DIPLOMARBEIT

3D Landmark Acquisition From Photographs

A Morphometric Approach on Human Faces

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Zusammenfassung

Das Ziel dieser Studie ist es, zu erforschen, ob es Software Alternativen zu 3D Oberflächenscannern gibt, die in der Lage sind, aus 2D Bildern 3D Modelle zu erstellen. Oberflächenscanner sind weit verbreitet und produzieren für gewöhnlich äußerst genaue Modelle von 3D Oberflächen. Die Nachteile solcher Scanner liegen in den hohen Kosten und der komplexen Handhabung und Wartung. Software Anwendungen dagegen sind kostengünstiger, einfacher zu bedienen (z.B. Transport) und zu warten. Darüber hinaus könnten sie in der Lage sein, schon vorhandenes Bildmaterial, z.B. von Verbrechensopfern oder Abbildungen historischer Persönlichkeiten, zu verarbeiten. Aus diesem Grund wurden zwei Software Lösungen, Eos systems PhotoModeler Scanner 2010 (Pm) und Singular Inversions FaceGen Modeller (Fg), in Hinblick auf Anwendbarkeit und Genauigkeit anhand einer realistischen Fragestellung der Anthropologie getestet: Dem Sexualdimorphismus in menschlichen Gesichtern. Die Ergebnisse der Software wurden gegen unseren "Goldstandard", den optoTop-He Oberflächenscanner der Firma Breuckmann GmbH (Br), getestet. Für diese Diplomarbeit wurden Oberflächenscans und sieben Fotos von insgesamt 65 Probanden (31 Frauen und 34 Männer) erfasst. Abhängig von dem verwendeten System wurden bis zu sieben Fotos benutzt, um die 3D Modelle zu erstellen. 12 Landmarks in den Modellen wurden benutzt, um eine Generalized Procrustes Analysis (GPA) der Daten zu rechnen. Procrustes Distances, centroid sizes und shape coordinates wurden für anschließende statistische Auswertungen herangezogen. Die Ergebnisse eines Permutationstests der shape space Daten zeigt signifikante Unterschiede in männlichen und weiblichen Gesichtern. Für Breuckmann sind die Unterschiede signifikant mit $p < 0{,}006$. PhotoModeler erreicht ähnliche, aber weniger signifikante Ergebnisse ($p < 0{,}024$). Im Gegensatz dazu konnte der FaceGen Modeller kein signifikanten Ergebnisse produzieren ($p < 0{,}17$). Die Analyse im form space wurde nur mit Breuckmann und PhotoModeler durchgeführt, da der FaceGen Modeller keine verwertbaren Größenangaben bereitstellt. Im form space sind die Ergebnisse für den Geschlechtsunterschied signifikant für die beiden übrigen Systeme (Breuckmann und PhotoModeler) mit $p = 0{,}0001$. Ein weiterführender Vergleich Breuckmann - FaceGen - PhotoModeler zeigte, dass die PhotoModeler Modelle signifikant näher am Breuckmann liegen, als die Modelle des FaceGen Modellers ($p < 0{,}00005$). Der Maximale Unterschied zwischen den PhotoModeler und Breuckmann Modellen lag bei 9,62 mm. Der durchschnittliche Unterschied ist mit 1,84 mm und einer Standardabweichung von 1,42 mm hingegen wesentlich geringer. Die Ergebnisse weisen darauf hin, daß der PhotoModeler eine ernsthafte Alternative sein kann, um 3D Modelle ohne einen Oberflächenscanner zu erstellen. Die Anwendbarkeit der Software ist nicht nur auf die Biologie beschränkt, sondern richtet sich an alle Gebiete, in denen die Verwendung von 3D Modellen notwendig ist.

Abstract

This study has the aim to explore if software alternatives based on 2-D images could be used to generate and measure 3-D surface models of faces instead of using genuine 3-D surface scanners. The latter are widely used and usually produce quite accurate models of 3-D surfaces. However, the disadvantages of such scanning systems are that they are rather costly and complicated to use and to maintain. On the other hand, software applications are less costly and easier in the handling (e.g. transport) and maintaining. Furthermore they would potentially allow to work with prior existing image material, e.g., photos of crime victims or paintings of historic figures. Therefore the applicability and accuracy of two software solutions, Eos systems PhotoModeler Scanner 2010 (Pm) and Singular Inversions FaceGen Modeller 3.4(Fg), were tested in a lifelike question of physical anthropology: The sexual dimorphism in human facial shape and form. The software results were tested against our 'golden standard', the optoTop-HE optical surface scanner from Breuckmann GmbH (Br).

For the thesis 3-D surface scans and 7 photographs of 65 test persons (31 female and 34 male) were obtained. Depending on the system, the software used up to 7 images to create the 3-D models. A set of 12 landmark points on the models was used in the next step to compute a General Procrustes Analysis (GPA) of the data. Procrustes distances, centroid sizes, and shape coordinates were used for the subsequent statistical analysis.

The results of a permutation test of the shape space data show significant differences in male and female faces. While for the Breuckmann system differences were significant at $p < 0.006$, PhotoModeler software solution arrived at a similar but less significant result ($p < 0.024$). FaceGen Modeller, in contrast, wasn't able to show any significant differences ($p < 0.17$). The analysis in form space could only be performed with the Breuckmann and PhotoModeler data because FaceGen models do not contain any usable information about size. In form space, the results of the sexual dimorphism are significant for both remaining systems (Breuckmann and PhotoModeler) with $p = 0.0001$. A further test of the systems between Breuckmann - FaceGen - PhotoModeler revealed that the PhotoModeler models come significantly closer to Breuckmann models than the FaceGen models do ($p < 0.00005$). The maximum difference between the PhotoModeler and the Breuckmann models was 9.62 mm. However, the mean difference is much smaller, i.e. 1.84 mm with a standard deviation of 1.42 mm. These results indicate that at least the PhotoModeler scanner could be a serious alternative to produce 3-D models without the use of a surface scanner. The applicability of the software is not limited to the use in life sciences but a large number of scientific fields wherever the use of 3-D models is necessary.

1. Introduction

1.1. Measuring the human face

For decades morphological research on human faces was performed either on the living subject or by means of 2D photographs. Within the last few years and with the development of new systems we are now able to produce three dimensional models of human faces. The methods and tools for data acquisition, processing and analysis of 3D shape and form are part of a new interdiscipline: Virtual Anthropology.

One very important subdomain of Virtual Anthropology to which this thesis contributes is Photogrammetry. Not only since the last years but also for the future, especially when looking at the challenges the society is currently facing. The range of the work in this field reaches from identification of individuals/ suspects for surveilence purposes and identification of crime suspects perpetrators to a lot of applications in medical research for surgical planning and even in social sciences, for example studies on attractiveness and sexual dimorphism. I will show that for all those purposes much work was done in the last years and that one need only a decent digital camera and a software to produce reliable and usable results. Full scale optical surface scanner are not mandatory for all questions in this field. They are costly and mostly complicated in useage but of course deliver greater resolution. There are, however, many applications that do not demand such high resolution, thus rather cheap and simple methods of creating 3D human facial models with software packages like PhotoModeler Scanner and Facegen Modeller can be applied.

Parts of this thesis were presented to the public at several occasions. The 3rd symposium of Facial Analysis and Animation 2012 in Vienna, Austria (Paul et al., 2012) and the 13. Jahrestagung der MVE-Liste 2013 in Nürnberg, Germany. I will start with an introduction to the field of facial morphology and the applicability of this study in particular, followed by a short introduction to the different systems I used for this study and close with a perspective of further use of the results for follow up studies.

1.2. Human Facial Morphology

In 1981 Leslie G. Farkas published his textbook *Anthropometry of the head and face in Medicine*. A second edition of this book was released in 1994. These atlases of the human facial morphology were the most comprehensive at this time and formed the standard literature for further work, as they established a new system for craniofacial morphology introduced by Farkas. This system included the use of anthropometric landmarks and the linear and angular measurement of distances and deviations between those landmarks (Farkas, 1994; Deutsch et al., 2012).

Since then a lot of other work was published in 2D and 3D as well for facial human morphology. Since the beginning of anthropology, much earlier than Farkas published his atlases, the sexual dimorphism in humans was a driving question. Although a lot of work was done in this field, the results of many studies on human facial morphology still show diverse results in many aspects. In 1993, Ferrario et al. examined the sexual dimorphism of the human face in shape and size by measuring the Euclidian distances between facial landmarks on 108 adults. The results showed that male human faces are longer and wider and the shape being more rectangular for male and more squared for female faces (Ferrario et al., 1993).

In 1995 a study on sex differences of the shape of facial soft tissue followed. By using a Fourier analysis, Ferrario et al. were able to correct for size and showed that there is no significant sexual dimorphism in the shape of the human face (Ferrario et al., 1995a). In 2005 Fink et al. investigated the correlation of seceond to forth digit ratio and facial shape (Fink et al., 2005). Facial width to height ratio (fWHR) was proclaimed to be shaped by sexual selection and highly dimorphic in human faces (Weston et al., 2007) but was later disapproved by (Lefevre et al., 2012). As one can see, there is a lot of discussion still going on, on the topic of human facial morphology. The broad variety of literature on this topic also includes studies that focused on attractiveness and asymmetry in the human face (Potter and Corneille, 2008; Ozdemir, 2012; Sforza et al., 2012).

1.3. Forensic and medical Applicabilities of the study

There is a wide range of applications in forensic and medical science to make use of photogrammetry. For instance, a big role in forensic science plays the identification of suspects or perpetrators on images of surveillance cameras on airports or other crowded places (Lynnerup et al., 2003; Lynnerup and Vedel, 2005). In medical science an important issue is the correct planning of surgeries in the facial region (Kovacs et al., 2006). It is always a tightrope walk between the art of reconstructing the patient's face to be as similar as possible to the state before an accident, and the technical limitations of the reconstruction techniques. In both aspects, forensic sciences and medical surgical planning, many efforts were undertaken to improve the techniques with the help of photogrammetry. PhotoModeler software is already in use by police authorities to reconstruct car accidents (Randles et al., 2010) and crime scenes. Randles was able to produce photogrammetric reconstructions of cars with a maximum difference of 3.2 cm and a mean difference of 0.1 ± 1.0 cm to the real model. With this study I try to evaluate a cheap but nevertheless reliable solution of photogrammetric applications: The direct use of 3D software to reconstruct human faces from a series of

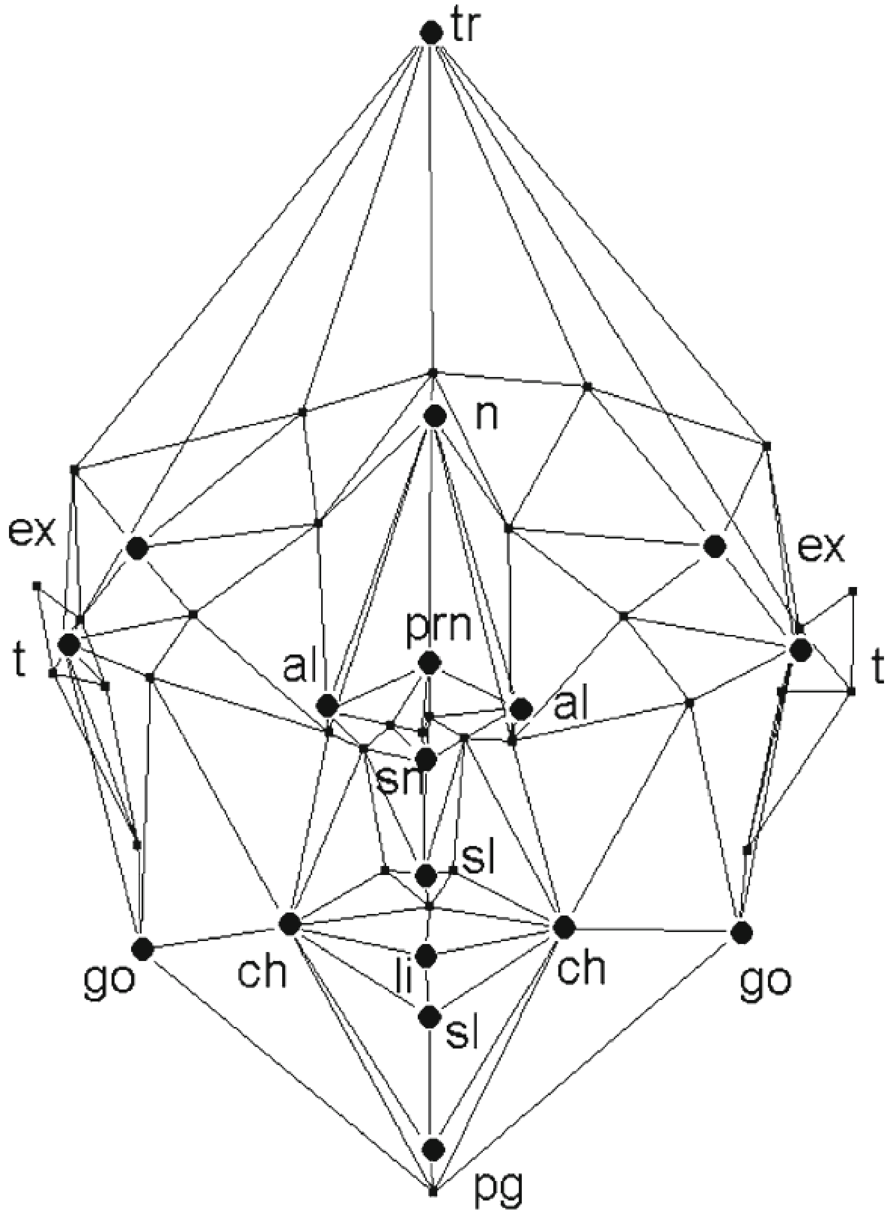


Figure 1.1.: Euclidian distances on the human face (Sforza, 2012)

2D photographs. Depending on the scientific question, the use of just a digital camera on the scene can be a great advantage over a surface scanning system that has fairly big requirements.

1.4. Breuckmann optoTOP-He

The Breuckmann optoTOP-He is a precision 3D optical surface scanner of the Breuckmann GmbH. The optoTop-HE system is equipped with a projector and a camera mounted on a beam. The scanner provides interchangeable beams in different lengths and lenses with different focal distances for the cameras and projectors depending on the actual size of the scanned object. The maximum depth resolution of the scanner also depends on the size of the object. With the image diagonal being 200-400 mm the scanner has a maximum depth resolution in the Z-plane of 4-8 μm (Breuckmann data sheet as of January 2005). For this study the Breuckmann scanning system is treated as the 'golden standard' as of its accuracy and high resolution that is proven in many studies (Gunz et al., 2009; Freidline et al., 2012). Along with the scanner itself comes a software suite (OPTOCAT 2007) which is used for calibrating the system, conducting the scans and handling the raw models. To produce a good scan of the human face the investigator should keep in mind that extensive facial hair and decoration like piercings can influence the scan and should be avoided.

1.5. PhotoModeler Scanner 2010

Eos Systems PhotoModeler Scanner 2010 is a piece of software that is capable of producing 3D models from a set of 2D photographs. The creation of the 3D wireframe models is quite time consuming and is rather complicated for the inexperienced user. There are several techniques to enhance the process of model creation like the use of 'coded targets'. The accuracy of the software strongly depends on the quality of the photographs, the surface properties, and the material the real world model is made of. The great advantage of the software is the wide variety of applications, whether it is human faces, the reconstruction of cars or the complete rebuilding of a 3D scenery. A study with an earlier version of PhotoModeler on facial identification showed the capability of the software in producing 3D wireframe models of human faces. The study showed that in 9 of 15 cases the faces where identified to the right person (Lynnerup et al., 2003).

1.6. FaceGen Modeller 3.4

The FaceGen Modeller by Singular Inversions was mainly developed to produce 3D models of human faces for computer applications. A great part of the software uses a standard model of the human face which can be morphed in many different aspects. From male to female and vice versa, different ethnic groups can be simulated and even motions can be brought to the model. The PhotoFit part of this software lets the user produce a 3D model out of a set of three photographs1 of the human face. The procedure of creating the 3D model is software guided which makes the process straight forward and takes about 5-10 minutes per model[1]. The literature about FaceGen Modeller focuses on the capability of the software to morph faces (random or from the PhotoFit) (Potter and Corneille, 2008). However independent of the used software there are a few restrictions that have to be kept in mind when taking the photographs. The test person should not wear glasses, the pictures should be taken without the flash or additional light sources and extensive make-up or facial hair can also influence the quality of the 3D model.

[1] depending on the hardware of the machine

2. Materials & Methods

2.1. Materials

2.1.1. Face Scans

For this study a total number of 65 surface scans of 31 female and 34 male students between 18 and 35 years of age were obtained. During the course of data analysis 2 male individuals had to be excluded after the GPA. A more detailed explanation follows in **Chapter 4.1**. All test persons signed a letter of agreement to allow usage of their scans and images for data analysis and presentation. All facial scans were obtained with a Breuckmann optoTop-HE optical surface scanner.

2.1.2. Facial Images

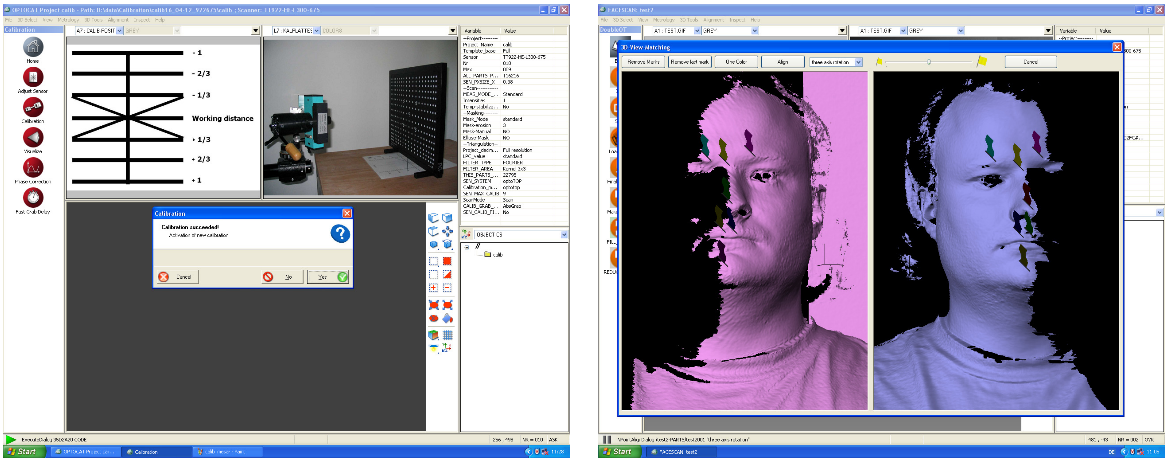
To ensure that the test persons show the same facial expression on the scan and the photographs, 7 facial images from different angles around the test persons were taken with a digital camera just before the scans were obtained. Neither additional lights, nor the camera's internal flashlight were used, only the normal background lights of the room. The camera distance to the object was about 1.5 m. The photographs were not standardized because part of the thesis was to test how the software handles 'everyday' pictures. The first 9 faces were captured with a Canon EOS which was replaced later by a Sony Cybershot DSC-W170 which captured the rest of the data sample. The exchange was necessary due to the fact that the Canon EOS was no longer available for the study.

2.2. Methods

2.2.1. Model Creation Breuckmann optoTOP-HE

As mentioned in section 1.4, the Breuckmann optoTop-He scanning system was used to produce the 3D surface scans. The first step in the process was to set up the scanner with the correct set of lenses for objects about the size of the human face, and than to calibrate the system. Calibrating the scanner took between 30 minutes and an hour till all necessary steps were conducted. Once the scanner was calibrated the test persons were instructed to sit down in front of the scanner in an upright position with a relaxed, neutral facial expression. One scan took about ten seconds to complete. After the scanning process the raw models were loaded in the OPTOCAT

2007 software 3D viewer to check if all wanted details were captured. After inspecting the models, the two separately obtained scans had to be joined. For aligning the scans, corresponding points on the surfaces of both scans were flagged (**Fig.2.1b**) and the software's matching algorithm aligned the parts automatically. In the last step all models were reduced in size to facilitate the further handling of the data and then exported to the .stl file format.



(a) Calibration process   **(b)** Align process in OPTOCAT 2007

Figure 2.1.: Generating a Breuckmann surface scan

2.2.2. Model Creation FaceGen Modeller 3.4

The procedure of creating the surface models in FaceGen Modeller was quite straightforward. The PhotoFit Tab section of the software is the part which is responsible for creating the models. The whole process is done in three simple steps but one has to be careful to meet a list of requirements. The model creation process starts with importing the photographs into the software. To meet the software's requirement that faces should be about 500 pixels in height, the photographs were cut with the free GNU Image Manipulation Program (GIMP), because the resolution of the raw photographs was about 3648 x 2736 pixels. The second step included setting the reference points on the photographs. Again this was relatively easy to accomplish as the software uses a predefined set and one needs only to match the right position, which is shown in an extra example image next to the working window. Once the reference points were set correctly, the model creation algorithm started. This process usually took between 5 to 10 minutes. According to Singular Inversions the speed mainly depends on the power of the GPU. After this was done, the models were exported to the .stl[1] file format.

[1] 3D systems stereolithography file format

After communication with Singular Inversions it became clear that FaceGen Modeller does not provide any absolute size information. A. Beatty stated (personal comm., 03.06.2013): *'The shape basis provided by FaceGen Modeller is the PCA distribution in the tangent-space to the (approximate) Procrustes space distribution of our dataset. (Singular Inversions uses a standard face model computed of several hundred faces and to which the surface texture of the calculated model is morphed in the model creation process). One of the reasons it's only approximate is that the internal model used to calculate this only covers the face area, not the entire head.'*

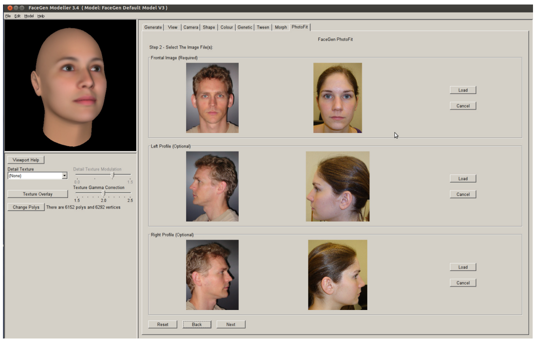


Figure 2.2.: PhotoFit in FaceGen

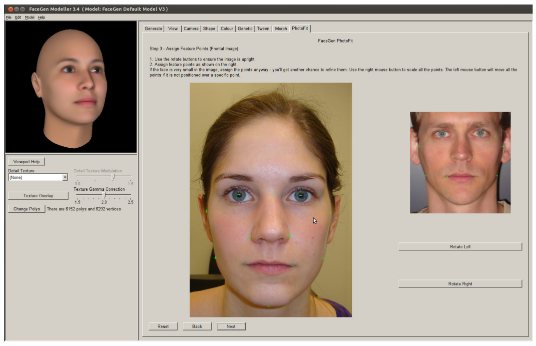


Figure 2.3.: Assigning the feature points

2.2.3. Model Creation Photomodeler Scanner 2010

The procedure with PhotoModeler Scanner 2010 was slightly different compared to the other systems, because no real 3D surface model was created during the process. At the beginning of the process, one has to decide which kind of project to use as there are several different kinds for different purposes. In this case the 'points-based project' was used. This is used when the model creation is based on single points only. For this 'points-based project', up to 7 photographs taken from different angles were imported into the project. The software has a few restrictions that are advised to be followed to guarantee accurate models. If the angle between two photographs is too low, accuracy is suffering. It is much better to use larger angles (up to 90°) to cover a greater area of details. At the beginning of each project the imported images are assigned to a camera calibration file and they come un-oriented. This means that the software doesn't know anything about the relationship between the photographs or the camera positions. To move on, the photographs have to be referenced. For image referencing the software uses so called 'reference points' to compute the 3D model of a scene. (While working with the images it is advised to reference no more than four images at the same time. The best way is to reference the images pairwise to minimize the chances for failure and to make troubleshooting easier). Setting the reference points was done by selecting a single image and clicking on the 'Mark Points Mode' tab. Care was taken to set the points on the corresponding spot in each image. In contrast to the FaceGen Modeller, the location of these points is not predefined and the decision, were to put points depends on the user. Thus in this case (no 3D surface model needed to be created to locate landmark points), the 12 landmark points for the later analysis are the same as those used for referencing the images. Once all the points were set on all images, the reference procedure was started by using the 'Reference Mode' tab. Here you have to select one image as the 'reference' and manually reference all the points in the images in regard to this 'reference'. After this is done the algorithm of the software provides an estimation of the accuracy and computes the 3D point cloud. Before exporting the 3D models, each project was scaled and oriented. The first models were scaled on the basis of known lengths of background structures and later on with help of coded targets. These coded targets were put on the wall and used during the later course of the data acquisition to enhance the process of image referencing in addition to the 12 points set in the probands faces.

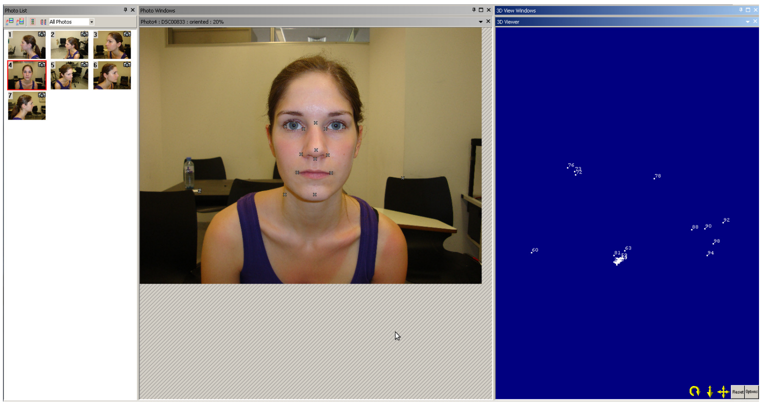


Figure 2.4.: Model creation in PhotoModeler

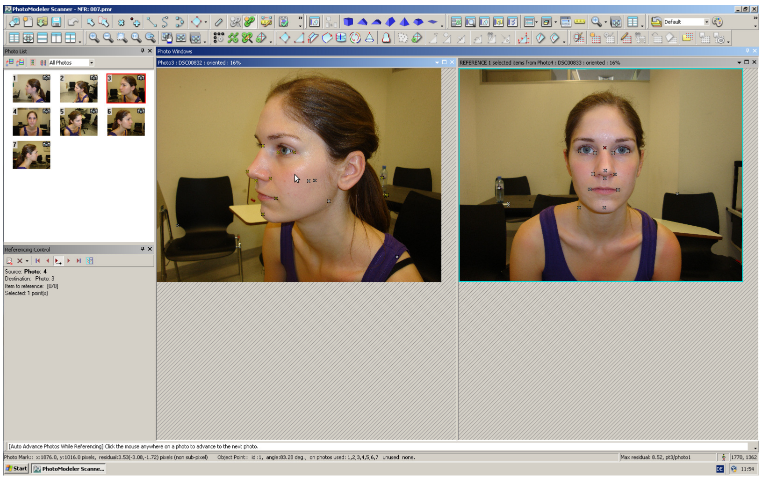


Figure 2.5.: Image referencing in PhotoModeler

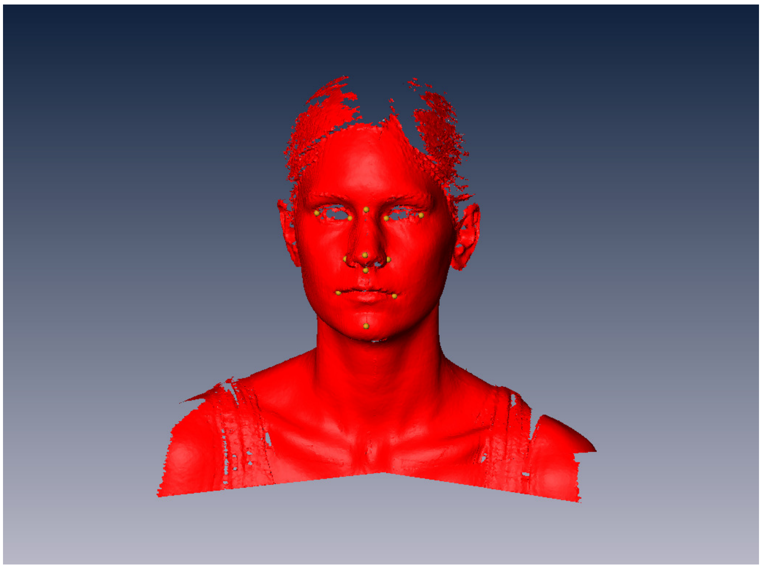


Figure 2.6.: Breuckmann face model with applied landmark points

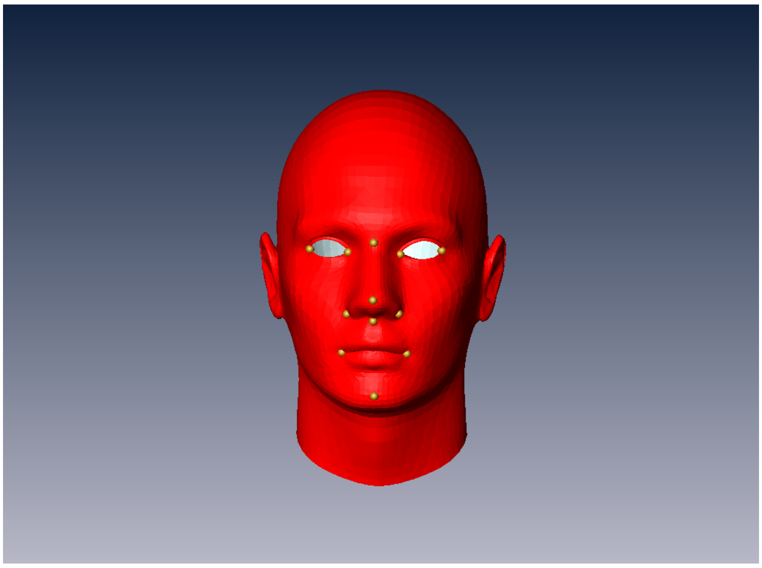


Figure 2.7.: FaceGen Modeller face model with applied landmark points

2.2.4. Landmark Points

An anatomical landmark is a point that is homologous on all specimens in the same sample. Geometric morphometrics adds a more technical aspect to this definition where a landmark point is not only defined by homology but also by its coordinates in a geometrical space (Bookstein, 1991; Schaefer et al., 2009). In a biological meaning the definition of homology includes tissues or structures in the body that share the same evolution or function. (Owen and Cooper, 1843)[2]. In his 1991 published textbook, Bookstein defined three types of landmarks.

These types are,

- Type I: *discrete juxtapositions of tissues*
- Type II: *maxima of curvature or other morphogenetic processes*
- Type III: *extremal points*

This list of landmark definitions was revised and extended by three additional types for semilandmarks to replace the definition from 1991 (Weber and Bookstein, 2011).

Extended list for landmarks and semilandmarks:

- Type I: *discrete juxtapositions of tissues*
- Type II: *extremes of curvature*
- Type III: *landmark points characterised locally by information from multiple curves and by symmetry*
- Type IV: *Semilandmarks on curves*
- Type V: *Semilandmarks on surfaces*
- Type VI: *Constructed semilandmarks*

The landmark points used in this study comply with the traditional landmarks used in anthropometry (Farkas, 1994; Vezzetti and Marcolin, 2012b), (Preedy, 2012). See table **2.1** for a complete list of the used landmarks and their definitions. Setting the landmark points on the models was done in VSG's Amira 5.4.3. (**Fig. 2.6 and 2.7**). To avoid confusion during analysis, the landmark points were numbered from top to bottom and left to right. Care was taken to set the points in the same order on each model. The landmark files were saved and the raw coordinates were extracted and transferred to the Morphologika file format and then used for the statistical analysis.

[2]'the same organ in different animals under every variety of form and function.'

Table 2.1.: Anthropometric landmark points

Landmark (number)	Name	Definition
n (1)	*nasion*	The sagittal midline point of the nasal root at the nasofrontal suture
ex (2/5)	*exocanthion*	The most lateral point of the palpebral fissure, at the outer commissure of the eye
en (3/4)	*endocanthion*	The most medial point of the palpebral fissure, at the inner commissure of the eye
prn (6)	*pronasale*	The most protrusive point of the nasal tip (apex nasi), identified in lateral view
al (7/8)	*alare*	The most lateral extents of the alar contours
sn (9)	*subnasale*	The midpoint of the point of inflection of the columellar base at the juncture of its lower border with the surface of the philtrum
ch (10/11)	*cheilion*	The most lateral points at the labial commissure
pg (12)	*pogonion*	The most protrusive anterior sagittal midline point of the chin

2.2.5. Geometric Morphometrics

In this section, I will give a short overview about the methods of geometric morphometrics but will concentrate on the parts that were important to my thesis, namely the principles of the Generalized Procrustes Analysis (GPA) and of the Principal Component Analysis (PCA).

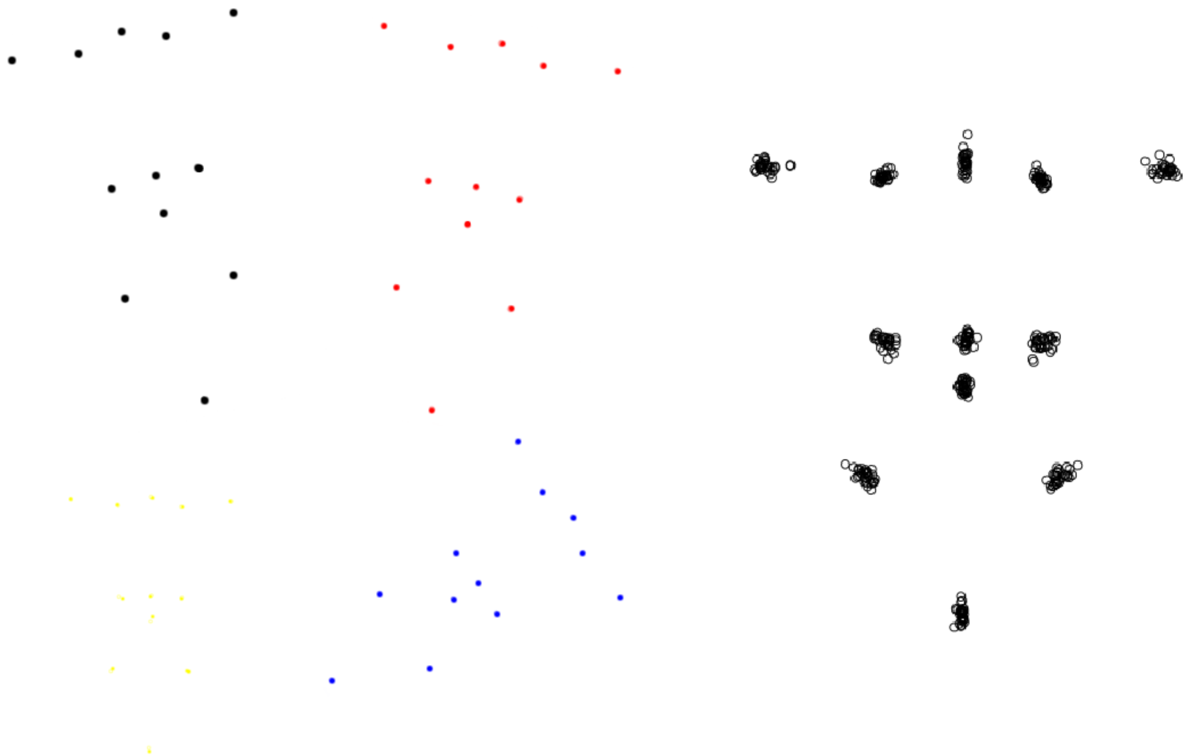
The principles of modern geometric morphometrics (GM) were well-established in the field of biology in the 1980s and 90s by the contribution of morphometricians like Fred Bookstein, Leslie Marcus, James Rohlf, Dennis Slice, and many others. The main concept of GM is to provide the tools for measuring and analysing differences in shape and size (Bookstein, 1991; Zelditch et al., 2004; Slice, 2005) through the use of landmarks, semilandmarks and ridge curves. (Bookstein, 1991; Buckley et al., 1999; Mitteroecker et al., 2004)

The idea of the Generalized Procrustes Analysis is to transform data sets in a way that makes it possible to compare the data arising from different coordinate systems in their shape and form. A GPA is performed in three steps. Scaling, translation and rotation of the data. Prior to the first step of the GPA the centroid for each landmark configuration on each form is computed separately. Scaling the form means that the Procrustes distance from the landmark points to the centroid equal 1 for each form. Translation will superimpose all forms on their centroids. In the rotation step the sum of the squared Procrustes distance of each landmark on each form will be minimized. See **Fig.2.8b** for a landmark configuration after a GPA. The output of a GPA contains the Procrustes shape coordinates, the Procrustes distances and the centroid sizes. The principles at the basis of a PCA are, to simplify complex datasets and detecting patterns of the variance of similarities or dissimilarities in samples. For finding these patterns PCA goes back to a variety of mathematics, for example eigenvalues, covariance matrices and singular value decomposition (SVD). I will not go into detail on the mathematics here, as they are already well described in many books and papers (Bookstein, 1991; Zelditch et al., 2004; Slice, 2005).

In this study the PCA was conducted to learn more about the variance of the sex differences in shape and size in my sample. Therefore the Procrustes shape distances computed in the GPA went to the analysis of variance into a PCA.

2.2.6. Statistical Analysis

Statistical analysis was performed with the EVAN Toolbox for the GPA and PCA, the statistical package R for the t- and permutation tests of the mean Procrustes shape coordinates and PAST for the permutation test of the logarithm of Centroid size and for computing the euclidian distances of the raw-coordinates. The design of the EVAN Toolbox makes morphometric analysis straight forward and keeps the needed steps from importing the data to the PCA-plots at a minimum. Import of the data



(a) Landmark data before GPA (b) Landmark data after GPA

Figure 2.8.: Generalised Procrustes Analysis

sets of my thesis was done in the morphologika file format. After the required nodes were added to the data window, several GPAs with different settings for shape and form space were performed. The output file of GPA contains the Procrustes shape coordinates, the centroid size and the Log of Centroid size which contains the size information of the models. The pairwise Procrustes distances for the Breuckmann - FaceGen and Breuckmann - Photomodeler data and the log of centroid sizes were than saved in text files for statistical analyses in R. In the software R paired t-tests for dependent samples were performed for the Procrustes distances to get to the deviation of the systems among each other. A script for permutation tests on the Procrustes mean shapes was done to get to the sex differences in shape space. For the differences in size a simple permutation test was performed in PAST.

3. Results

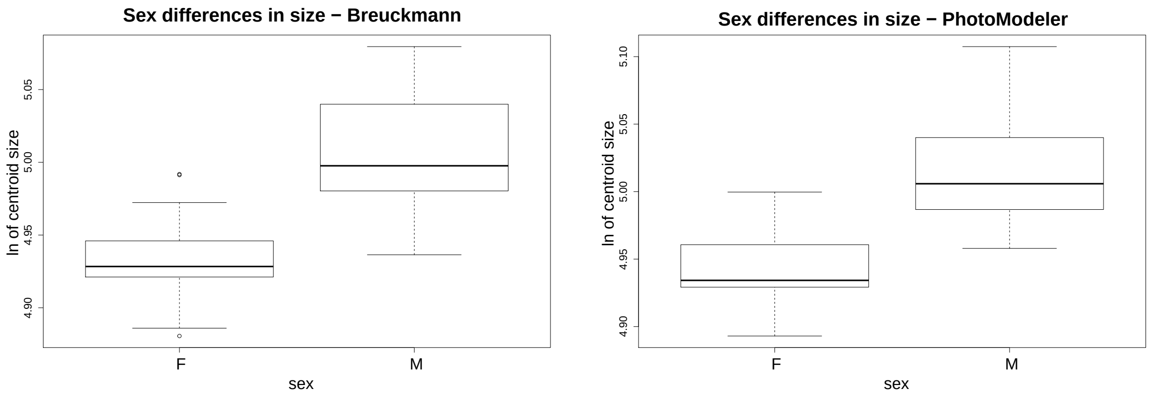
3.1. Sexual Dimorphism

To gain a first but detailed impression of the sex differences both in shape and form space, PC-plots of the data were computed (The PC-plots were moved to the Appendix in **Chapter A** for a larger visualization of the details). The plots for shape space demonstrate rather indistinct sex differences (**Fig. A.9, A.10, A.11**). However the results of a non-parametric randomization test (permutation test) of the male and female Procrustes mean shapes show highly significant sex differences in shape for at least the Breuckmann and PhotoModeler data ($p < 0.006$ for Breuckmann and $p < 0.03$ for PhotoModeler). The FaceGen data show no significant differences in shape whatsoever ($p < 0.17$). For size, only Breuckmann and PhotoModeler data could be used because the FaceGen models have a non-valid scale (see **Chapter 2.2.2**). A permutation test of the log of Centroid Size generates highly significant results for both, the Breuckmann and PhotoModeler data ($p = 0.0001$) (**Fig. 3.2**), meaning that male faces are larger in size than female faces. The corresponding PC-plots of the size differences also show a clear separation between the male and female groups (**Fig. A.7 and A.8**).

(a) Typical male shape **(b)** Typical female shape

Figure 3.1.: Morphological shape differences (exaggerated by the factor 1.5)

A PCA of the data shows that the morphological differences in shape space between male and female faces affect the overall shape of the faces. Male faces are higher but narrower, leading to a more rectangular shape (**Fig. 3.1a**) while female faces are wider, therefore leading to more squared faces (**Fig. 3.1b**). Both models were exaggerated by the factor 1.5 to make the shape differences more prominent. To visualize the related shapes for the systems, the faces were warped in shape space along PC 1 and PC 2 and copied into the plots (**Fig. A.9 and A.10**). The results for the sexual dimorphism in this study are resembling the earlier work of Ferrario and co- workers who's findings show that the overall male face is greater in size and when looking at the shape it is more narrow but higher. In contrast the female overall face is smaller compared to the male face but wider in shape (Ferrario et al., 1996, 1993).



(a) Breuckmann

(b) PhotoModeler

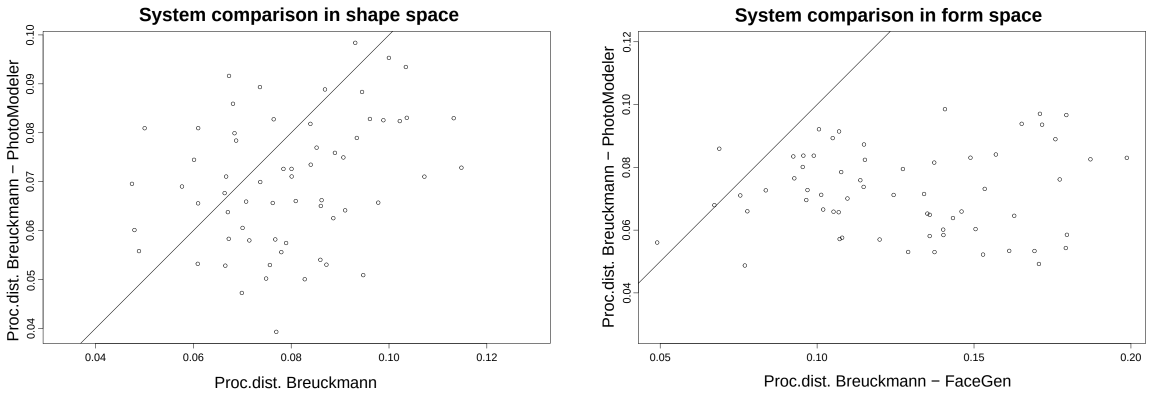
Figure 3.2.: Sexual dimorphism in Size

3.2. System Comparison

The results of a paired t-test after the GPA show clearly that in shape space in 45 out of 63 cases the PhotoModeler models come significantly closer to the Breuckmann models (the 'golden standard' here) than the FaceGen Modeller ($p < 0.00005$, two-tailed). The analysis was performed also in form space. This result is even more significant. PhotoModeler beats FaceGen Modeller in 60 out of 63 cases. But again, FaceGen modeller doesn't acutally allow for form space analysis because of the lack of sensible size information[1]. See **Fig. 3.3** for the results of the paired t-test. The line segments in figures **3.3a**, **3.3b**, **4.4a** and **4.4b** indicate the separation of the system pairs (Br-Fg and Br-Pm) by their Procrustes distances. All cases right of the line represent the cases where the Procrustes distances are greater for Br-Fg and vice versa. If the Procrustes distances Br-Fg would equal the Procrustes distances Br-Pm, all points in the plots would align with the line segment. For a further system-to-system comparison, the Euclidian distances of the raw landmark coordinates for the Breuckmann and PhotoModeler models were computed for each possible pair of the 12 landmarks. In total, 3465 distances (55 landmark pairs of 63 individuals)

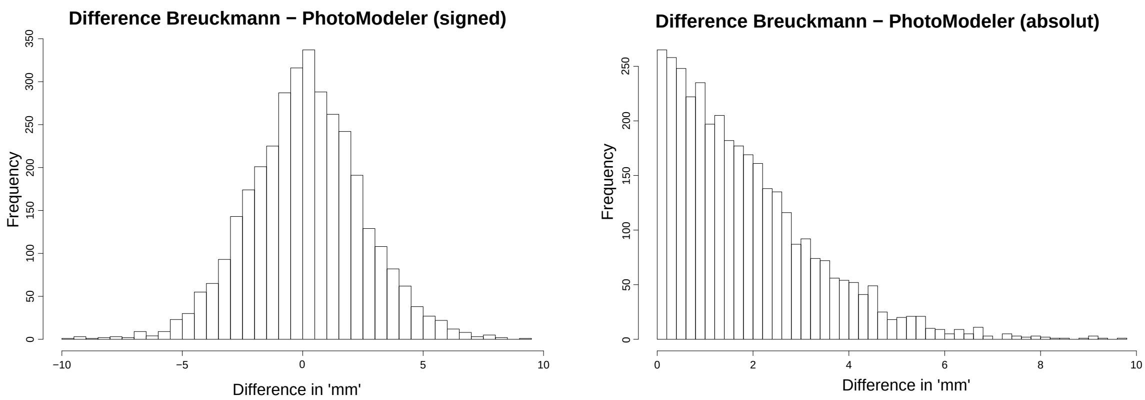
[1]'See Chapter 2.2.2 for more details on this topic'

were computed after excluding landmark point 12 from the analysis (See **Chapter 4.1**). The results reveal a maximum difference of 9.62 mm between Breuckmann and PhotoModeler data and a mean difference of 1.84 mm. The standard deviation of the measurement is 1.42 mm (**Fig.3.4**).



(a) Procrustes Distances Shape Space **(b)** Procrustes Distances Form Space

Figure 3.3.: Procrustes distances Br-Fg and Br-Pm in form and shape space with line segments (for an explanation of the line segments see **Chapter 3.2**)

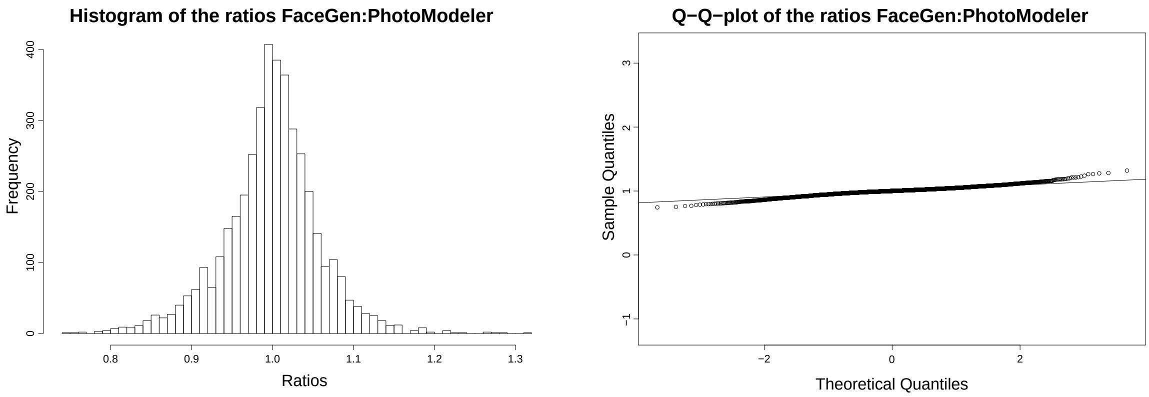


(a) differences signed **(b)** differences absolut

Figure 3.4.: Histograms of the distance between Br-Pm in mm

To gain insight to which extent the systems are different in shape a direct comparison between PhotoModeler and FaceGen Modeller was done by looking at the distance ratios in shape space. These distance ratios would reveal any bias in the relation between the two systems. A total of 4026 distances between each possible pair of landmarks for each individual and system where measured and the ratios between the two systems were computed by dividing each distance measurement of FaceGen

Modeller by the correspondent measurement taken from PhotoModeler. The results reveal that, in general, the inter landmark distances in FaceGen Modeller are slightly smaller than in PhotoModeler with an overall ratio of 0.998. A histogram and a Q-Q plot (**Fig. 3.5**) of the data show that the ratios are close to being normally distributed.



(a) Histogram of the distance ratios **(b)** q-q plot of the distance ratios

Figure 3.5.: Histogram and q-q plot of the distance ratios

Again to have a better visualization of the data PC-plots were computed. The plots show a distinct separation between FaceGen Modeller and the two other systems after the GPA, both in form and shape space (**Fig. A.1 and A.4**). The group means of the Breuckmann and Photomodeler data are plotting considerable closer together, with the FaceGen data forming a more separated group. This fact becomes more obvious when looking at the different PC-plots where the systems were plotted pairwise (Br-Fg and Br-Pm). The PC-plots reflect the results of the statistical analysis of the system comparison. **Fig. A.2 and A.3** show the Procrustes distances between the systems in form space and **Fig. A.5 and A.6** show the Procrustes distances for shape space.

4. Discussion

4.1. Discussion

The aim of this study was to show weather a relatively simple and cost-efficient software solution is capable of producing 3D models accurate enough to be used in lifelike problems in physical anthropology, for instance determining sexual dimorphism of the human face. The results of this study show clearly the potential of the software in comparison to a genuine optical 3D surface scanning system. Regarding a lifelike question as we have it with the sexual dimorphism, the PhotoModeler Scanner software was able to produce the same significant results as the surface scanner in shape space ($p < 0.03$ for PhotoModeler and $p < 0.006$ for Breuckmann) and in form space ($p < 0.0001$ for both systems). The FaceGen Modeller software didn't meet the requirements to produce significant results, neither in shape ($p < 0.17$) nor in form space (for the known reasons).

Looking at the difference between the systems reveals that PhotoModeler comes significantly closer to the Breuckmann models in shape space than the FaceGen Modeller ones ($p < 0.00005$, two-tailed). The PC-plots underscore the results of the statistical analysis **(Fig. A.4)** showing that the Procrustes mean shapes of the Breuckmann and PhotoModeler data are plotting closer together whereas the FaceGen Procrustes mean shape is separated clearly from the two others. Knowing that PhotoModeler comes closer to the 'golden standard' Breuckmann, the question remains on how close does PhotoModeler really come? The results reveal that the maximum difference between the systems is 9.62 mm and the mean difference is 1.84 mm. 93% of the 3465 distances are within the range of 4.3 mm, which corresponds to 3x the standard deviation of 1.42 mm (**Fig. 3.4**). A difference of 9 mm or higher occurs in total 5 times. In 4 of these cases all nasal landmark points (6-9) are involved. One case is related to the cheilion points. All of these points that are involved in producing the biggest distances are prone to errors because the exact locations of these points are hard to be identified in 3D. A study by Fourier et al. (2011), that focused on the accuracy and reliability of anthropometric landmarks, showed that the highest standard deviation in distance measurements include the nasal points (±5 mm for the distances *al* - *al* and *al* - *prn*, ±6 mm for the distances *n* - *pg* and *sn* - *pg* and ±10 mm for the distance *ch* - *ch*). The results are independent from the measuring method, be it in a traditional way with a calliper or virtual on a 3D reconstruction. In physical anthropology a difference of 9.62 mm is rather huge compared to the dimensions of a human head. The average height of a human head is about 197 mm for male and 184 mm for female individuals

(Vasavada et al., 2008). With a measured maximum difference of 9.62 mm between Breuckmann and PhotoModeler this difference would be 4.88 % for males and 5.23 % for females for the total height of the head. For the average width of the head (153 mm for males and 148 mm for females) this would represent a difference of 6.29 % for male and 6.5 % for female individuals. When concentrating on the parts of the head that are actually covered with landmark points in this thesis the difference becomes even more striking. The average morphological face height (*gnathion* - *nasion*) is about 121 mm for males and 111 mm for females. The average for the biocular width (*exocanthion* - *exocanthion*) is about 89 mm for males and 87 mm for females (Farkas et al., 2005). This results in differences in the morphological face height of 7.93 % for males and 8.66 % for females and 10.76 % for male and 11.08 % for female individuals for the biocular width. The percentages for the mean difference between Breuckmann and PhotoModeler (1.84 mm) are 1.52% for males and 1.66% for females for the morphological face height and 2.07% for males and 2.11% for females for the biocular width.

To sum up the results of the analysis of the sexual dimorphism and the system comparison, one has to approve that the PhotoModeler system was able to show the same general shape and size differences in human faces as the Breuckmann scanner did. Our findings are in agreement with the literature on this topic (Ferrario et al., 1993, 1995a, 1996; Fink et al., 2005), only the FaceGen Modeller wasn't able to produce according results for the sexual dimorphism. Furthermore the system comparison showed that FaceGen Modeller is significantly different from either of the two other systems. This becomes more obvious when looking at the raw image and the 3D models. **Figure 4.1** shows specimen 34 which plots near the mean shape in all systems and specimen 63 which plots at the fringes of the distribution (**Fig. 4.2**).

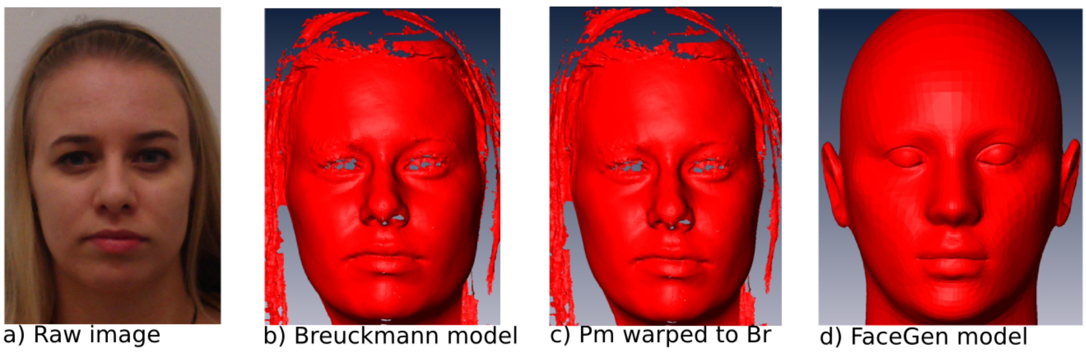


Figure 4.1.: Raw image and face models of subject 34

During the course of the study, it was necessary to exclude test persons 18 and 48 from the analysis for several reasons. Individual 18 was excluded because of extensive facial hair which made creating the models impossible. The complex structure of facial

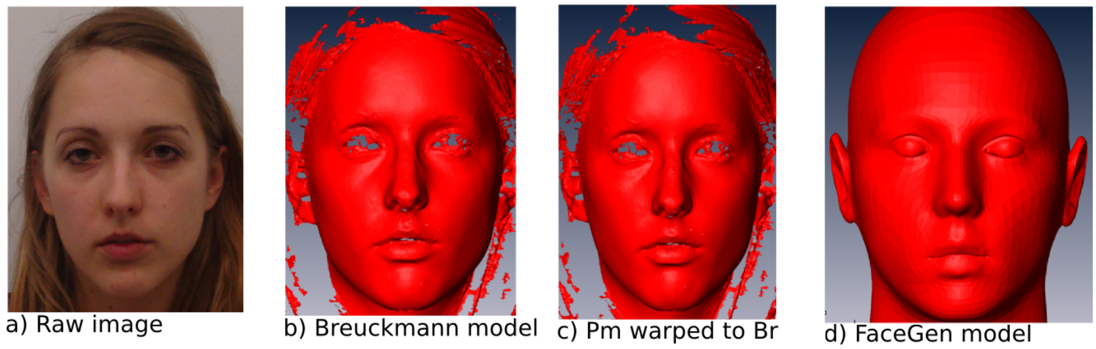
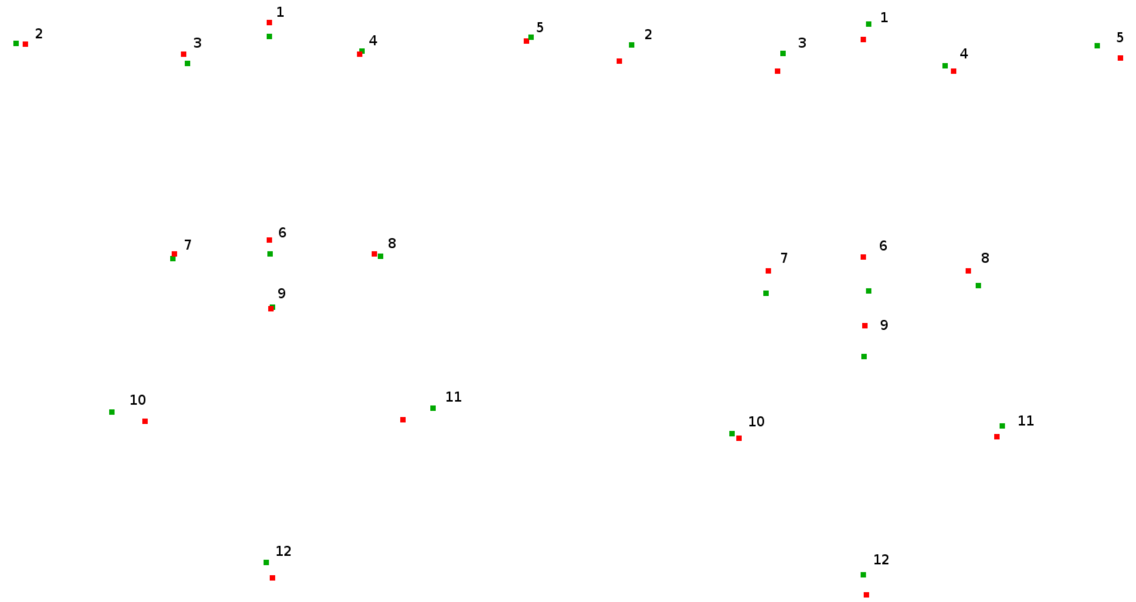


Figure 4.2.: Raw image and face models of subject 63

hair is very complicated to capture with an optical surface scanner as the Breuckmann optoTop-HE. Those parts of the face that are covered by hair appear as a 'black hole' in the final models. For both software solutions, extensive facial hair is a problem too. The model creation process requires the investigator to manually set reference points on the faces and this becomes imposible when parts of the skin are not visible. However a minor extent of beard is still acceptable for the software. The great obesity of individual 48 on the other hand made it necessary to exclude it from the analysis as well. It was very hard to identify the exact location of the position of the landmark points 2 and 5. Because of his obesity, the *epicanthus* covered a great part of the region around the *exocanthion* on both sides. Although individual 48 didn't show up as an outlier during the analysis of the sexual dimorphism or the system comparison, problems appeared during the computation of the distance between PhotoModeler and Breuckmann. The greatest differences in the distances observed between PM and BR for landmark points 2 and 5 were within individual 48.

Apart the two individuals mentioned, generally all the distances connecting to landmark point 12 (*pogonion*) created problems and were excluded in a second run of the distance analysis because this point was the reason for the extraordinary differences in the distances between PM and BR. It was the most error-prone point to identify of all landmarks and was therefore responsible for most of the deviation between the systems. After exclusion of landmark point 12 from the analysis, the maximum difference between Breuckmann and PhotoModeler dropped to 9.62 mm compared to 12.72 mm with landmark point 12 included. I am aware of the fact that markings on the probands faces could have been set directly before taking the pictures. But this would have only helped to improve the accuracy of one of the three systems (PhotoModeler Scanner) because I used the 3D surface models of the other systems for setting the landmarks. In PhotoModeler scanner no markings were set because I wanted to test the systems for their 'real life' applicabilities and in real life predefined markings on human faces are unrealistic.

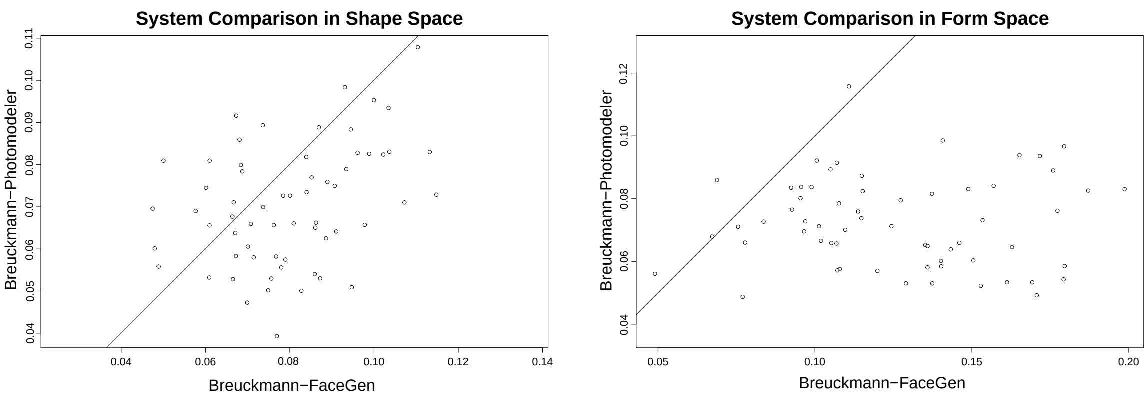
Individuals 3 and 9 were outliers in the PC-plots of the sexual dimorphism in shape space for each system which had a great influence on the results of the analysis. The decision had to be made weather to exclude them or not. After inspection of the raw photographs and all the corresponding models, a possible error during data collection or the model creation process could be ruled out. Individual 3 and 9, though male, plot in the female region of the diagrams, their facial morphology was markedly different from that of the other males. However, the sample size here is very small and one goal was to come close to realistic conditions. In a larger sample, such faces would undoubtedly appear and therefore they were not removed from the sample. A detailed inspection reveals the morphological differences. In individual 3, the *pogonion*(12) is shifted more towards the oral region compared to the mean, and the left and right *cheilion*(10/11) are shifted temporally (**Fig. 4.3a**). In accordance with the findings of this thesis and the literature, the shifting of the landmark points leads to a compression of the lower face in the longitudinal direction and at the same time to a dilation in the temporal direction leading to a more female shape of the face. In Individual 9, all nasal landmarks (*pronasale*(6), *subnasale*(9), *alae*(7/8)) and the *pogonion*(12) are shifted towards the oral region (**Fig. 4.3b**) which again leads to a compression in the longitudinal direction and a resemblance with the female shape (**Figure 4.3** visualizes the landmark points in Breuckmann however the observation applies to all systems).



(a) Shape difference in spec. 3 **(b)** Shape difference in spec. 9

Figure 4.3.: Differences in the facial morphology between the mean shape and specimens 3 and 9 (mean in red, specimen in green)

To see how the results change excluding no. 3 and 9 from the analysis, the results are given here. The corresponding PC-plots can be found in the Appendix. Looking at the PC-plots for shape space, the fact still remains that the plots are undifferentiated insofar as the separation of the group means for male and female individuals is concerned (**Fig. A.14, Fig. A.15, Fig. A.16**). And as the literature shows, this has to be expected for shape (Ferrario et al., 1995a). However a permutation test of the male and female Procrustes mean shapes shows that not only Breuckmann ($p < 0.003$) and PhotoModeler ($p < 0.014$) but now also FaceGen Modeller ($p < 0.016$) produces significant differences in shape space. For form space analysis the fact remains that FaceGen Modeller isn't capable of producing any size information. Therefore the results only involve Breuckmann and PhotoModeller ($p = 0.0001$ for both systems) (**Fig. A.12 and Fig. A.13**). When compared to the findings in **Chapter 3.1**, the changes for the shape results differ slightly for Breuckmann and PhotoModeler but have a great influence on the results of the FaceGen data. In form space no change in the results was observed whatsoever. The results for the system comparison are not effected by the exclusion of individuals 3 and 9. As the deviation from the mean was observed in all systems this was to be expected. Even with the fact that individual 9 changes the ratio slightly in the direction of FaceGen. In 44 out of 61 compared to 45 out of 63 cases in shape space the Procrustes distances Br-Fg are greater than the Procrustes distances Br-Pm. In form space in 57 out of 61 compared to 60 out of 63 cases the Procrustes distances Br-Fg are greater than the Procrustes distances Br-Pm (**Fig. 4.4**). Only 1 case does not have much influence on such a significant finding.



(a) Procrustes Distances Shape Space

(b) Procrustes Distances Form Space

Figure 4.4.: Procrustes distances Br-Fg and Br-Pm in form and shape space with line segments (without 3 and 9; For an explanation of the line segments see **Chapter 3.2**)

This fact is true also for the direct comparison between Breuckmann and PhotoModeler (the mean changes from 1.79 to 1.81 mm) and the ratios between FaceGen and PhotoModeler (stays 0.998 in both cases).

Another point that has to be addressed is the sample size. It is no surprise that with a rather small sample of 63 individuals outliers can have a huge impact on the results of the analysis. A greater sample size would have been more robust against these special cases. Especially when looking at the sexual dimorphism a greater sample would have also covered more morphological characteristics. When looking at the sample size and morphological characteristics another aspect becomes important. The selection of the landmark points. This study was limited to a set of 12 landmarks of the types I to III. And as Weber et al. (1998) showed, only landmark points of type I are strictly defined and therefore are easy to be identified on a 3D object. landmarks of types II and III are problematic because of their indistinct definitions. This leaves it to the interpretation of the observer to identify the right location of the point. The limitation to use only landmark points of types I to III was necessary because no 3D surfaces were generated with PhotoModeler Scanner which means that it wasn't possible to set the landmark points on a surface model. In PhotoModeler Scanner the landmark points were used as reference points to generate the wire frame model. With the use of semilandmarks and ridge curves a lot more morphological information can be gathered to complement the parts of the face where otherwise no information can be collected but that are very important for the facial morphology (Bookstein, 1991; Mahoor and Abdel-Mottaleb, 2009; Schaefer and Bookstein, 2009; Schaefer et al., 2009; Weber and Bookstein, 2011).

5. Conclusions

5.1. Conclusions

The work in this thesis aimed at showing alternative ways to capture the features of 3D objects and to produce 3D surfaces for numerous applications. For a lifelike question such as the sexual dimorphism in the human facial morphology, this thesis was able to show that at least one alternative to a 3D surface scanning system is available that produces accurate data. PhotoModeler scanner is capable of producing three dimensional models from 2D images of faces accurately enough to obtain similar biological results, both in shape and form space, as the 'golden standard' in this setting. However, with a maximum difference of 9.62 mm between the Breuckmann optoTop-He and the Photomodeler scanner, one has to be cautious. The use of this data is definitively limited and not suitable for detailed morphometric analyses in physical anthropology or forensics. But with a more sophisticated setting that includes more camera stations that take the pictures simultaneously the results could be improved (Eos Systems inc.: PhotoModeler Knowledge Base. http://www.photomodeler.com/kb/entry/100/, 30th September, 2013).

In contrast to PhotoModeler scanner, the FaceGen Modeller doesn't produce 3D forms, just 3D shapes. The analysis of the system comparison showed clearly the differences in the Procrustes distances. In 45 cases (shape space) (**Fig. 3.3a**)/ 60 cases (form space) (**Fig. 3.3b**) the Procrustes distances for Br-Fg were greater than for Br-Pm. This fact reveals that FaceGen doesn't provide any sensible scale information and therefore makes it unusable for questions where size information plays an important role, which is practically any application involving morphometrics. It is limited in its use to the creation of models that more or less resemble those human faces where the 2D images were derived from. It wasn't able to produce the same significant biological results for sexual dimorphism in shape space (form is impossible with this system) than the other systems with the complete sample. It was not until the two special shapes (no. 3 and 9) were excluded from an analysis that results became significant. An advantage of the software is nevertheless the ability to morph the faces between several expressions, ethnicity and ages.

It is however questionable if the handling of the software can be improved in the future to allow it for the use in follow-up studies to this thesis. The pure ability to reproduce biological data in a more or less laboratory environment may not be sufficient. There is the need for improving the accuracy of the PhotoModeler scanner when working with human faces. This improvement can for example be achieved by putting more effort into the capturing process of the photographs. But the use of 4 connected cameras and markers on the probands' faces disconnects the software from the use with 'every day' photographs which could be very useful, e.g. in forensics. There is no statement possible about the actual usability of the software in handling such 'every day' photographs at the moment. Although not completely standardized, all the photographs that were taken during this thesis were taken under the same conditions. It will be interesting to know how the software performs when photographs taken with different cameras at different locations and light conditions are used and when no camera calibration file is present. Although this was too time-consuming to be implemented in this thesis it could be part of a follow-up study. The still growing field of photogrammetry produces more and more sophisticated solutions to produce 3D models from 2D photographs. Today, there are a lot more solutions available on the market than at the time when the first ideas to this thesis were formed.

6. Acknowledgements

I am deeply grateful to my supervisor ao. Univ.-Prof. Dr. Gerhard W. Weber for taking on my ideas and for giving me the opportunity to realise this diploma thesis. He accompanied me during the long time of the data collection and analysis with his council and showed me more than once how important and responsible the work as a scientist is. I would also like to thank him for his productive commentary on my draft and last but not least for his support and the very successful cooperation during the past years.

I would like to thank Prof. Fred L. Bookstein for his introduction to the field of Geometric Morphometrics and the contribution to this thesis and the posters, that were presented at the FAA 2012 in Vienna and the MVE meeting 2013 in Nürnberg.

Additional thanks go to Univ.-Prof. Dr. Manfred Hochmeister for his inspiring lecture on forensic Sciences at the Medical University of Vienna, which planted the seed for this thesis.

Mag. Martin Dockner for his lecture on the basics in using LaTeXwhich encouraged me to make use of it to write my thesis. I would also thank him for giving me many advises during my thesis which helped a lot in improving the layout.

Michelle Coquerelle, PhD for giving me a great introduction in the statistics of geometric morphomterics with R and providing me with the R-code for my statistical analysis.

Further I would like to thank my collegues Cinzia Fornai, Msc and Stefano Benazzi, PhD which were captured in the same office and gave me a lot of stimulation for my scientific work.

The Department of Anthropology at the University of Vienna that made it possible to trace the thesis and that supported me with financial aid in producing the posters.

Also, my thanks goes to all the voluntary participants that generously allowed me to scan their faces and to take pictures of them.

And last but not least the most thankful I'm about my family and their ongoing believe in the success of my work and their never ending support!

A. Appendix

A.1. PC-plots of the system comparison (form and shape space)

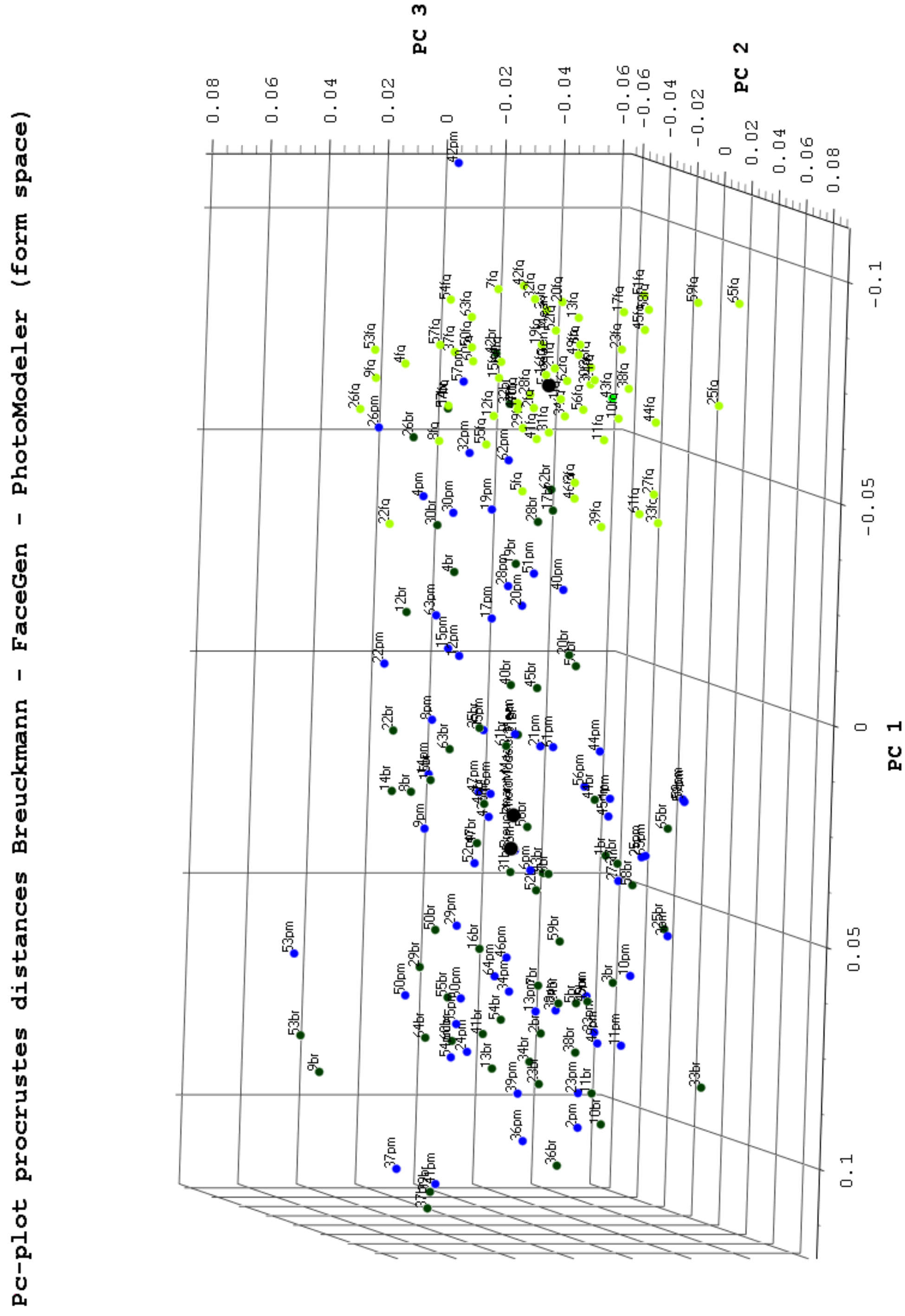


Figure A.1.: PC-plot of the system comparison in form space

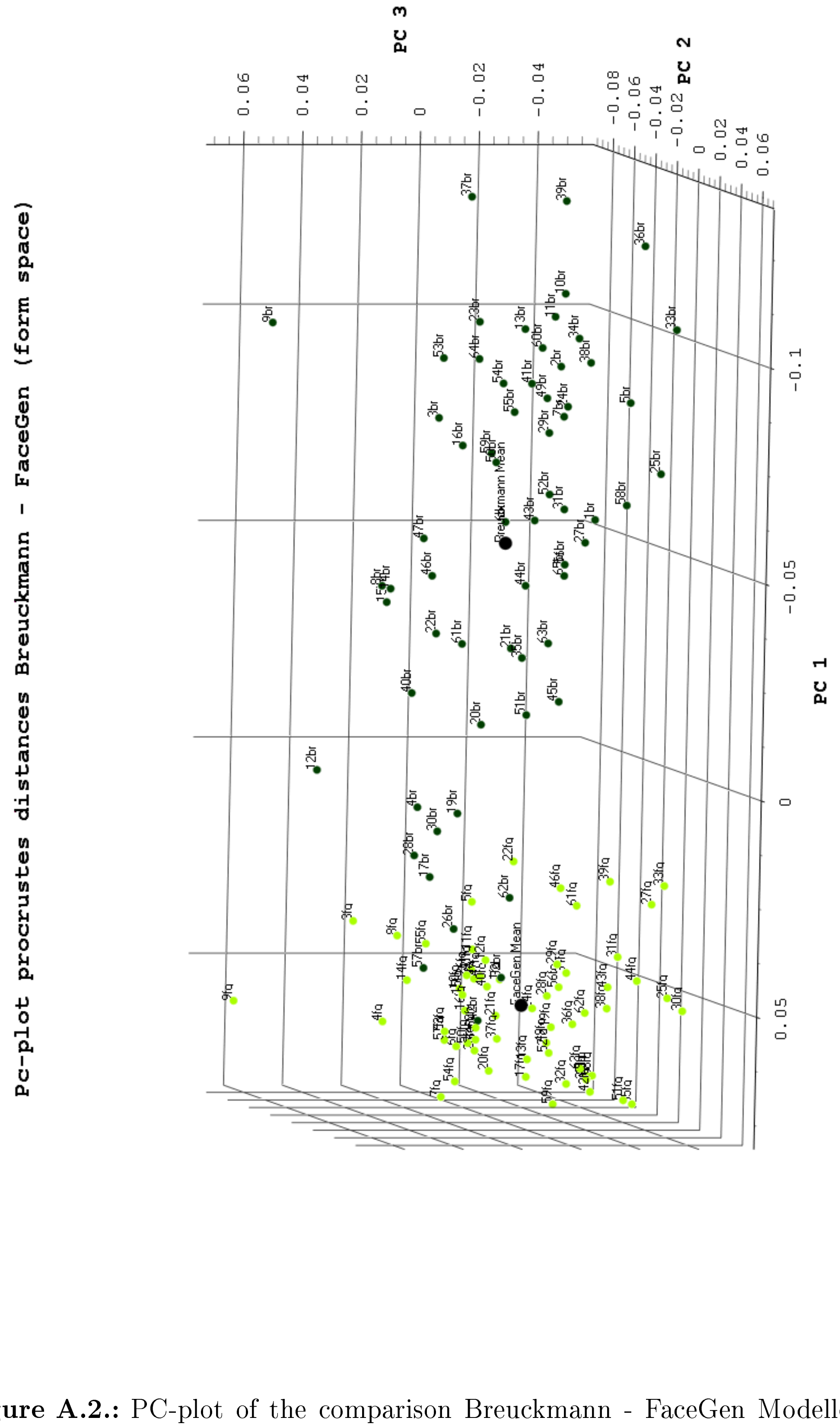


Figure A.2.: PC-plot of the comparison Breuckmann - FaceGen Modeller in form space

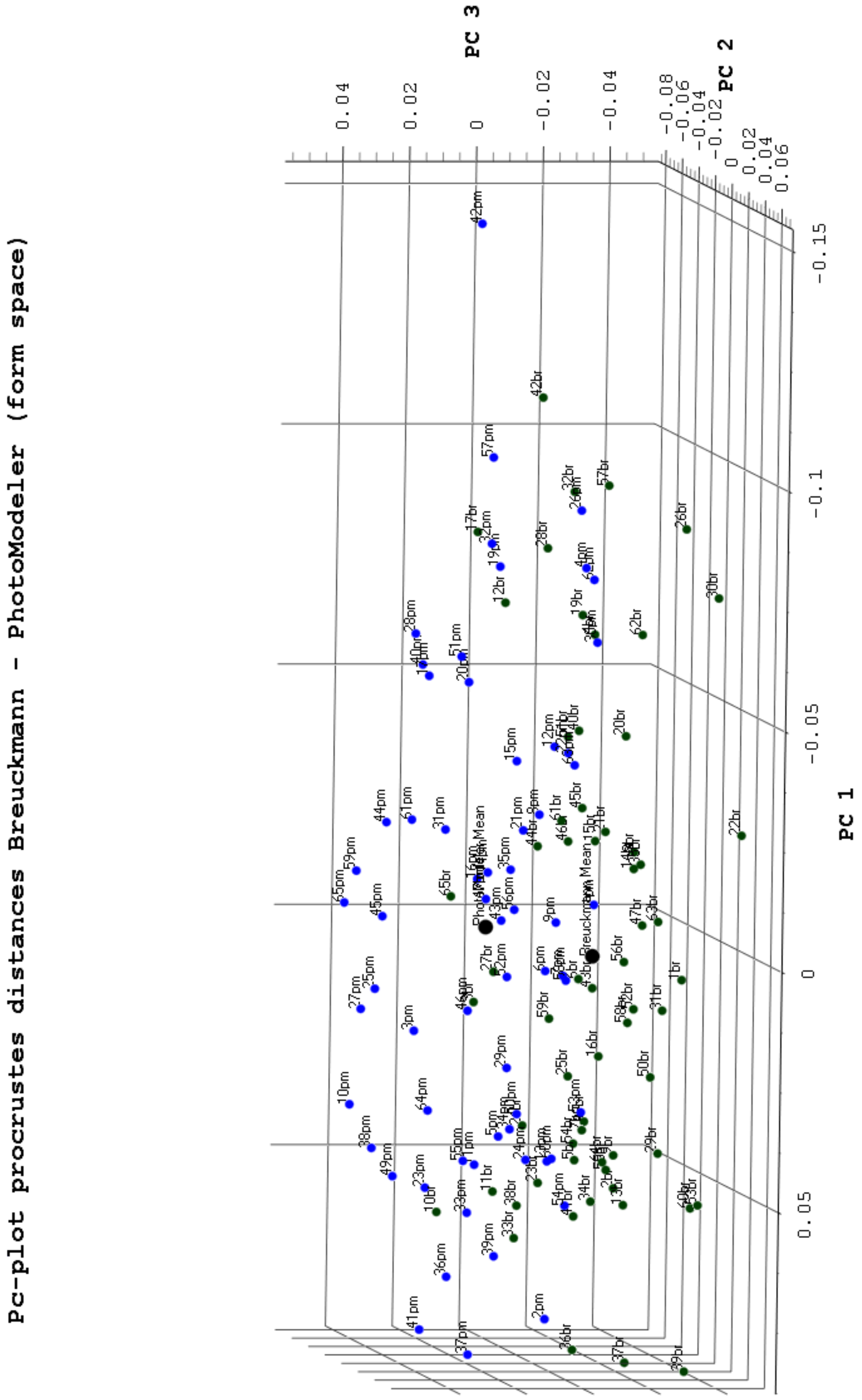


Figure A.3.: PC-plot of the comparison Breuckmann - PhotoModeler in form space

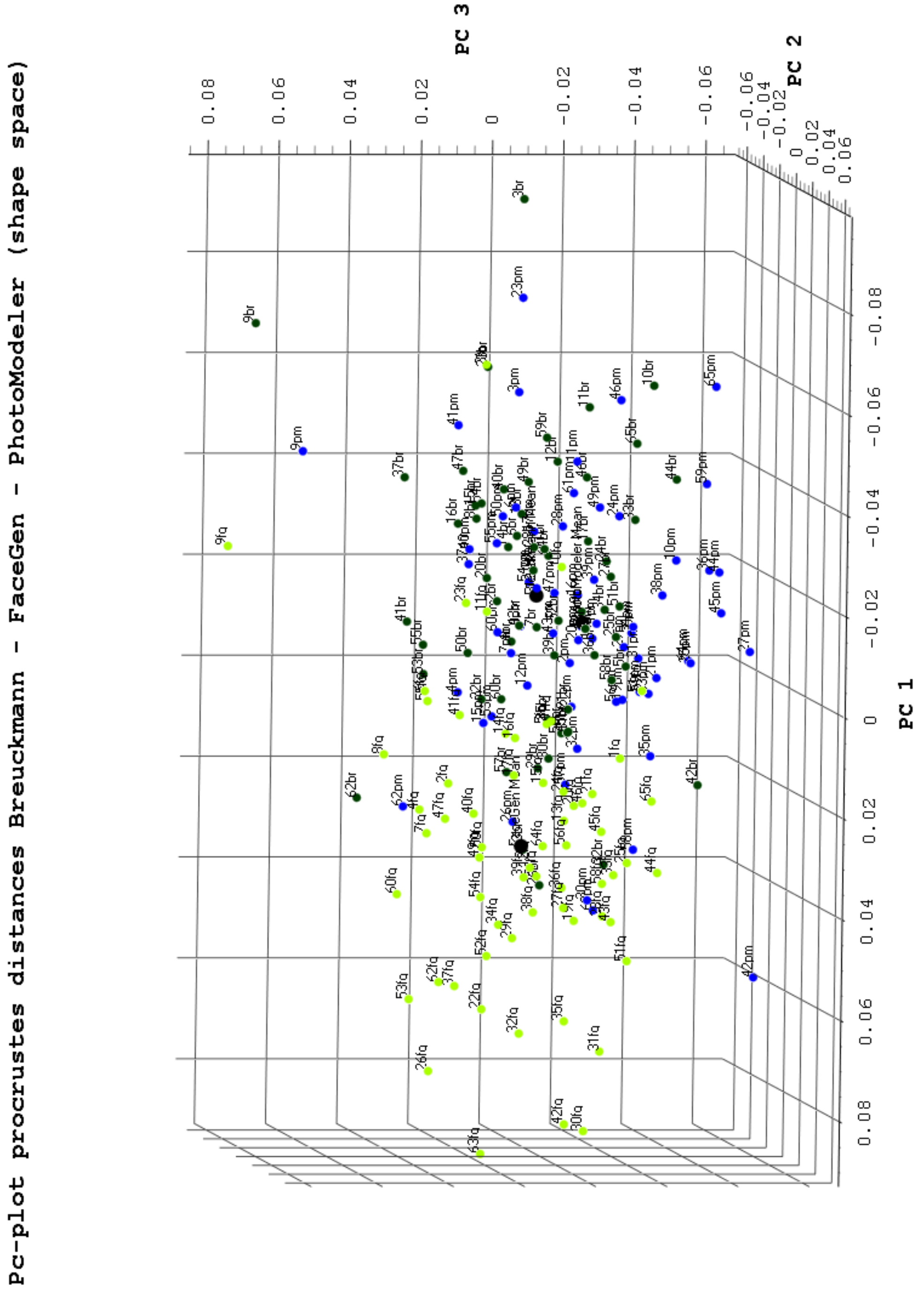


Figure A.4.: PC-plot of the system comparison in shape space

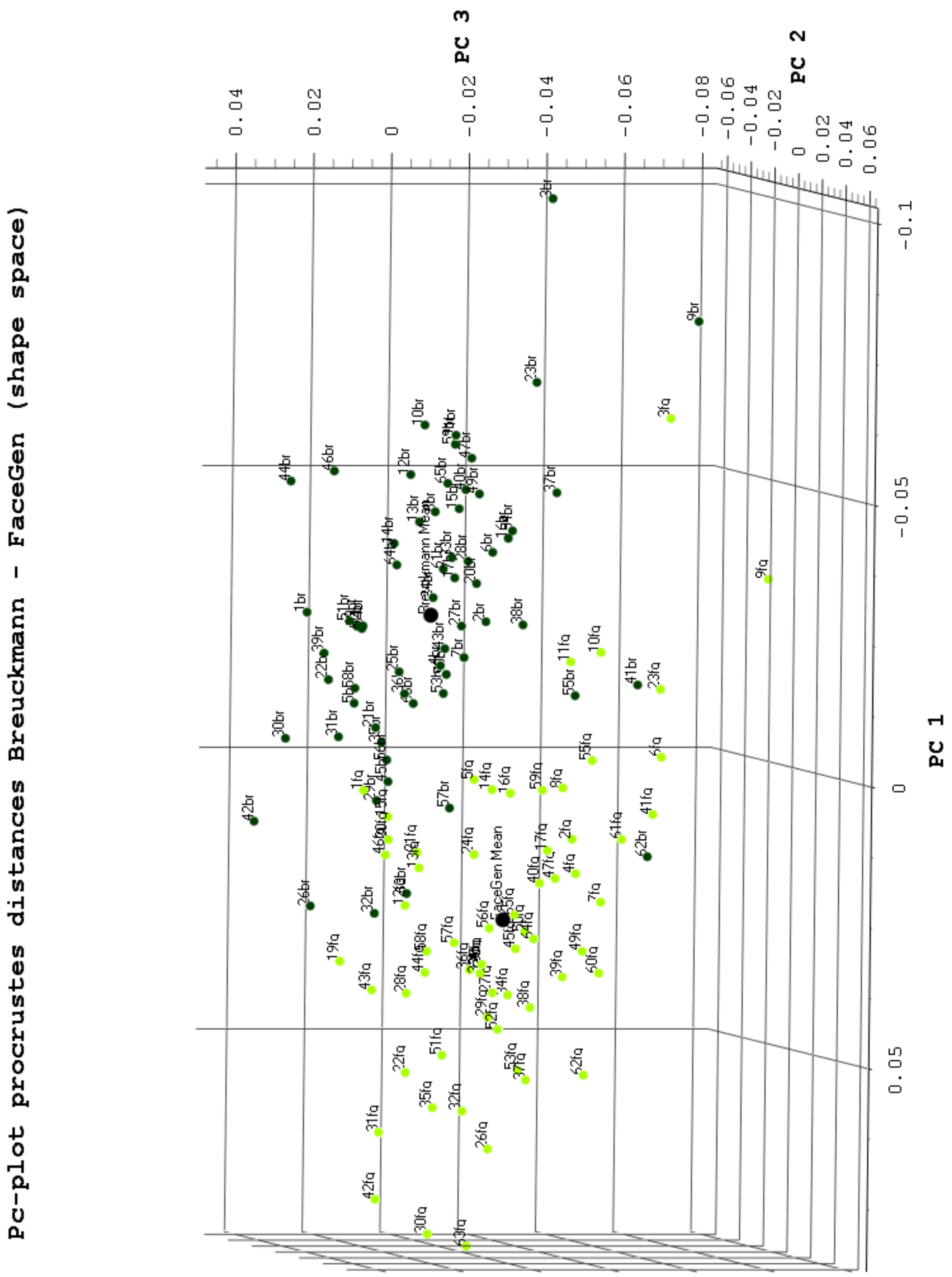


Figure A.5.: PC-plot of the system comparison Breuckmann - FaceGen in shape space

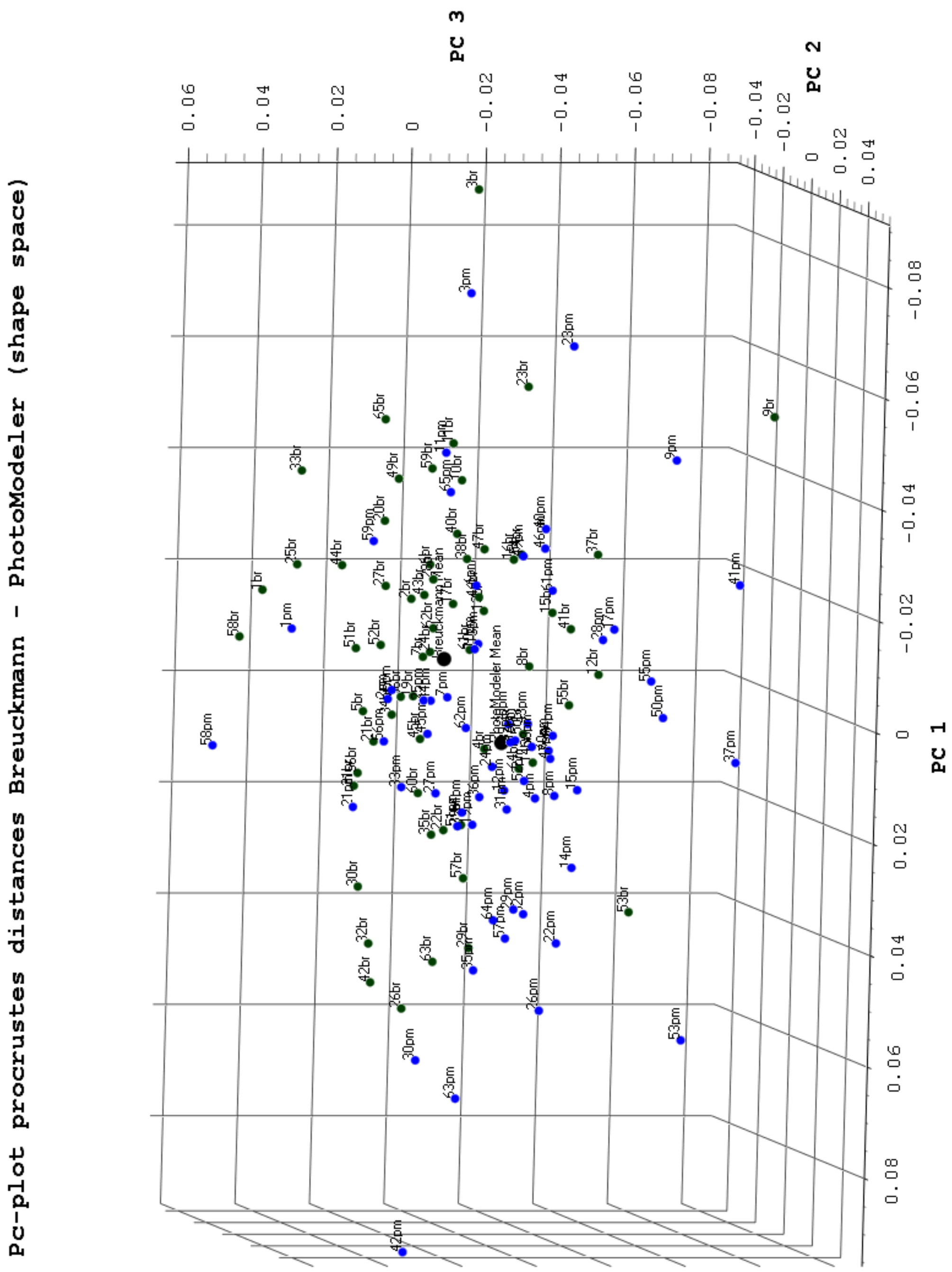


Figure A.6.: PC-plot of the system comparison Breuckmann - PhotoModeler in shape space

A.2. PC-plots of the sex differences (form and shape space)

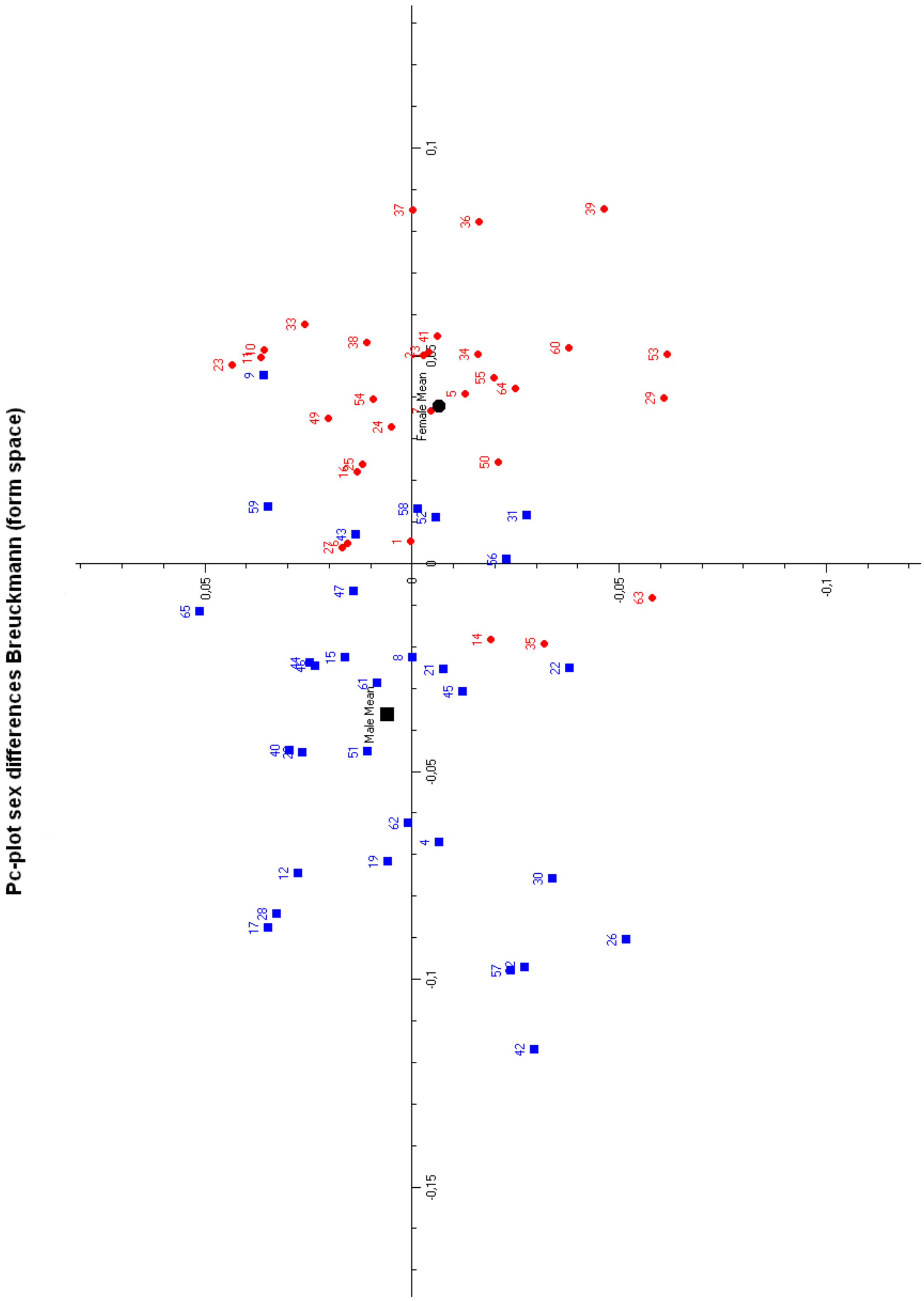


Figure A.7.: PC-plot of the sex differences in Breuckmann in form space

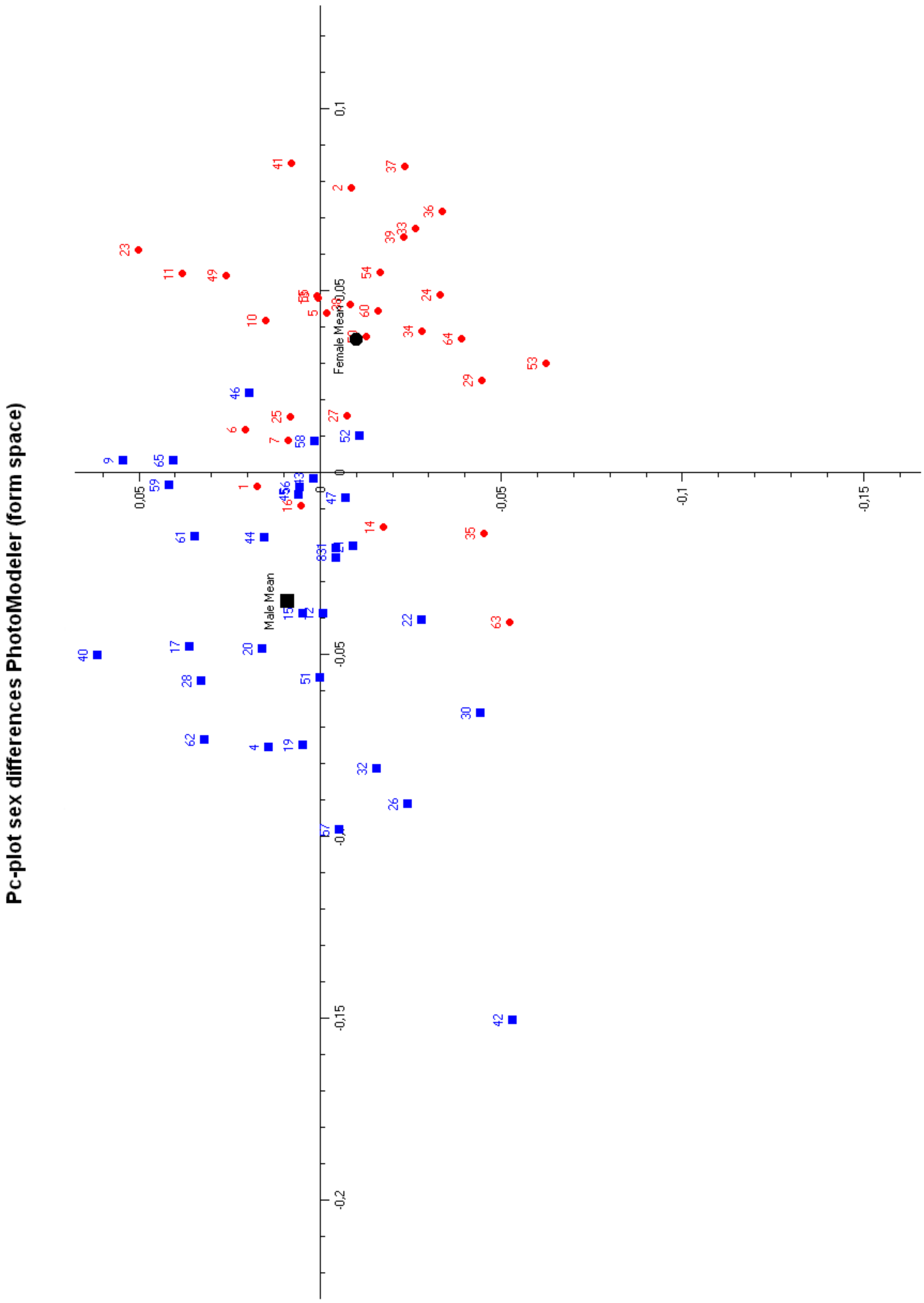


Figure A.8.: PC-plot of the sex differences in PhotoModeler in form space

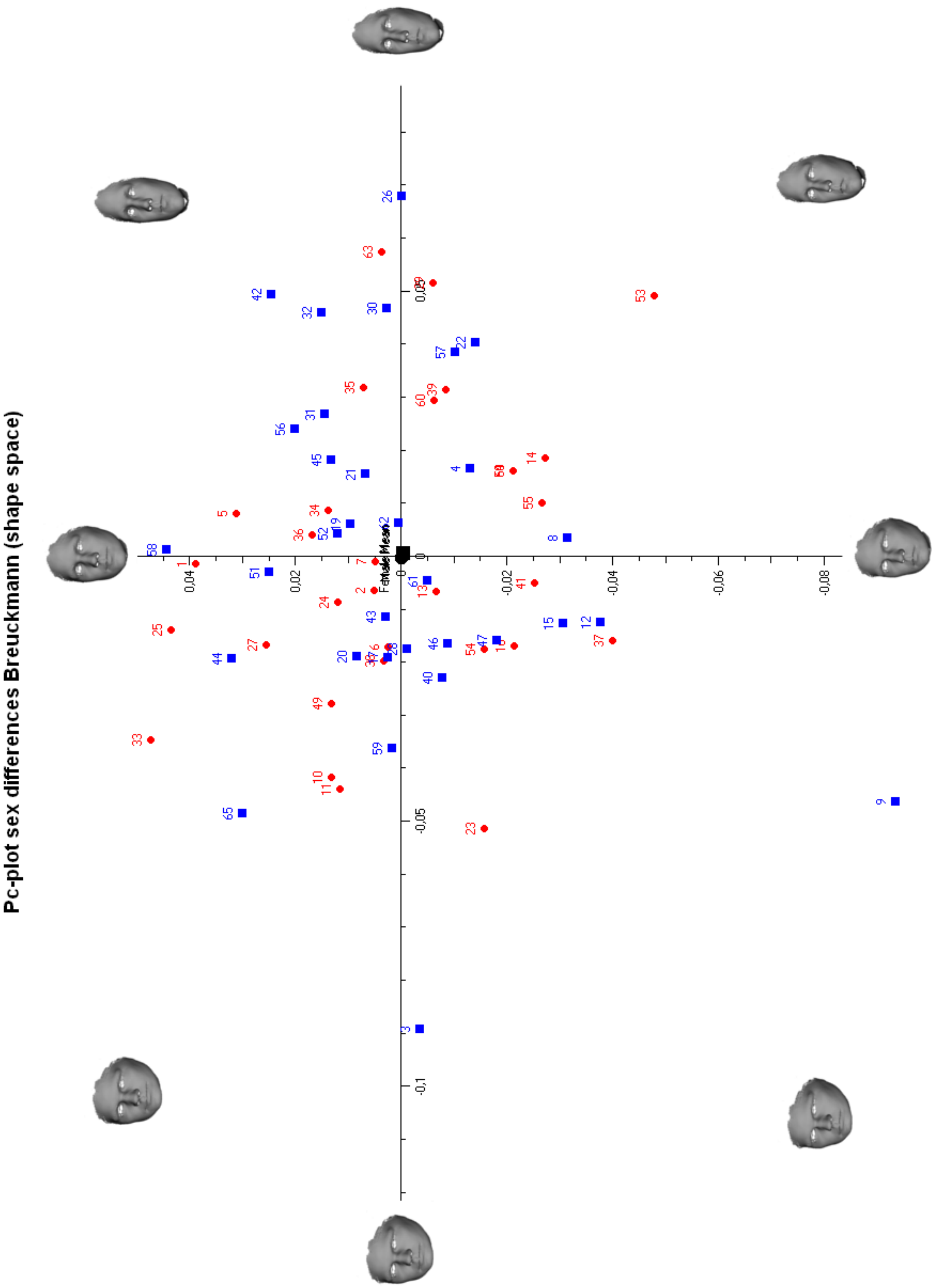


Figure A.9.: PC-plot of the sex differences in Breuckmann in shape space

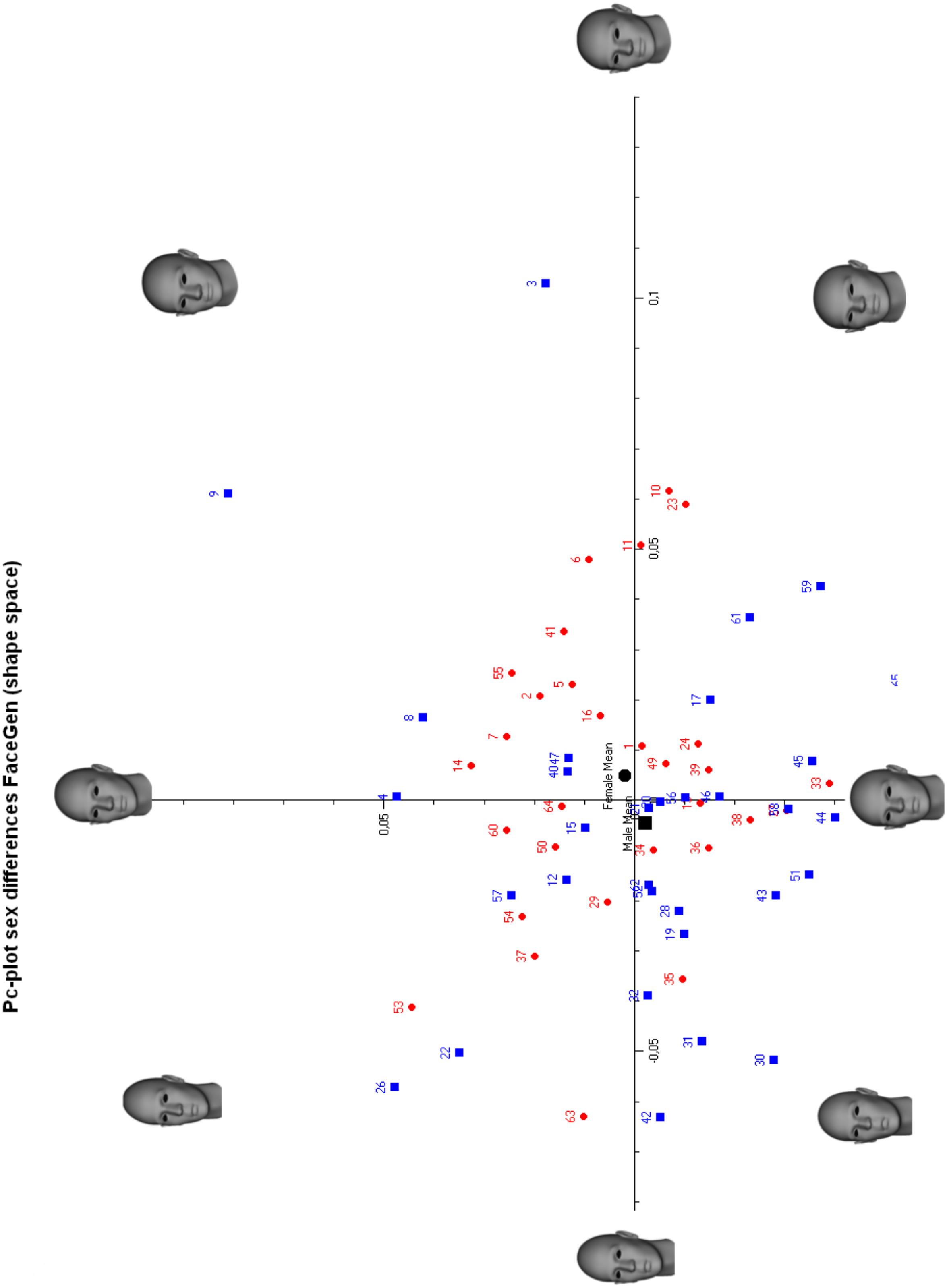


Figure A.10.: PC-plot of the sex differences in FaceGen in shape space

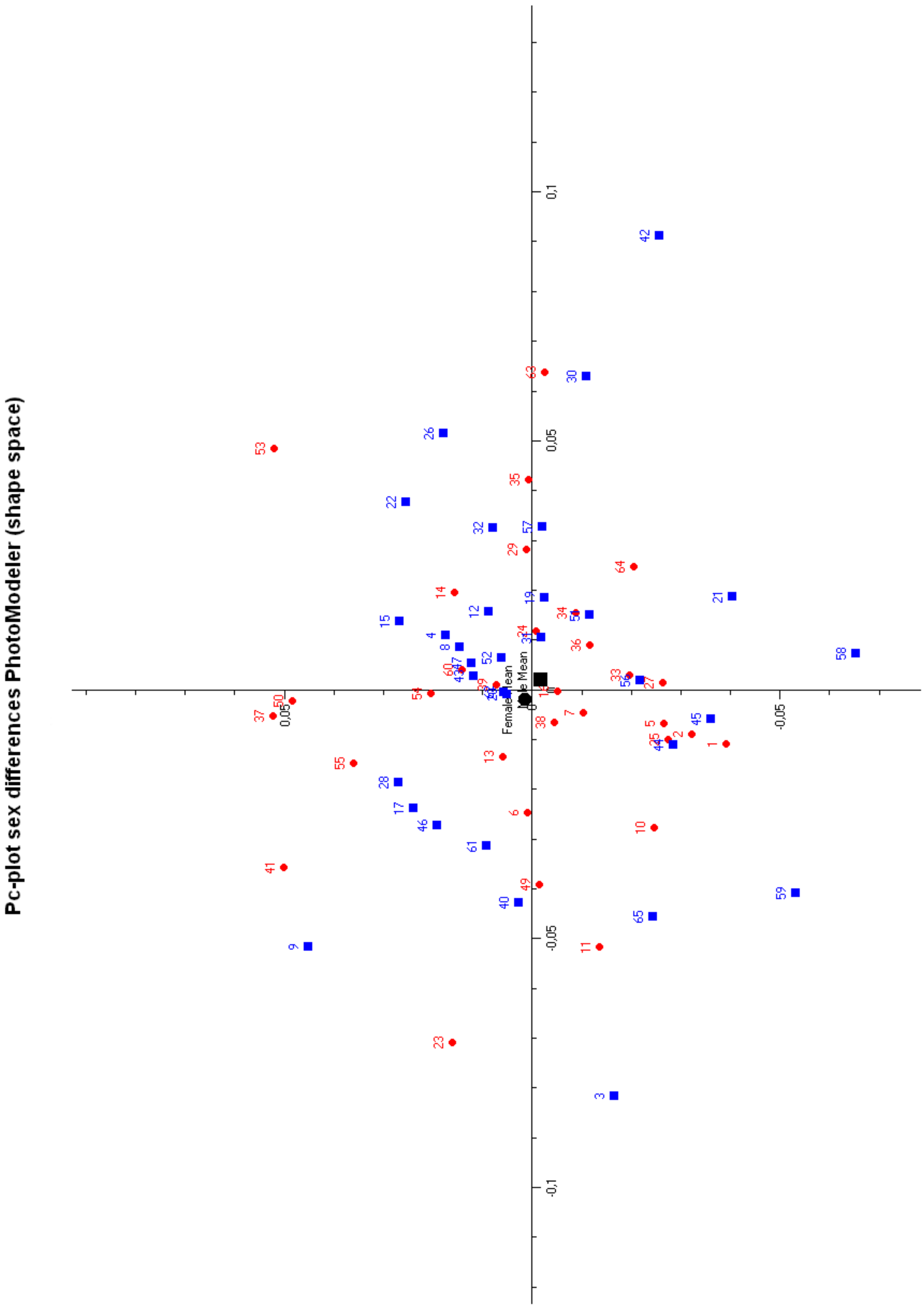


Figure A.11.: PC-plot of the sex differences in PhotoModeler in shape space

A.3. PC-plots of the sex differences with 3 and 9 excluded

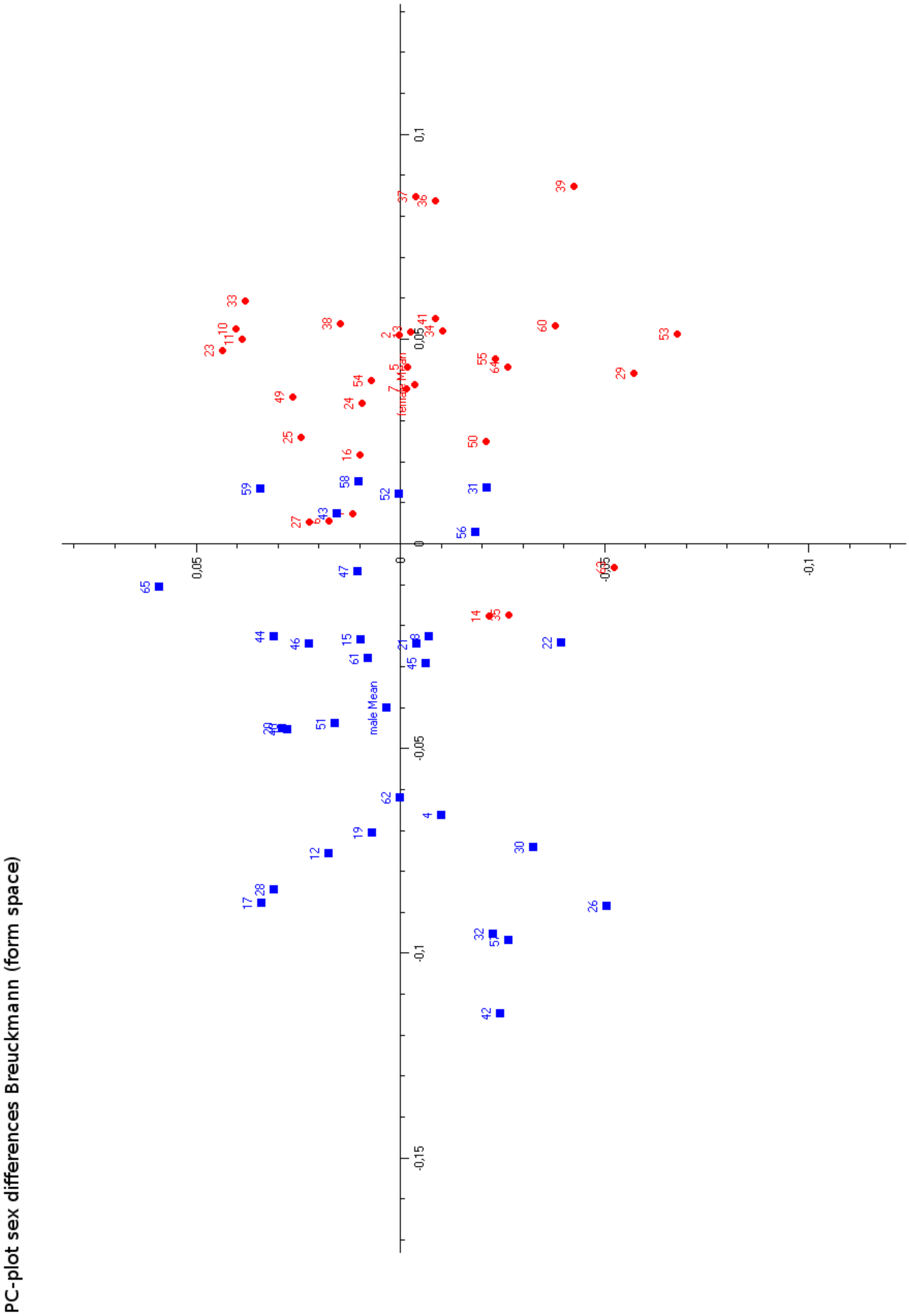


Figure A.12.: PC-plot of the sex differences in Breuckmann in form space (without 3 and 9)

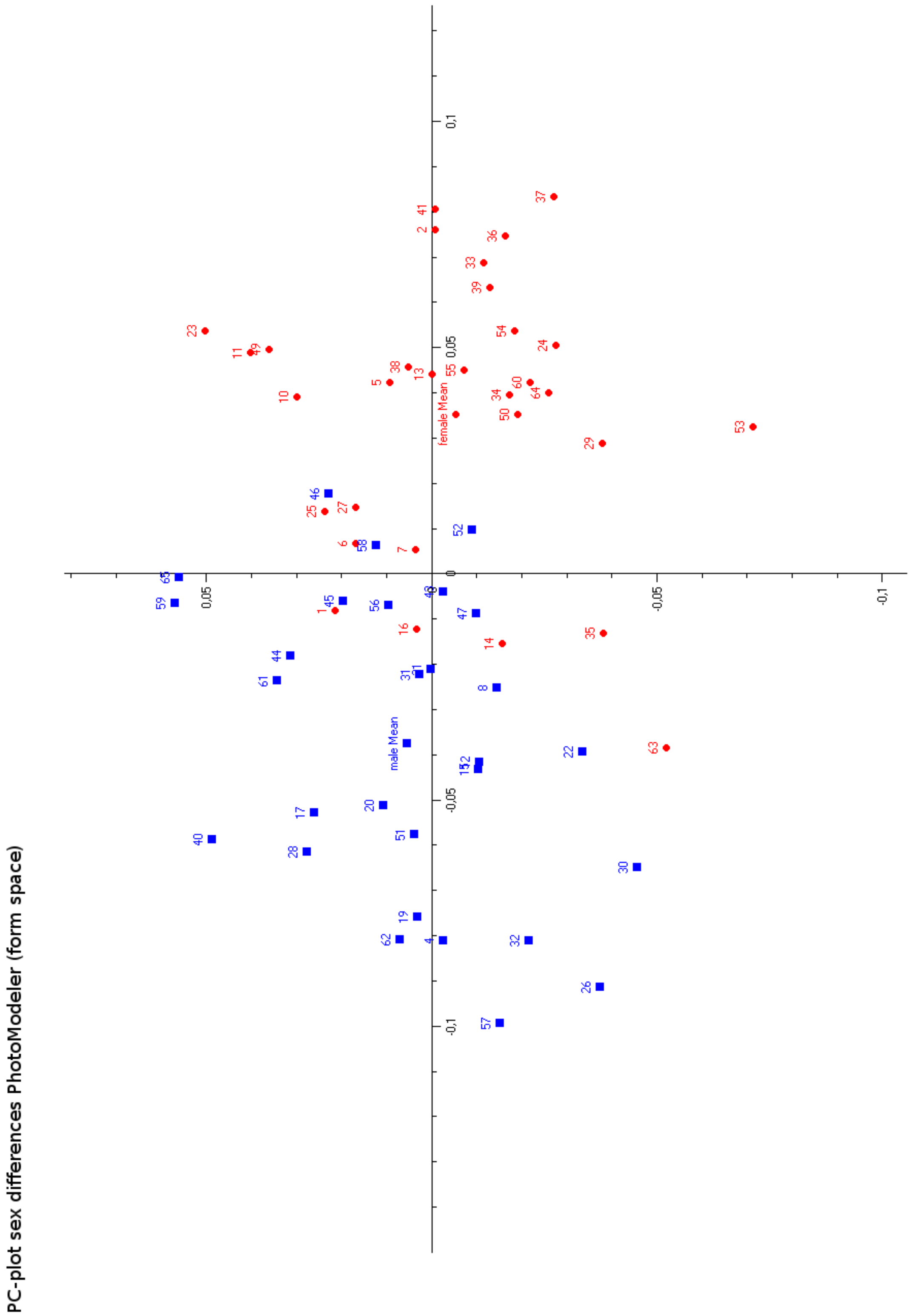


Figure A.13.: PC-plot of the sex differences in PhotoModeler in form space (without 3 and 9)

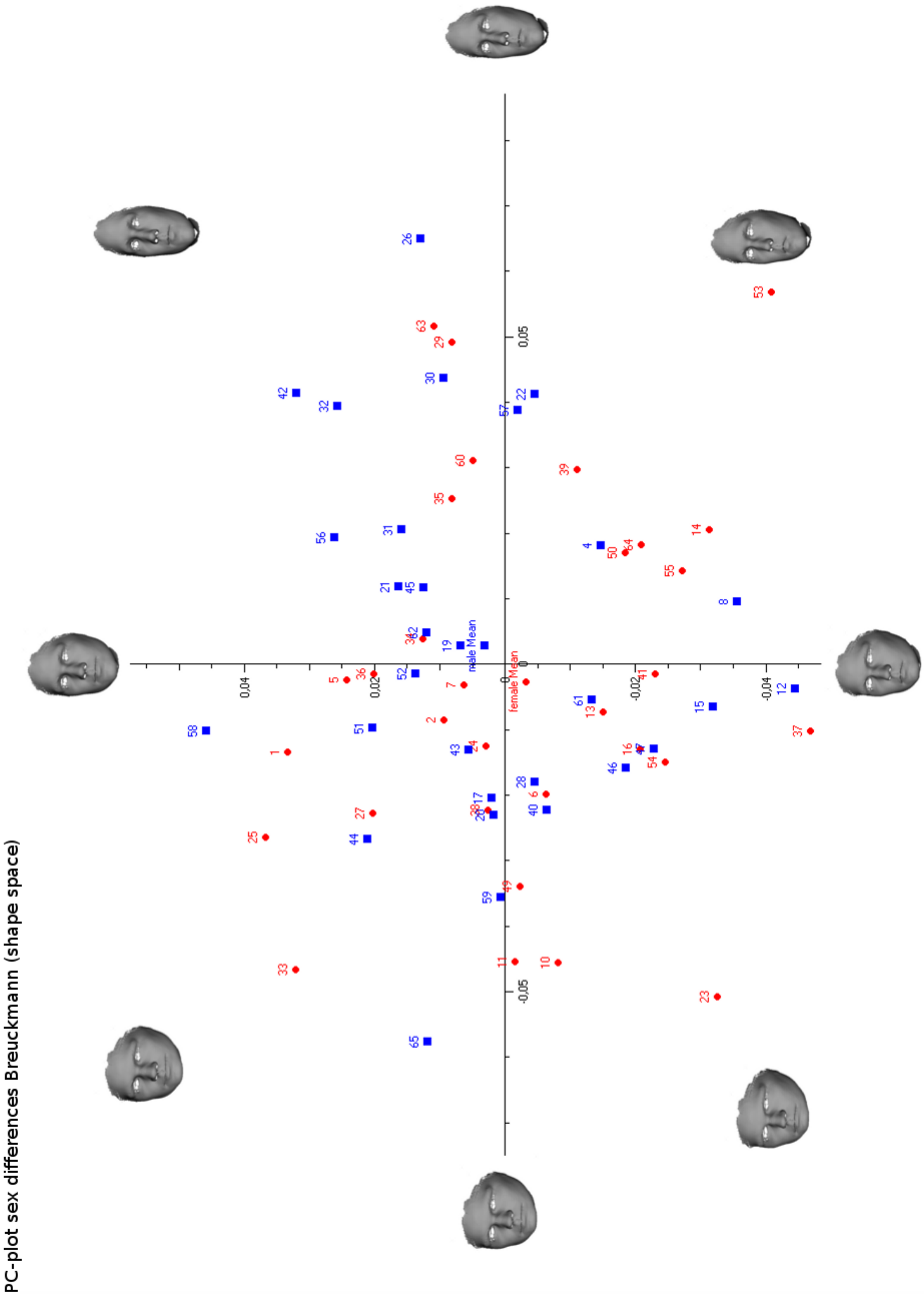


Figure A.14.: PC-plot of the sex differences in Breuckmann in shape space (without 3 and 9)

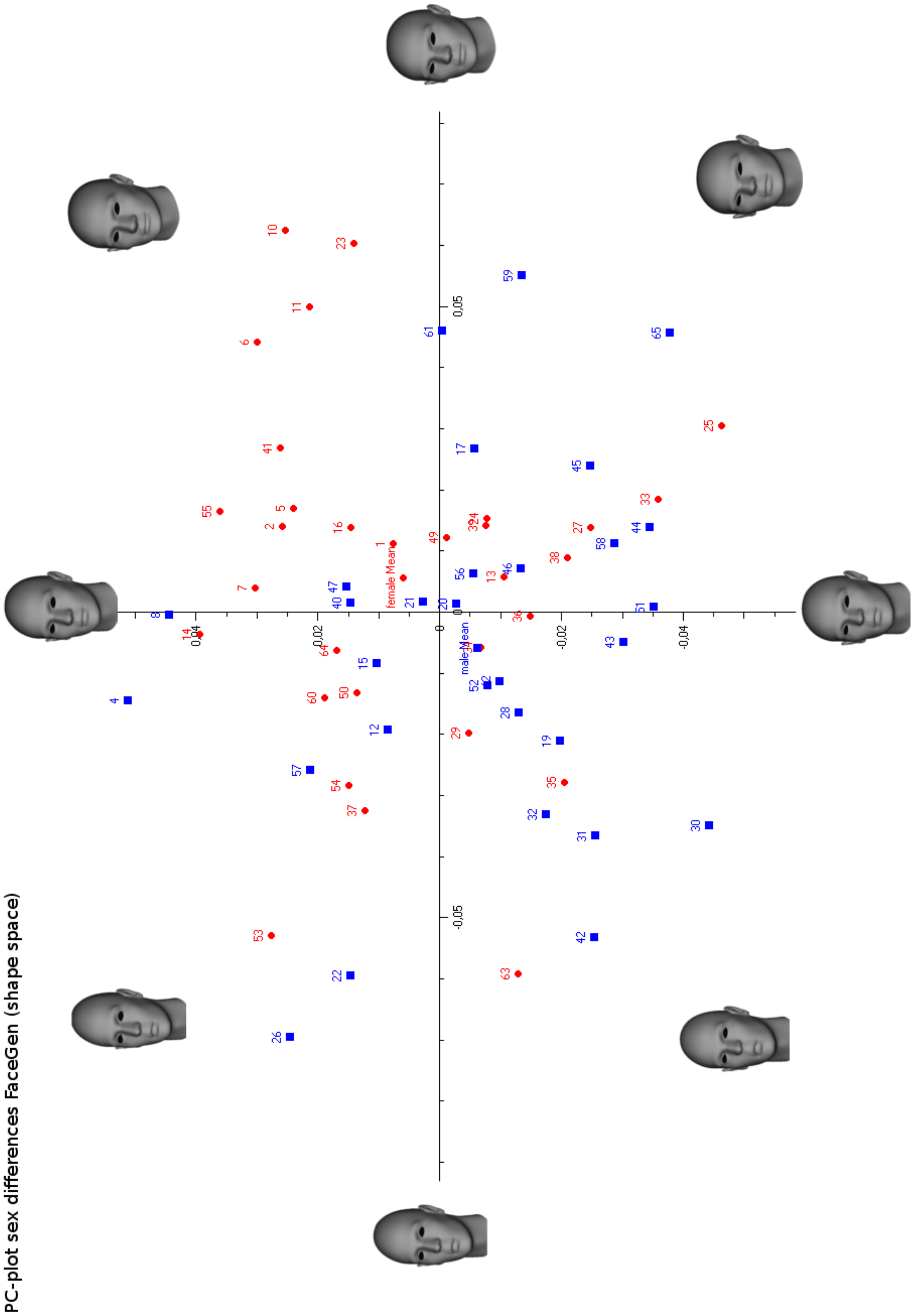


Figure A.15.: PC-plot of the sex differences in FaceGen in shape space (without 3 and 9)

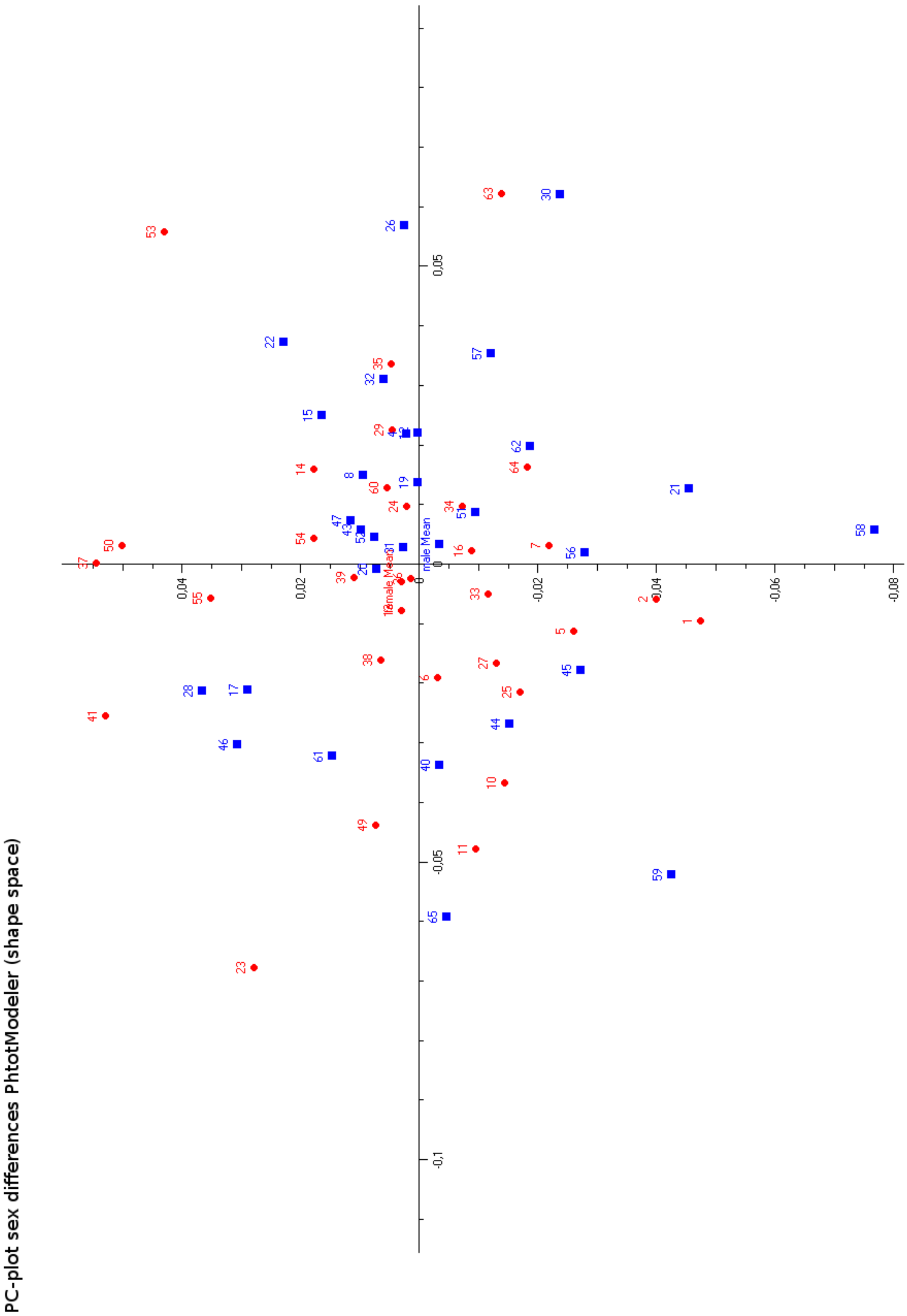


Figure A.16.: PC-plot of the sex differences in PhotoModeler in shape space (without 3 and 9)

A.4. Letter of agreement

Einverständniserklärung

Tobias Paul
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Name: Prob.-Nr.:

Alter:

Hiermit erkläre ich mich einverstanden, dass die im Rahmen der Diplomarbeit von Hrn. Tobias Paul am Dept. für Anthropologie erhobenen Daten (Oberflächenscans und Fotografien des Gesichtes) für die wissenschaftliche Auswertung herangezogen werden dürfen.

____________________ __________________
Ort, Datum Unterschrift

Ich stimme ferner zu, dass die Oberflächenscans und Fotografien (ohne Nennung des Namens) in Publikationen verwendet werden dürfen.

____________________ _____________
Ort, Datum Unterschrift

List of Figures

„Ich habe mich bemüht, sämtliche Inhaber der Bildrechte ausfindig zu machen und ihre Zustimmung zur Verwendung der Bilder in dieser Arbeit eingeholt. Sollte dennoch eine Urheberrechtsverletzung bekannt werden, ersuche ich um Meldung bei mir.“

List of Tables

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Curriculum Vitae

Tobias Paul

PERSONAL DETAILS

Place of birth	Marburg, Germany
Citizenship	german
Family status	single, no children

EDUCATION

Mar. 2013 – Sept. 2013	**Diploma thesis:** 3-D Landmark Acquisition From Photographs - A Morphometric Approach on Human Faces
Oct. 2007 – Oct. 2013	**Co-registration** Medical University of Vienna
Oct. 2005 – Oct. 2013	**A442, Physical Anthropology** University of Vienna (Austria) - Virtual Anthropology (Mag. rer. nat. program)
Oct. 2002 – Jul. 2005	**Physical Anthropology** Johannes-Gutenberg-Universität (Mainz, Germany) - Palaeoanthropology
Mar. 2002 – Oct. 2002	**Chemistry** Philippsuniversität Marburg (Germany)
May 2001	**A-levels** (Abitur) Gymnasium Philippinum (Marburg, Germany)

TEACHING EXPERIENCE

2009 – 2013	Lecturing tutor: **Micro-Computer Tomographie und die Handhabung von Volumendaten**

WORKING EXPERIENCE

Sept. 2011 – Dec. 2011	Ferial Trainee **FTW Forschungszentrum Telekommunikation Wien GmbH**

ADDITIONAL QUALIFICATIONS

Language skills:	German (mother tongue); English (fluent)
Technical skills:	Micro-CT, 3D surface scanner, MicroScribe
Software skills:	Microsoft Windows, Linux, Microsoft Office, LibreOffice, LaTeX, Inkscape, SPSS, R, Amira, Brainsuite, EVAN Toolbox, FaceGen Modeller, FSL, ImageJ, Landmark, Morpheus, Osirix, PAST, PhotoModeler Scanner

SCIENTIFIC ACTIVITIES

Publications

2013 — “Seeing through the face: a morphological approach in physical Anthropology”
Proceedings of the 3rd Symposium on Facial Analysis and Animation. 06/2013, p. 6

2011 — "A reassessment of the Neanderthal teeth from Taddeo cave (south Italy)"
Journal of Human Evolution. 10/2011, pp. 377-387

Posters

2013 — “Seeing through the face: a morphological approach in physical Anthropology”
The 3rd International Symposium on Facial Analysis and Animation, Vienna (Austria)

2012 — “Seeing through the face: a morphological approach in physical Anthropology”
13. MVE-Jahrestagung, Nürnberg (Germany)

PERSONAL INTERESTS

Human evolution, 3-D modeling, Hiking, Literature, Music, New Media

Eidesstattliche Erklärung

Ich versichere, dass ich meine Diplomarbeit ohne Hilfe Dritter und ohne Benutzung anderer als der angegebenen Quellen und Hilfsmittel angefertigt und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe. Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

Wien, den 30.09.2013

Nachname: ____________________ Vorname: ____________________

Matrikelnummer: ____________________ Unterschrift: ____________________