also 3D objects. [9]

The parametric development of the first basic pattern construction made it possible to develop a first prototype of the program, which so far only uses a few construction parameters. The goal of this prototype development was to test the feasibility. The following dimensions were used for the prototype of the interactive pattern construction.

Basic Pattern	Model Construction
Breast girth	Strap width
Under breast girth	Bar girth
Chest girth	Cup horizontal seam
Lower length	Width under bust band
Arm step	Curve under bust band
Dart 1 [ra1]	Upper shape under bust shape
Dart 2 [ra2]	Closing width
Strap Start	Shape arm step
Center front to center chest	Upper cup shape
Upper Chest start to center chest	Lateral cup shape
Lower chest start to center chest	Bar shape

Table 2 Dimensions for Prototype

For the further development of the interactive pattern construction, a short draft was worked out in which order measurements and parameters should be queried in the program to obtain a custom-made pattern construction. The measurements of the proband are automatically imported from the scan into the programmed pattern construction using another plug-in for the Grasshopper program.

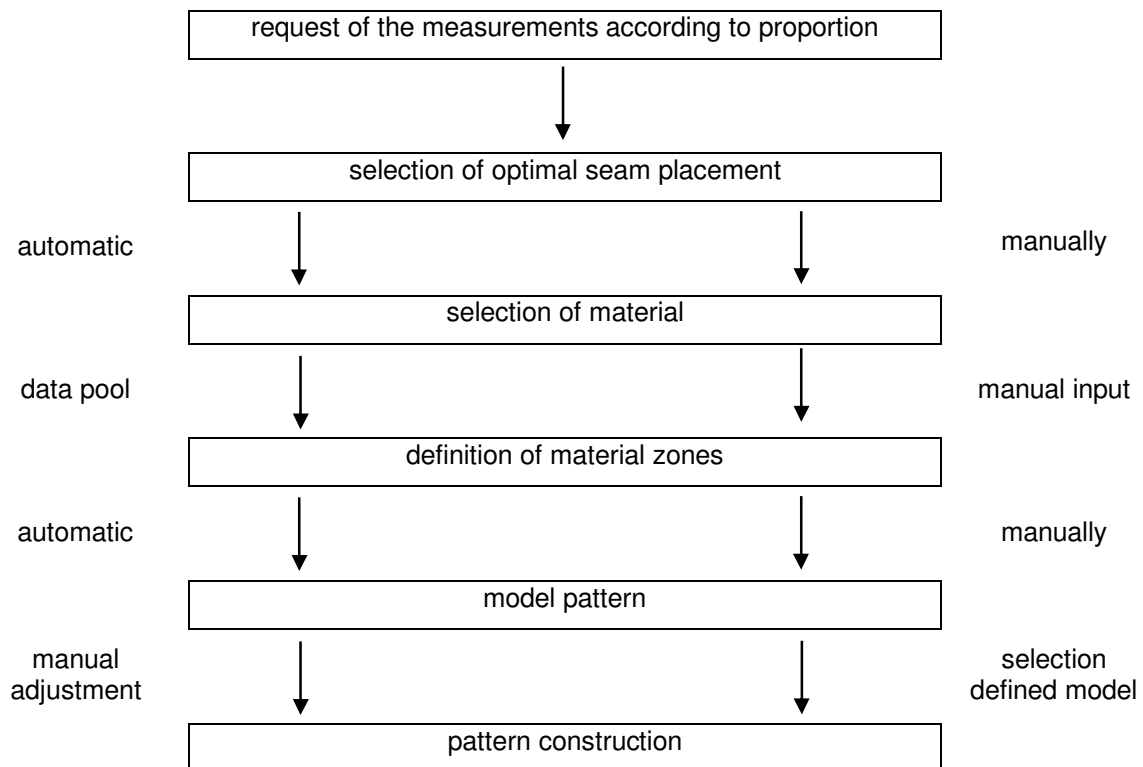


Table 3 Principle sketch interactive pattern construction

The idea is to first query the dimensions by proportion. From this, the program can automatically select the optimum seam lines based on the results from basic pattern researches and material testing. Alternatively, these can also be selected manually using the drag and drop bar. The available materials can then be selected in the program from a data pool or set manually based on defined material parameters. Depending on the breast shape, the material zones or the materials to be used must then be selected according to the seam shape. Finally, the bra shape can be selected.

These queries are then used to create the pattern construction based on the measured and calculated body measurements.

5. Conclusion

Important work on the development of an automated product construction process for tailored bras using breast-specific measurements from 3D body scans in conjunction with an interactive pattern construction have been completed. Thus, a new scanning method was developed and new breast-specific measurements could be defined. Furthermore, a pattern program for a basic pattern in Rhinoceros could be developed, for which different pattern systems and the optimal shape of the female breast were analyzed in advance. The placement of the seams on the cup and the use of the material properties in the different cup zones for shaping the natural form of the breast were considered.

in the further course of the YourBRA project, the material properties must also be tested further and implemented in the modular design system. This project also involves basic research, since today's size system is not sufficient to adequately describe the female breast, since only the difference between the bust and under bust circumference serves as a measure, whereas here the volume of the breast serves to construct a pattern. Women with the same body measurements can have significantly different breast volumes and shapes. Especially in the breast area it is still a challenge to measure customers or to use avatars to develop apparel. An avatar with an exchangeable chest area, which can also have different firmness, would be a solution. Therefore, the goal is to learn more about the shape of the breast, the shape differences between dressed and undressed breast and the age-dependent deformation of the breast to take another step towards the creation of soft avatars.

Furthermore, for this project the 'shrinkwrap' function must be embedded into the interactive pattern program in Rhino. Recording the pattern, the fit must be further modified in the construction development by using different materials or by adapting determination of the elastic limit of each material according to DIN 53835-13. If the material is stretched beyond this limit, plastic deformation of the material occurs, which in the long run leads to a reduction of the supporting effect. By determining the elastic limit, the pattern can be adjusted so that the elongation of the material remains within the elastic deformation, thus ensuring the durability of the finished product.

Finally, an analysis of individual production processes for economical and efficient resource planning with a focus on automation and networking is necessary and adjusted accordingly to achieve efficient and economically expedient production.

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