Universidad del País Vasco / Euskal Herriko Unibertsitatea
BILBOKO INGENIARITZA ESKOLA
ESCUELA DE INGENIERÍA DE BILBAO

GRADO EN INGENIERÍA EN TECNOLOGÍA INDUSTRIAL

TRABAJO FIN DE GRADO

3D SCANNING, REVERSE ENGINEERING AND RAPID PROTOTYPING OF MEDICAL-BREATHING MASKS

Alumna: Maura Alaez, Victoria

Director: Eguiraun Martinez, Harkaitz

Curso: 2018-2019

Fecha: Lunes, 1 de Julio de 2019

Acknowledgements

To Xabier Amezua Lasuen, whose expertise regarding 3D scanners was of undeniable help for the achievement of this work.

Index

FIGURES INDEX

TABLES INDEX

1. ABSTRACT

The purpose of this work is to create a prototype of an adaptor for two different commercial medical-breathing masks by means of 3D scanning and reverse engineering. The motivation for this investigation is the need to provide a solution to certain clinical cases in which the standard breathing masks commercialized do not adjust correctly to the patient’s features. The Hospital of Cruces and the Product Design Laboratory of the Engineering School of Bilbao are collaborating to investigate on a solution for it. The process includes a first phase of scanning involving 3 different 3D scanners: GO!SCAN, Handy REVSCAN and ATOS Compact Scan. The obtained images shall be processed using their corresponding software: VX Elements for the two former scanners and GOM Inspect for the latter, in order to prepare them for the second phase which consists of an analysis and comparison of the different scans and scanners to find out the best option to perform this work. Once the best option has been selected, an adaptor shall be created by means of VXElements. This adaptor is finally printed in silicon and tested on the corresponding breathing mask.

RESUMEN

El objetivo de este trabajo es crear un prototipo de un adaptador para dos máscaras de oxígeno distintas mediante escaneado 3D e ingeniería inversa. La motivación para esta investigación es principalmente la necesidad de proporcionar una solución a ciertos casos clínicos en los que las máscaras que se comercializan no se adaptan correctamente a los rasgos del paciente. Por ello, el Hospital de Cruces y el Laboratorio de Diseño del Producto de la Escuela de Ingeniería de Bilbao colaboran para investigar una solución. El proceso incluye una primera fase de escaneado que incluye el uso de 3 escáneres diferentes: GO!SCAN, HandySCAN y ATOS. La imagen obtenida se procesará con su software correspondiente: VX Elements para los dos primeros escáneres y GOM Inspect para el último, con el objeto de preparar dicha imagen para la segunda fase del proyecto, que consiste en analizar y comparar los resultados obtenidos para encontrar la mejor opción para este proyecto. Una vez se ha decidido la mejor opción, se crean ambos adaptadores con VXElements. Finalmente, se imprimen en silicona y se prueban sobre la máscara correspondiente.

LABURPENA

Lan honen helburua, bi oxigeno maskara desberdinentzat baliagarria den egokitzaile baten prototipoa sortzea da. Horretarako, 3D eskaneatua eta alderantzizko ingeniaritza erabili dira. Ikerketa honen motibazioa, merkaturatzen diren maskarak pazienteen ezaugarri fisikoetara egokitzen diren kasu klinikoetatik abiatzen da. Hori dela eta, egoera honi aurre egiteko asmoz, ebazpen bat bilatu nahi da. Horretarako, Gurutzetako Unibertsitate Ospitaleak eta Bilboko Ingeniaritza Eskolaren Produktuaren Diseinuaren Laborategiak bate egin dute arazo honi aurre egiteko. Prozesu hau bi fasetan banatzen da. Lehenengo fasean, eskaneatua 3 eskaner desberdinen bitartez egiten da: GO!Scan, Handy REVScan eta ATOS. Jarraian, hauetatik lortutako irudia, eskaner bakoitzari dagokion softwarearekin prozesatzen da. Zehatz-mehatz, aipatutako lehenengo bi eskanerrak VXElements softwarearekin prozesatzen dira eta aipatutako azken eskanerra, berriz, GOM Inspect-ekin. Hauen helburua, irudia 2. Faseko prestatzea da; izan ere, 2. Fase honetan, lortutako emaitzak aztertu eta alderatu nahi direlako, proiektuari hobeto egokitzen zaion aukera hautatzeko asmoz. Ondoren, kasuaren beharretara hobeto egokitzen den aukera erabakitzen da eta VXElements bitartez egokitzailea sortzen da. Azkenik, silikonan inprimatu eta dagokion maskaran egiaztatzen da.

2. INTRODUCTION

3D scanning is a technology used to create a digital model out of an object, so that it can be saved, edited and then 3D printed. A 3D scan can give a wide amount of information about the object in a procedure called reverse engineering. The 3D scanner gathers information on a determined object by projecting a light pattern or laser on such object, which will allow the software to identify the surface of interest that will be processed after the scanning procedure finishes.

2.1 Context and Motivation

The first devices of this kind started to be developed at the end of the 20th century (the first records of a paper on 3D scanning being published date from 1982) and they are increasingly used for various purposes, which range from industrial design, reverse engineering or prototyping to the preservation of works of art, sports, or the entertainment industry, among others.

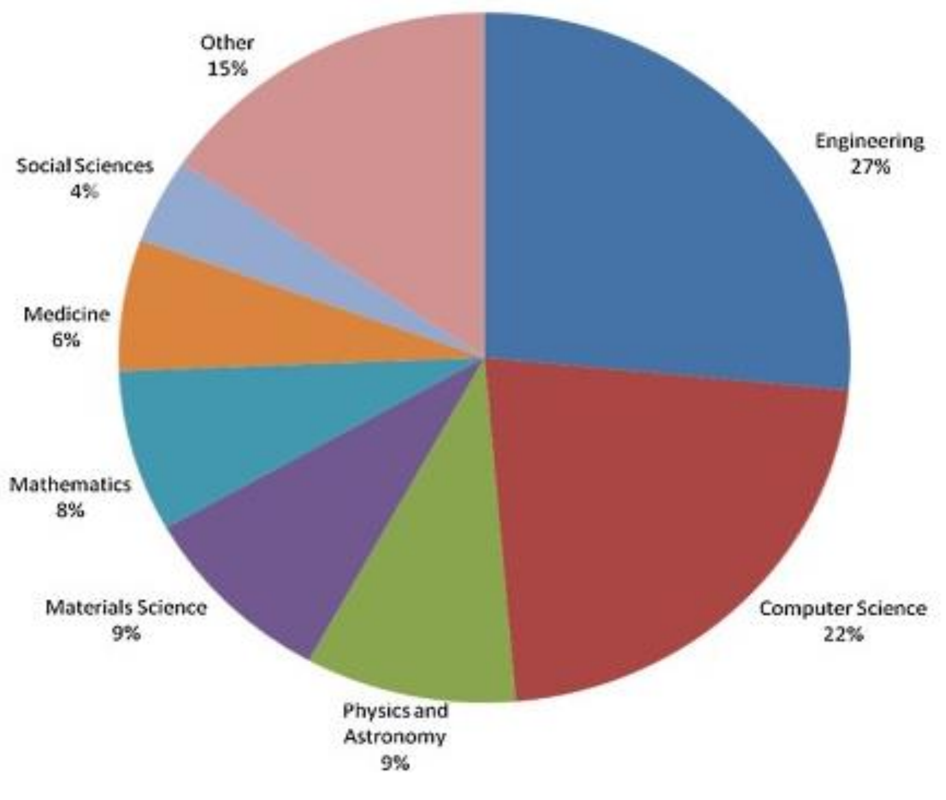

Figure 1: Area wise publications on 3D Scanning. (A. Haleem, M. Javaid, Department of Mech. Engineering, New Delhi, India)

Figure 1 (A. Haleem, M. Javaid), shows this wide variety of fields about which 3D scanning articles were published, being engineering the predominant field.

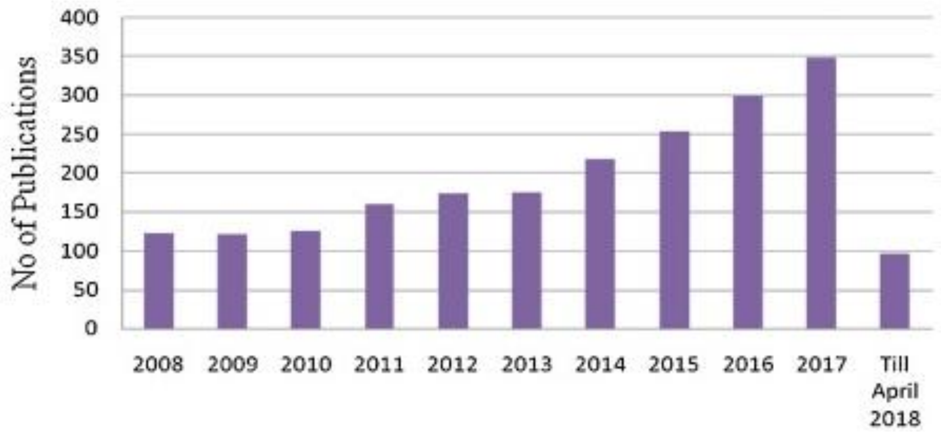

Figure 2: Year-wise publications on 3D scanning (A. Haleem, M. Javaid, Department of Mech. Engineering, New Delhi, India)

Figure 2, obtained from the same article by A. Haleem and M. Javaid, reports the increasing tendency in the number of publications related to 3D scanning.

The present work fits within the prototyping and reverse engineering field. It is related in particular to the personalized medicine field, that pursues better patient care by tailoring decisions, practices, interventions or products to the individual patient based on their particular condition or features.

Personalised medicine is one of the biggest challenges in the 21st century for medicine as a science, and involves adapting treatments, practices, interventions or products to each patient based on their particular condition or features. Part of it is related to analysing the patient's genetic or epigenetic information to adapt the drug therapy or preventive care. That field is undoubtedly a matter of biomedicine, but when it comes to adapting a certain device or item, engineering should be involved. In essence, adapting a device to the patient's features is a move away from the 'one size fits all' approach, and by means of 3D scanning, computer aided design and 3D printing this approach is becoming a reality.

This project is part of a collaboration between the Hospital of Cruces and the University of the Basque Country represented by the Engineering School of Bilbao, in which medicine and engineering are conjoined. The doctors of the paediatrics unit in the Hospital of Cruces have the aim of adapting commercial medical-breathing masks to the individual patient. In certain cases, a lack of proper fitting of these masks can determine the success or failure of a treatment. The objective is to get 3D images from both the mask and the patient and by means of Reverse Engineering, build an adaptor that will be later printed by means of a 3D printer.

2.2 Objective and secondary objectives of the Work

The objective of this work is to **build an adaptor for the breathing masks**. In order to find the best way to do this, there are several secondary objectives:

- Scan 2 different masks by means of three 3D scanners
- Comparison of the results obtained from the different scanners
- Use of Reverse Engineering to create the adaptor to each mask.

2.3 Structure of the Document

Firstly, in the State of the Art section, different related works will be analysed and evaluated in comparison with the subject of this work. Additionally, some theoretical concepts related to statistics will be explained to ensure a better understanding of the results obtained.

Then, an in-depth description of the different steps carried out in the achievement of this work will be shown. The first phase consists in observing and preparing the mask that is going to be scanned. Secondly, a scanning process should be carried out to get the 3D images of both masks. Next, a comparison between the different obtained images and the scanners will be carried out to choose the best and most suitable one for this issue. Lastly, after checking that the scanning procedure is correctly performed, an adaptor should be created by means of computer aided design software tools.

The last sections of this project will be focused on discussing the results obtained, the future investigation lines and the final conclusions.

3. STATE OF THE ART

3.1 Previous engineering and medicine-related works

3.1.1 Splints

A splint is an object used in orthopaedic medicine to fasten broken or dislocated joints. They have traditionally been made of plaster. The arrival of 3D scanners and printers have allowed various companies to produce personalised substitutes.

Nowadays, these substitutes can be produced by 3D printers, which can print them using PLA, a special polymer similar to plastic but biodegradable. It is obtained from corn starch or sugar cane. This thermoplastic is widely used in 3D printing.

The procedure to obtain this type of splints is very similar to the one followed in this work to obtain the adaptors. Firstly, it involves a 3D scan of the patient's limb. Then, a shell is created over the limb and after giving it the correspondent thickness, it is sent to the 3D printer, that will create a plastic model of it. The most important advantages of this products in comparison to the previous plaster-made ones are:

- Lightness
- Waterproof
- They are personalised, and therefore adapt to the anatomy of the patient
- The design can be adapted to generate a stronger resistance on the points needed and to allow a softer or more comfortable in other areas
- They allow air circulation, therefore avoiding bad smell and irritation
- They can be opened and closed, allowing the doctor to inspect the state of the injury

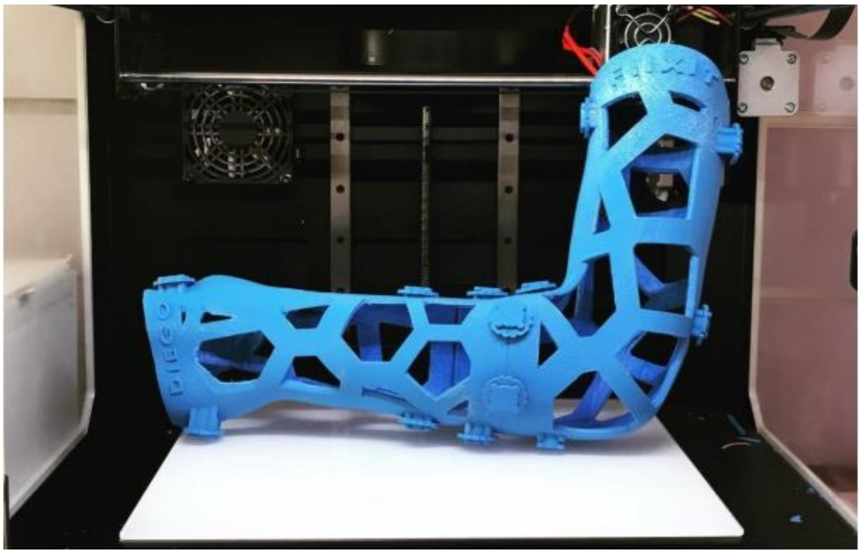

Figure 3: 3D printed splint by the Spanish company *Fixiit*. It has several holes that allow ventilation and immediate observation of the situation of the injury.

3.1.2 Surgical Tools

Cardiovascular surgeons from the Regional University Hospital of Malaga are introducing the use of 3D printed tools during surgeries thanks to the work carried out by Ignacio Díaz de Tuesta (currently working in La Paz Hospital in Madrid). He adapted various elements to the patient's need and, so far, these personalised instruments have been produced and used with 30 patients in open heart surgery. Some of the elements created include:

- Protective aortic valve
- Paravalvular catheter
- Cutaneous incision calibrating trail

Figure 4: 3D printed tools created to measure and adapt to the particular case in surgical procedures.

So far, surgeons worked based only on experience. As these objects are not left inside the patient's body, they can be sterilized and reused again in the following surgeries when needed.

3.1.3 Implants

The dental sector was one of the first to include 3D printing technologies in the fabrication of implants. 3D design and printing technologies make it possible to create fast, better quality elements adapted to the patient. There's a wide variety of elements that can be created in this field:

- Orthodontic brackets for daily use
- Teeth covers
- Tooth implants

Figure 5: 3D printed implant and model

3.1.4 3D printing for surgical situation reproduction

3D printing can also be used to print organs. The technology is not fully developed for the organs to be introduced into a patient's body in a transplant, but mock-ups of them can be created (adapting them in size and shape), so that the surgeon can practice incisions and procedures that will later be carried out in the operating room. This initiative has been carried out by the Sant Joan de Déu Hospital in Barcelona. They print this mock-up in a soft material that tends to be as close as possible to the real texture of an internal organ.

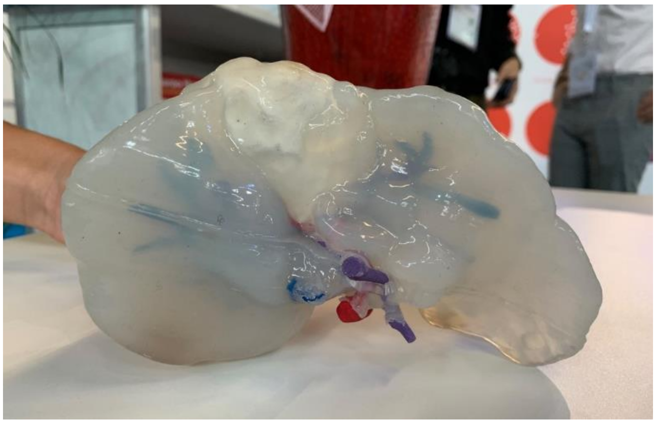

Figure 6: Example of 3D printed organ by the Sant Joan de Déu Hospital in Barcelona.

Apart from printing organs, they also print tumours and include them in silicon-made moulds of organs to recreate the real situation and the exact place where the tumour is located according to the results of the tests carried out on the patient beforehand. This kind of procedures allow the surgeon to study the particular case closely and practice. When used, it has significantly increased the success rate of the surgery.

Figure 7: 3D printing of a tumour, on which an incision has been practiced.

4. THEORETICAL FOUNDATION

4.1 3D Scanners' Functioning

A 3D scanner constructs a 3D digital model of the outer part of a physical object. The hardware normally consists of 1 or more cameras and a light source that is projected onto the object (blue or red LED light or laser).

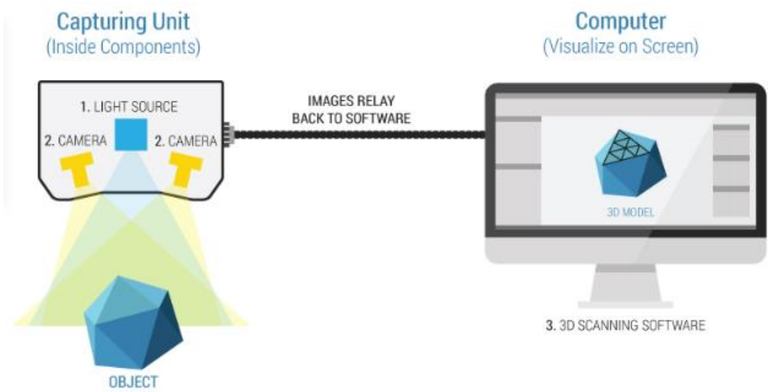

Figure 8: Scheme of the scanning elements and procedure

Figure 8 shows a simplified scheme of the functioning of these devices. The system works as follows:

I. The light source projects LED light (usually parallel beams) onto the object.
II. The light pattern gets distorted when projected on the surface of the object.
III. The cameras capture the image and the 3D scanning software and triangulates the image to calculate the object's shape, depth and surface information. The result is, first, a 3D point cloud that is then transformed into a mesh (triangulation). This mesh is converted into a 3D representation of the object, what is known as a CAD object.

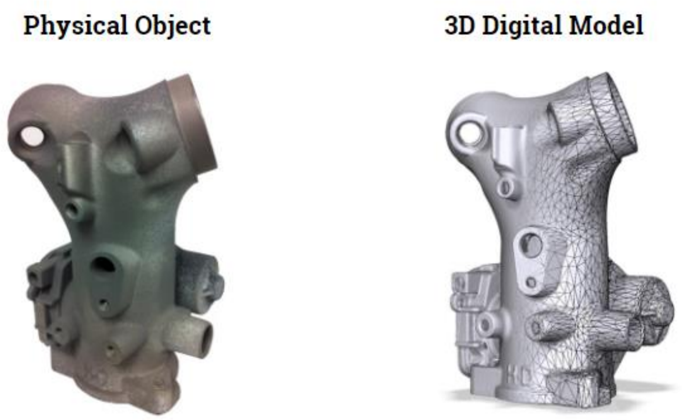

Figure 9: Difference between the real object and the 3D model created by means of 3D scanning.

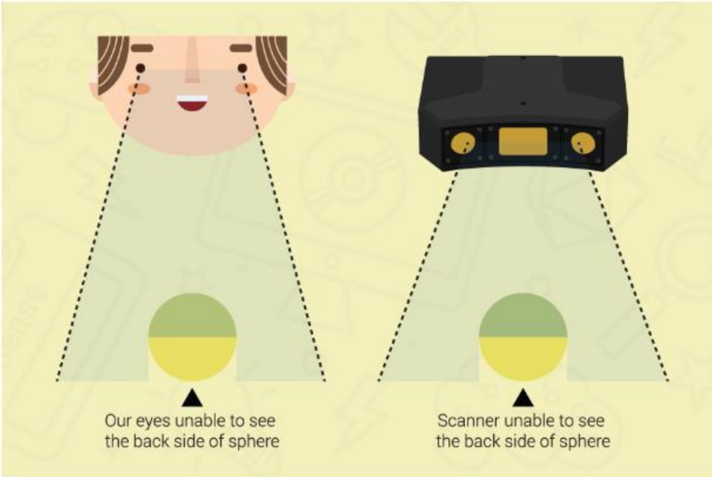

Figure 10: Comparison between human eye’s and 3D scanner's vision range.

Figure 10 shows that 3D scanners have a vision range very similar to that of the human eye. So, to get a complete 3D image of the object, several images will be needed from different angles. It is also important to point out that scanners that use 2 cameras are likely to be more reliable than one that uses 1 camera.

It is remarkable to point out that the cameras need to be able to recognise the surface. Thus, if such surface happens to be too shiny or transparent it will not be possible for the scanner to recognise it. Analysing and preparing the object is an important part of the scanning process. In order to solve this issue, several layers of powder have to be added.

4.2 Statistical Concepts

a) Arithmetic Mean ($\bar{x}$): It is the result of adding all the data and dividing the result over the total number of elements.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{N} \tag{1}$$

b) Standard Deviation (σ): it is *the square root of the average of the squared distances* from each data point to the mean.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{N}} \tag{2}$$

c) Normal Distribution: it is a curve often referred to as “bell curve” that englobes the totality of the data points. The area under the curve is normally separated in smaller regions from $(\bar{x} - n\sigma)$ to $(\bar{x} + n\sigma)$.

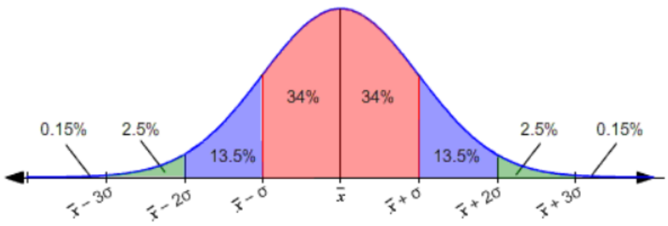

Figure 11: Normal Distribution Curve

Figure 11 shows an example of the normal distribution, where the general percentages assumed when evaluating the standard deviation can be seen. These values are approximate.

d) Error Distribution: the concept is the same as that of the normal distribution, but with an average of 0. The curve has the same exact shape as the "bell curve" above.

5. Steps to be carried out in the achievement of the work

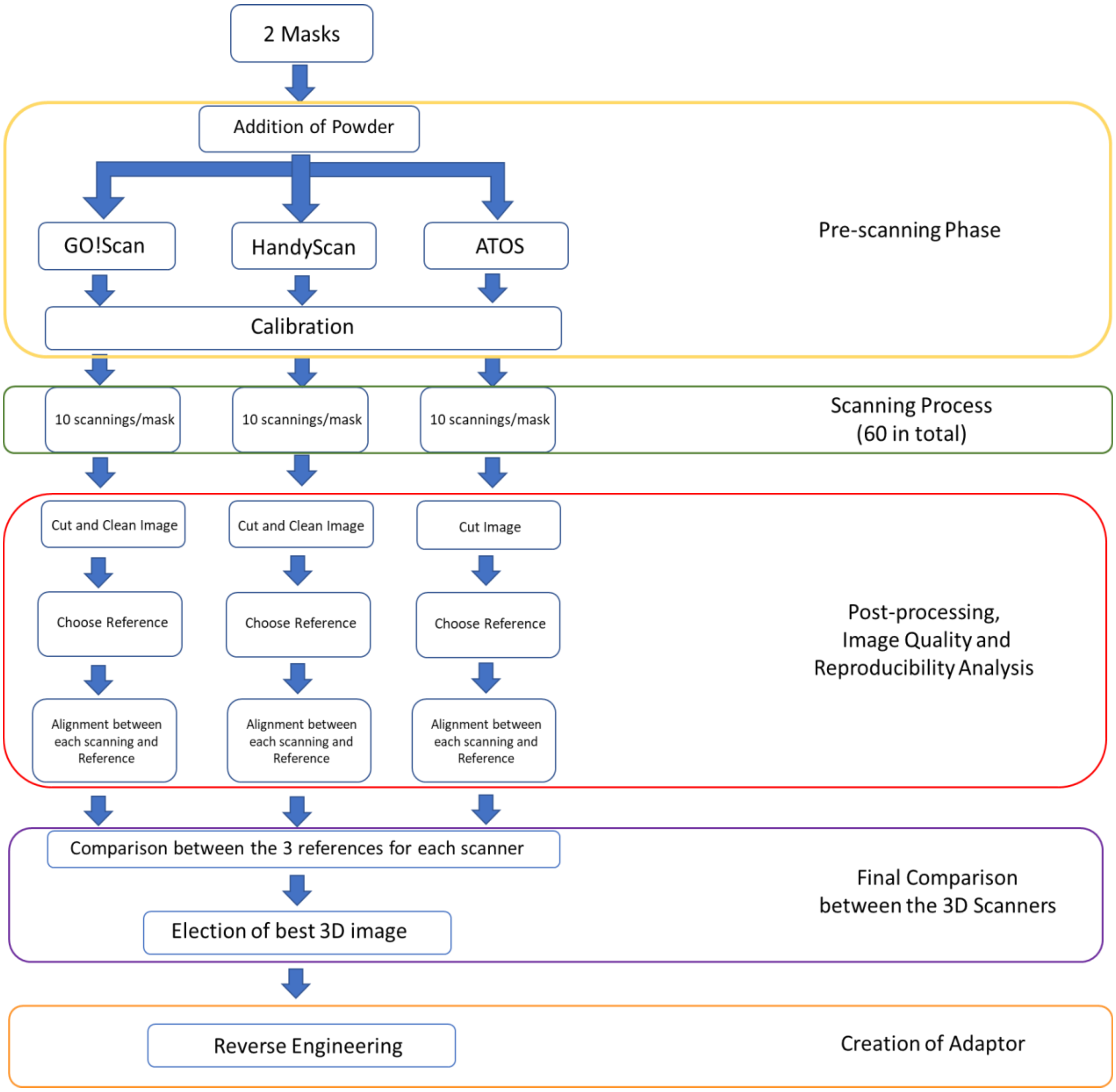

Figure 12: Concept Map of the Algorithm followed in the achievement of the work

Figure 12 shows the different steps taken in the consecution of the work. There are 5 important phases:

a) **Pre-scanning phase**: It englobes the preparation of the masks and the scanners. In the case of the masks, powder must be added and the positioning targets must be placed. To prepare each scanner, the calibration must be carried out.

b) **Scanning process**: 10 different scans of each mask with each scanner have to be obtained.

c) **Post-processing, Image Quality and Reproducibility Analysis**: The scans have to be compared between themselves to decide if the scanner itself is reliable enough for the work. Apart from that, each image must be cut and prepared in the same way to ensure accurate comparison results.

d) **Final Comparison**: The references of the scanners will be compared to choose the most suitable 3D scanner for the purpose of this work.
e) **Creation of Adaptor**: Once the choice is made, by means of Reverse Engineering, an Offset and Shell will be added, creating the final adaptor.

6. LIMITATIONS OF THE STUDY

- **Issues related to the masks**

– Transparent surface: If the surface does not reflect the light, the scanner will not be able to see the surface and the image obtained is likely to show holes or blank areas due to the lack of information supplied. To solve this problem, it is enough to apply white powder spray paint.
– Inaccessibility of an area of interest: Some pieces of the object can be covering a specific area and may be preventing the device from capturing some necessary information. It is important to contemplate the object and decide if certain pieces should be removed beforehand to uncover such area.
– Soft surface: This point is linked to the first point of this list. In case the white dust spray paint is applied and there is a soft surface (thin silicon, plastic or similar), the spray may not be correctly attached to it and it can cause the thin layer of dust applied to crack. To prevent this, the mask should be treated with extreme care and transported very slowly to the scanning area. If the cracks turn out to be too big or unstable and end up making the scanning procedure impossible, another solution could be to apply a layer of lacquer before the white dust spray to help this spray get stuck.

- **Issues related to the scanners and the scanning process**

– Vibrations: The ATOS is especially sensitive to any vibrations or disturbances. A suitable room and moment should be found for it to work properly. If it is shaken it can get de-calibrated and force to re-start the whole scanning process.
– Lighting: it is important in the case of the ATOS COMPACT to have a dim light environment, so that the structured light projected is undisturbed.
– Portability and manipulation: The ATOS COMPACT scan is considerably more complex to manipulate and use. It implies using a big stand that makes the structure weight >30 kg.
– Calibration: in case of the ATOS Compact it requires experience. Otherwise it can take a long time to start scanning.

- **Issues related to the software tools**

– VXElements does not allow to carry out an automatic alignment. The manual way also works, but introduces human error, as the points cannot be exactly chosen. In the course of this study, it was not possible to access a computer that could run the alignment automatically.

7. MATERIALS AND METHODOLOGY

7.1 Materials

7.1.1 Breathing masks

2 commercial medical-breathing masks are compared. The models are:

- Philips Oro-Nasal Mask Respironics AF531: from now on referred to as **Mask A**.

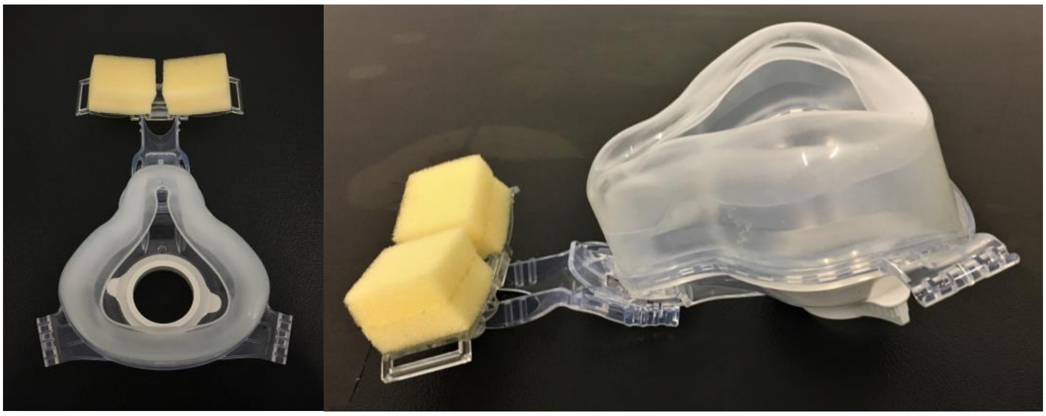

Figure 13: Philips Oro-Nasal Mask Respironics AF531

- Philips Respironics PN831 nasal mask: from now on referred to as **Mask B**.

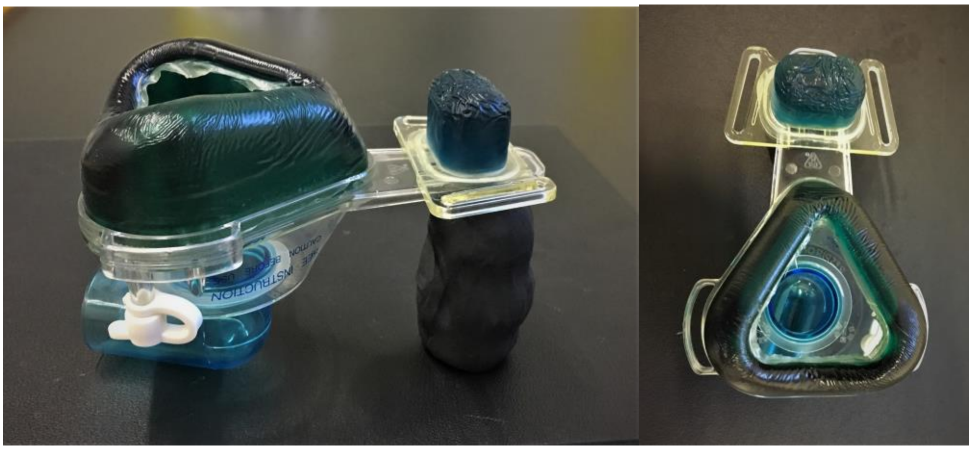

Figure 14: Philips Respironics PN831

7.1.2 3D Scanners

a) GO!SCAN 3D

The first scanner used is the GO!SCAN 3D by Creaform3D. This scanner is characterized by its simplicity and high speed. It projects white LED light onto the object and immediately shows a preview of the obtained image in the computer's screen. It does this by triangulating constantly the surface thanks to the positioning targets.

It does not require more than 5 minutes to get a 3D digital model of the object. While keeping the trigger pulled, the camera will take pictures of the object continuously.

It uses the software tool VXElements.

b) Handy REVSCAN

The second scan is the Handy REVSCAN, also from the Creaform3D brand. In this case, the scanner projects a red LED light on the object through the top centre lens. The one on the bottom projects a red cross that indicates the area that the cameras at the sides are capturing. Using triangulation, these cameras can determine the position of the scanner in relation with the object at all times. They use the retroreflective positioning targets placed on the objects (as in the subsection above) as a pattern to follow, and, combined with the red cross and its deformation on the surface of the object, get a complete 3D scan of its geometry.

The scanning procedure is very similar to that of the GO!SCAN, as they are both products of the Creaform3D brand. It also uses the VXElements software tool. The version used for this work is Version 6.3.

c) ATOS COMPACT scan 5M

The ATOS scanner uses narrow-band blue light that projects onto the surface creating precise fringe patterns that the 2 cameras on the side capture. That system is based on the stereo camera principle. The calibration process allows the system to know in advance the beam paths of both cameras and the projector and thus, allows to create and calculate 3D coordinate points from three different ray intersections. To get the required images for this work, 2 different kinds of lenses can be used. In this case, the big ones were chosen. The smaller lenses would have been more precise, but that level of accuracy is not necessary for this issue. The software employed by this scanner is the GOM Inspect. This work was performed using the GOM Inspect 2018 free version.

Table 1 shows the most relevant data and features of each scanner, being the GO!SCAN the least accurate one and the ATOS the most precise and accurate one.

Table 1: Summary of each of the scanner's main features

	GO!SCAN 3D G1	HandySCAN REVscan	ATOS COMPACT scan 5M
Weight	1,1 kg	980 g	4kg + Stand
Measurement Rate	550,000 measurements /s	18.000 measurements /s	1s /picture
Light Source	White light (LED)	II (eye safe)	Blue Light
Resolution	0,500 mm	0,100 mm	5 or 12 megapixels
Accuracy	0,300 mm/m	Up to 0,020 mm + 0,200 mm/m	0,017-0,481
Scanner			

7.1.3 Positioning targets

Each scanner has its own stickers that must be placed on the rotative base where the mask is located for the scanning process.

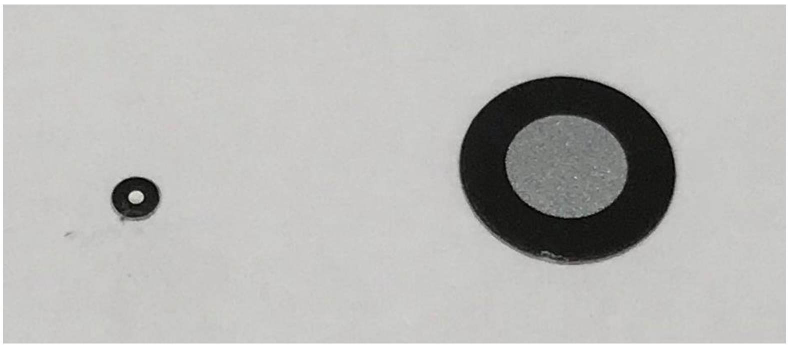

Figure 15: Positioning targets for ATOS and CREAFORM Scanners

Figure 15 shows the corresponding sticker for each scanner brand. The small one corresponds to the ATOS Compact Scan and the other one to GO!Scan and Handy REVScan (as they are both from the Creaform brand). It is important not to confuse these stickers. If the wrong one is used the scanner will not recognise it.

7.1.4 Powder

Figure 16: White Powder Spray by Helling

The white powder used to cover the shiny areas is shown in Figure 16. The model is NORD-TEST U89. The manufacturer indicates that the average particle size is of 2,8 μm. The thickness of a layer is around 20 μm. In this work, a maximum of 3 layers are added, which would be the equivalent to 60μm. This thickness is insignificant compared to the dimensions of the masks, so the application of powder will not affect or distort the results.

7.2 Mask Preparation Methodology

7.2.1 Adding the powder

Before applying the powder to Mask A, it is necessary to remove the irrelevant areas that can get in the way of the scanner.

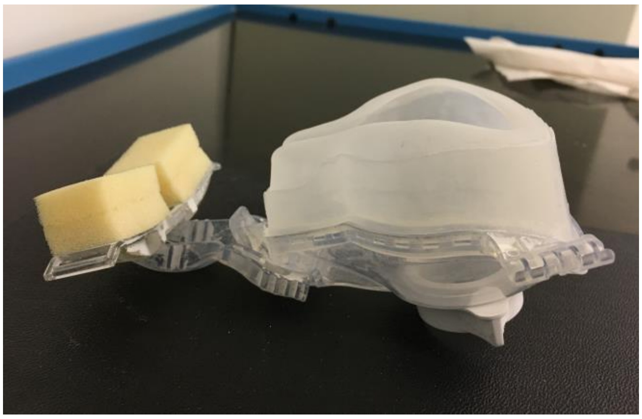

Figure 17: Mask A after removing upper silicone cover

Figure 17 shows Mask A right after removing the irrelevant area. Besides, it was also necessary to remove the yellow sponge (that serves as a protection for the patient when the mask is being used) as it stands in the way for the scanning procedure with the ATOS scanner, preventing it from seeing the relevant area behind it.

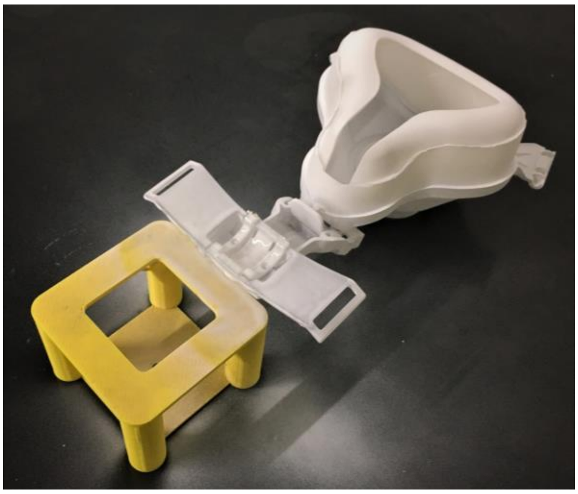

Figure 18: Powder application on Mask A

Figure 18 shows Mask A ready to start the scanning process after the application of the powder. It is important to note down that 2 layers of white powder were added, to ensure it would resist the amount of time the scanning procedure lasted and guarantee that all shiny surfaces are correctly covered.

As for Mask B, the preparation is less demanding. It is enough to apply 3 layers of the white dust spray paint and handle it with care while moving it. No elements have to be removed. In this case 3 layers were added because Mask B is made of a very soft gel material that caused some cracks to appear after the white powder application. These 3 layers ensured it resists the necessary time for the scanning process to be completed.

Figure 19: Powder application on Mask B

7.2.2 Placement of the positioning targets

Every scanner includes a specially designed set of round shaped stickers which are the retroreflective positioning targets. They are used as a reference for the software, that will capture the image by triangulating the position of the targets at all time. These stickers must be correctly placed on either the object or its base. In this work, the positioning targets are placed on the rotative base.

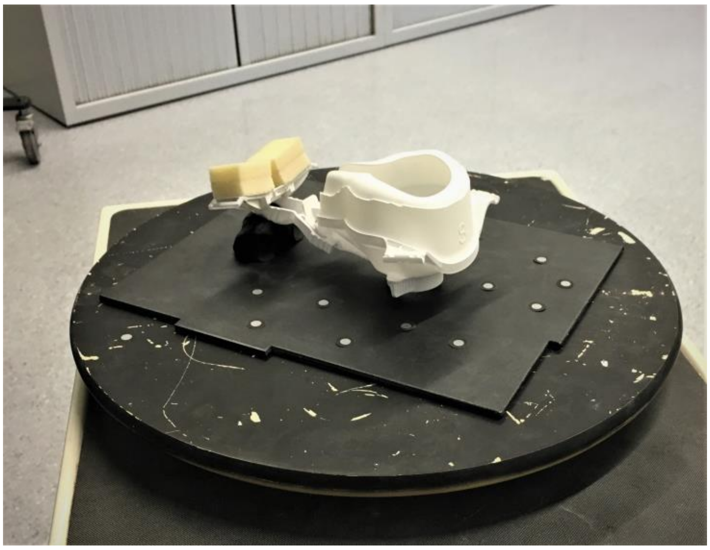

Figure 20: Scanning set-up with Mask A and positioning targets on the base

7.2.3 Calibration of the scanner

Calibration is the first step of the scanning procedure. It is important to do it on a regular basis, as it guarantees a more exact and reliable result. In this study, the calibration should be carried out in the beginning of the scanning.

Moreover, a new calibration should be performed when changing the subject of study. In other words, several repetitions can be obtained with the first mask but when starting to scan the second mask, a new calibration should be carried out.

a) GO!SCAN

The scanner includes a small wooden piece with a pattern on it called the calibration plate. It is included in each scanner's case and is meant to be used exclusively with the device assigned, as every plate is specifically calibrated for each scanner.

First, the program VX Elements must be open and after entering the VX Scan screen, click on Calibration on the top left-hand side of the screen. The program will show the calibration plate and a rectangle. The scanner should be pointing directly at the plate. From that point on, it consists on approaching the scanner to the calibration plate and, following the instructions appearing on the computer's screen, slowly separate the device from the plate while making the rectangles of the screen match. This process is repeated for ten progressively increasing distances. If the scanner is held at the correct angle and position, the scanner can just be slowly raised and all the calibration points will be quickly hit. Once all the points are hit, the program will spend a few seconds optimizing.

It is an easy process that does not require a specific training or experience. The elapsed time is around 1 minute.

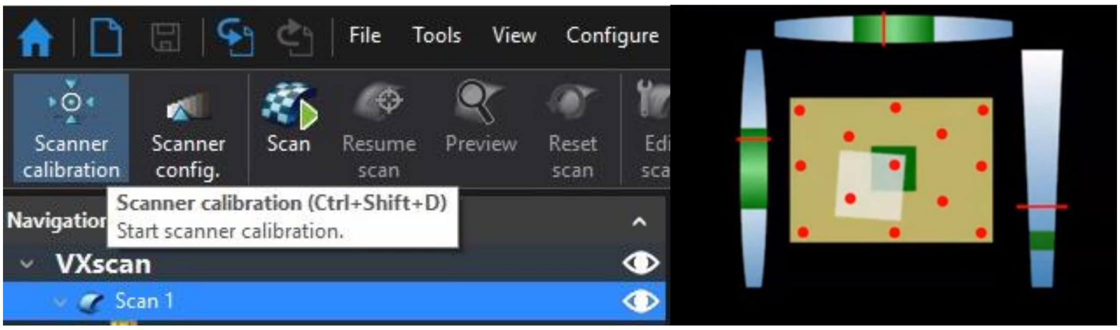

Figure 21: Calibration screen

b) Handy REVSCAN

The screen will show and require the scanner to be positioned at different angles and distances from the calibration plate that the operator must follow. The complexity, in comparison with the previous one, lies in the fact that, in this calibration, several movements shall be performed simultaneously. The device must be rotated and moved closer or further while keeping the red cross correctly pointed at the plate.

c) ATOS COMPACT

First, the device needs to prepare and get warm. Once the timer on the screen ends, the calibration starts. The process consists of a series of pictures that must be taken with the calibration plate being positioned at different distances and angles. The scan is lowered down gradually following the instructions from the programme and later on tilted and turned until a total of 18 images are taken. If performed manually, this process can take up to 20 minutes. If the time that it takes to get warm is considered, it can take around 45 minutes to be able to start the scanning process.

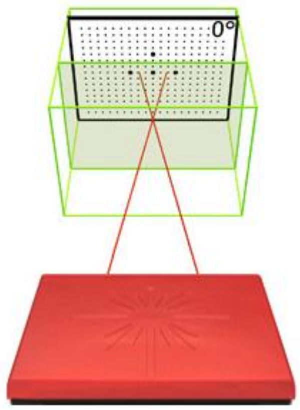

Figure 22: ATOS Calibration scheme

7.3 Scanning Process Methodology

With the objective of fulfilling scientific rigor and to test the reliability of the procedure as a whole, 10 scans shall be taken of each mask with each scanner.

- GO!SCAN 3D and HandySCAN

Both scanners are used in the exact same way while scanning. While keeping the trigger pulled, the camera will take pictures of the object continuously.

Scheme of movements:

i) Always start with the device on top of the object getting a bird's-eye view of it.
ii) Change the angle of the device 30 degrees down with respect to the vertical and move the base of the object slowly until a 360 image of the object is obtained. This way, the software can even get some information from the inner part of the object, if pointed correctly at it.
iii) Lower it 30 degrees more to capture the part of interest for this work more accurately and fill the remaining holes. Once the object has been rotated 360 degrees, the scanning will be finished and the trigger can be released.

- ATOS COMPACT Scan

This scanner is different from the other two in the way it captures the object. The other scanners do it in a continuous way. This is, while pulling the trigger the scanner keeps taking images of the object non-stop. In the case of the ATOS COMPACT, it takes one picture at a time, by pressing the 'spacebar' in the keyboard. Each picture must be taken separately, and the software joins them one by one when obtained, providing the resulting image, processed afterwards by means of the GOM Inspect software tool.

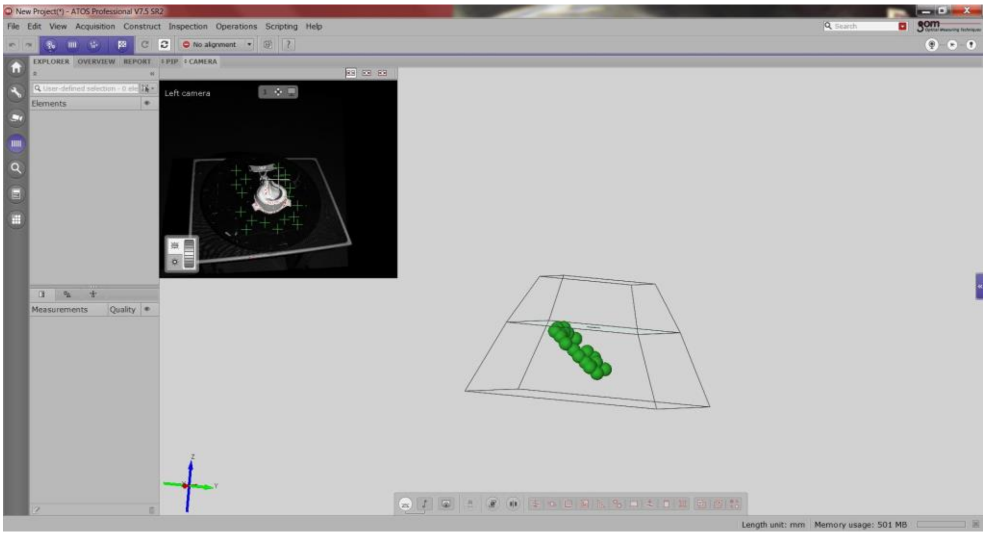

Figure 23: Correct positioning of the mask in front of the ATOS scanner

Figure 23 shows a pyramid shaped prism. Before pressing the 'spacebar' and capturing the first images, it must be ensured that the area of interest delimited by the positioning targets (in the Figure 23 represented as the green dots) remains in the volume between the two bigger planes as it can be observed. That means the object is well positioned and ensures a good result.

Then, the same scheme of movements (this time taking individual images) should be followed. It is important to start in the same position and following the same scheme of movements described with the previous scanners.

Figure 24: 2 different positions of ATOS scanner during the scannign process

7.3.1 Image check and processing

Before processing the image, it is advisable to check that the 3D digital image's surface is correctly scanned and that all the necessary information was captured by the scanner. Sometimes, some holes may appear. In those cases, in which the scheme of movements was followed and any hole is detected, it is not necessary to start from the beginning. It is enough to point directly at that part, pull the trigger, (or take a picture in case of the ATOS) and check again afterwards if the hole is finally filled.

After that, the image is ready for processing. A document will be created and it will be stored in the following formats:

- ***.csf**: Native format of VXElements
- ***.ginspect**: Native format of GOM Inspect
- ***.stl**: "Standard Triangle Language". It stores the solid CAD object, formed by means of triangulation.

Depending on the software used for the post-processing, it may be necessary to export those native formats to *.stl.

In the case of the ATOS scanner, before processing the image the object must be isolated and the irrelevant areas deleted. As this scanner provides a high-resolution image, processing the uninteresting points would mean a considerable increase in the processing time.

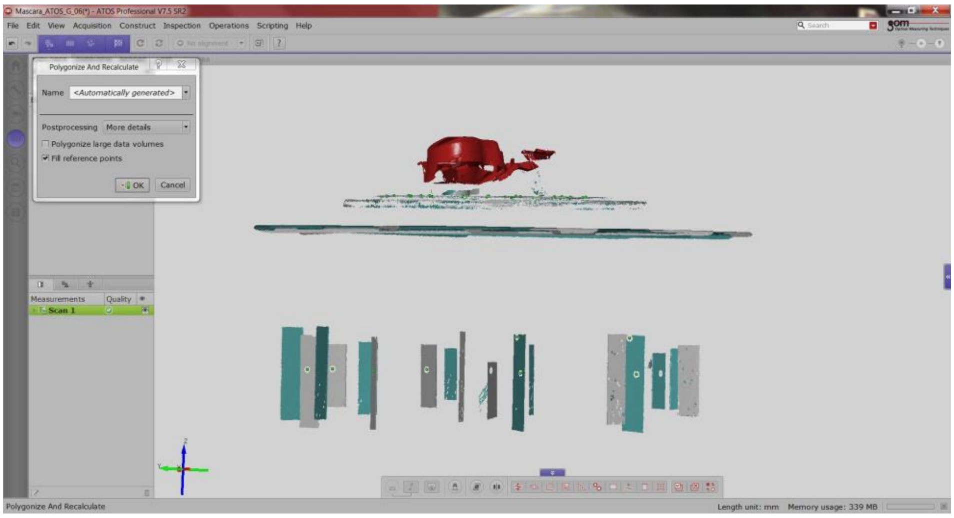

Figure 25: Mask A scanning result

Figure 25 shows the 3D image of mask A right after finishing the scanning process. Before processing and saving the image, the mask must be isolated.

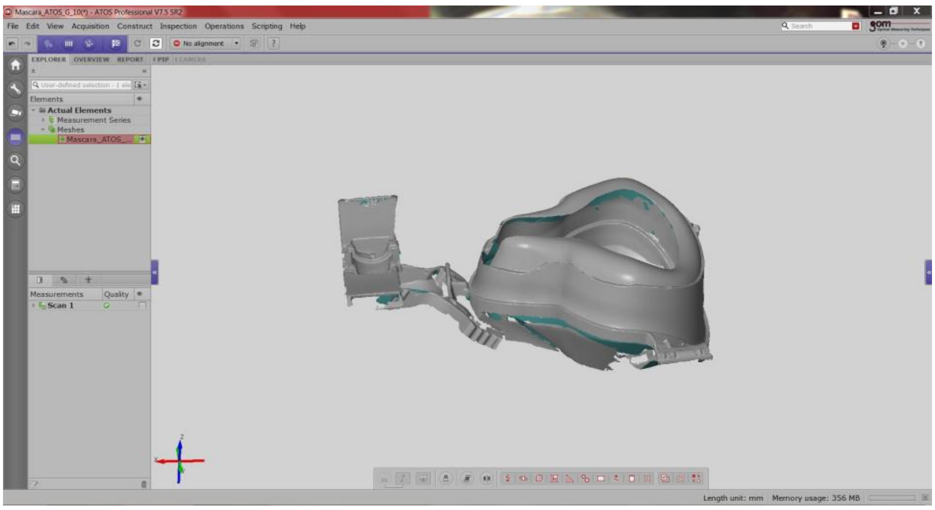

Figure 26: Mask A isolated and ready to save

Figure 26 shows the result after mask A is selected and the environment has been removed. After this, the image has to be saved both in the standard native format and in *.stl for future use.

7.3.2 Post-processing and Comparison

- Post-processing via VXElements

The 3D image contains more information than the one required for the comparison and the prototyping, so a previous cutting process must be carried out to clean the 3D digital model and isolate the area of interest. Otherwise, the comparison would not be exact enough, as it would include too many different points that would introduce an unwanted error.

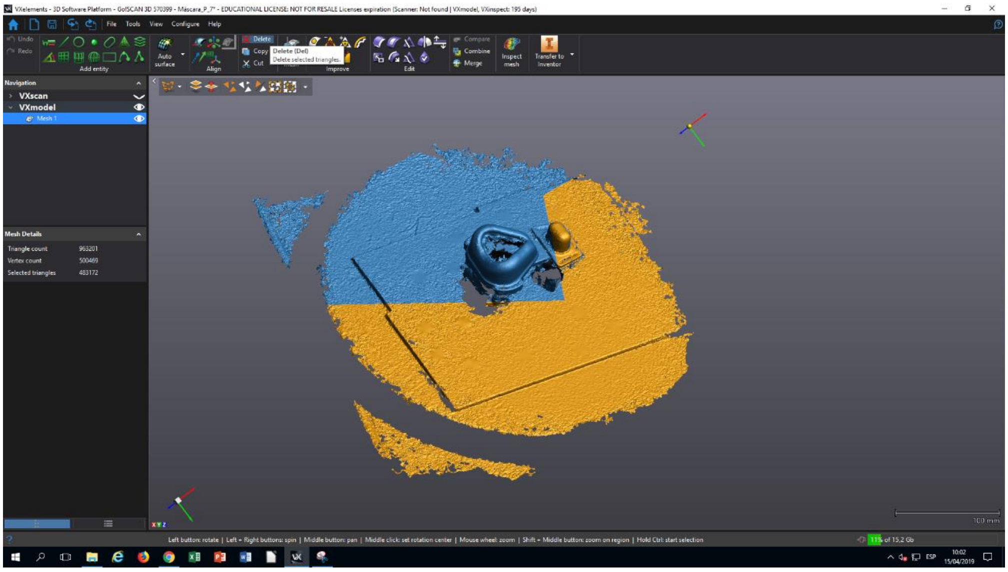

Figure 27: Selection of irrelevant points

Figure 27 shows that the original 3D image obtained includes the base and parts of the mask that are not relevant for this study. Thus, they must be selected by pressing on "Free Form Selection" – hold "Ctrl" and click repeatedly with the mouse to select an area (in Figure 27, in yellow).

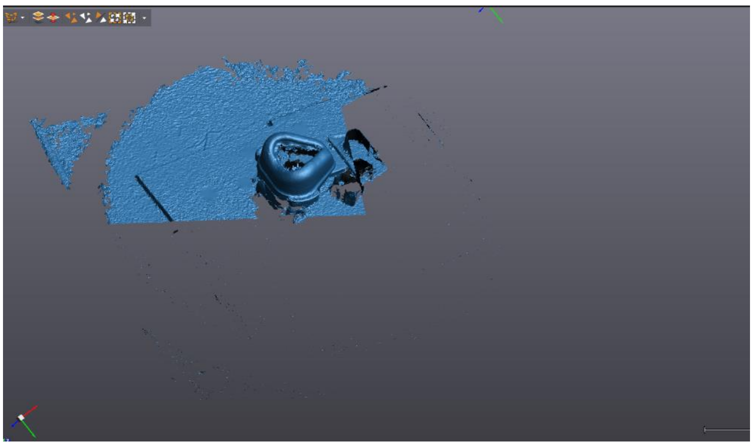

Figure 28: Result of the removal of selected points

If we observe Figure 28 carefully, the program only deletes the triangles directly on the surface shown in shiny blue.

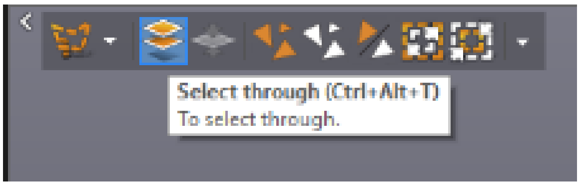

Figure 29: Selection bar on VXElements

Figure 29 shows 'Select through', which is the option that has to be selected to delete every triangle encircled by the selected area.

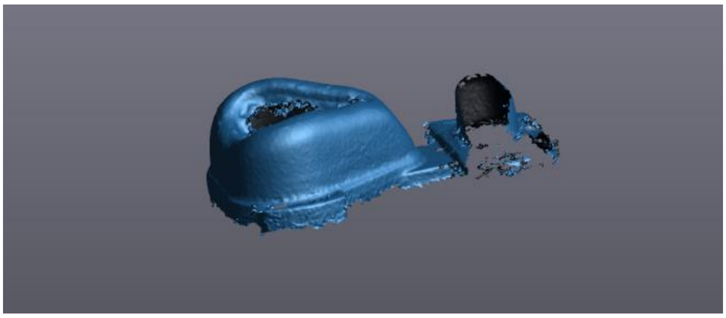

Figure 30: Mask B once the environment has been deleted

Figure 30 shows Mask B isolated, once the elements of the base and the environment have been deleted.

The following step requires the geometry of the object to be followed very carefully.

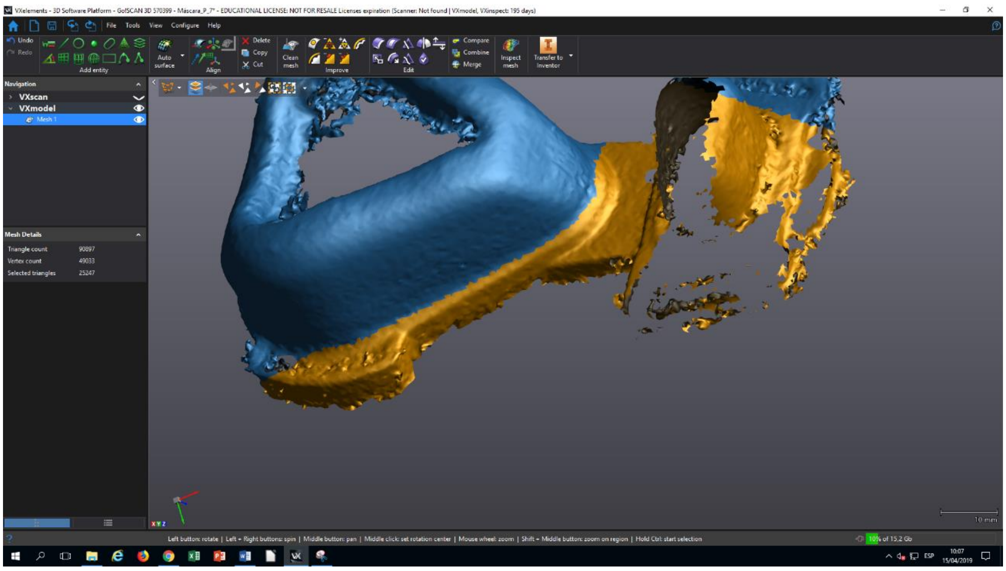

Figure 31: Selection in Mask A

Figure 31 shows the line followed to cut Mask B in particular. The geometry of the mask allows to cut all the different scans homogeneously. This part of the cutting process can be selected and deleted directly while keeping the "Select through" button activated. It is important to check, after deleting every piece of surface, that no relevant information was eliminated. If so, it is necessary to undo the action and start again with the selection.

Special care should be taken when cleaning the inner part of the mask.

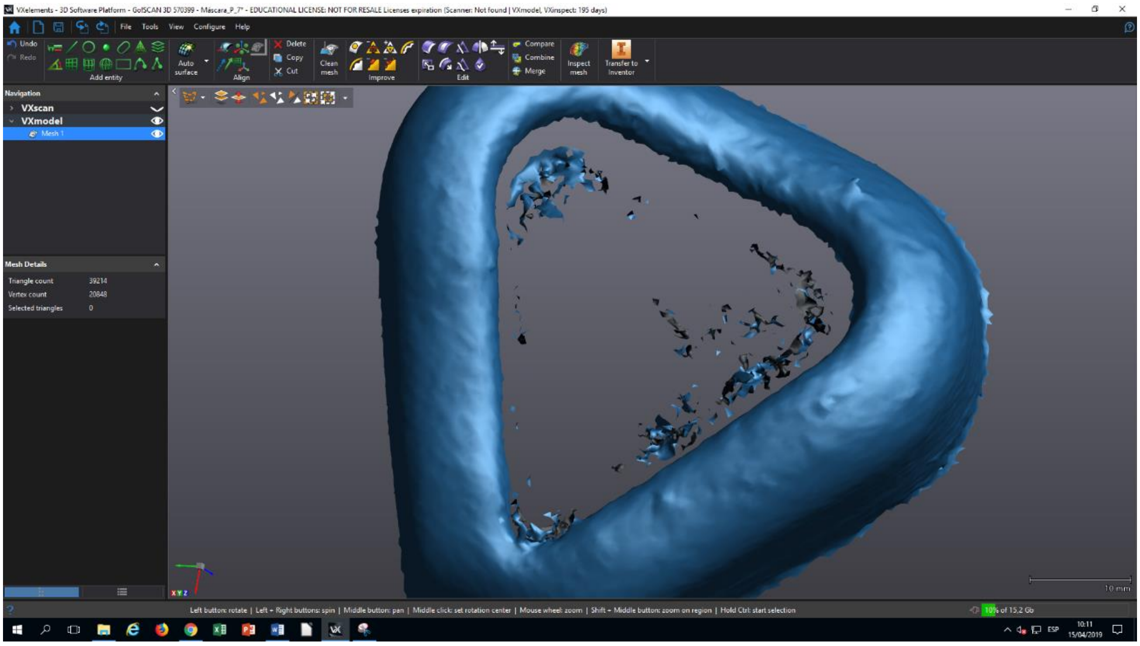

Figure 32: View of the triangles and pieces inside Mask B

The "select through" should be deactivated to ensure that the surface of the mask behind it is not eliminated. For the remaining triangles in Figure 32 there is a particular function that is useful.

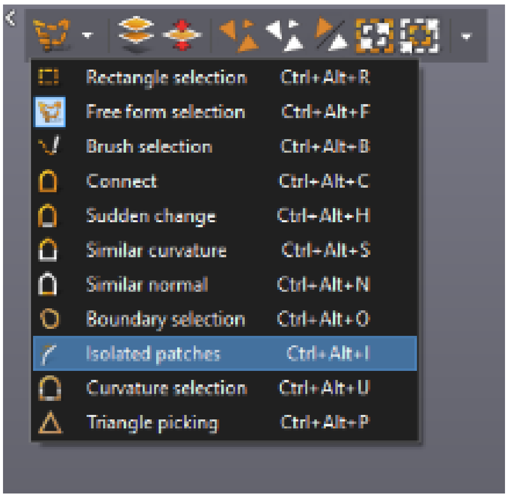

Figure 33: Function to remove isolated triangles

Figure 33 shows the most suitable way to delete those remaining groups of triangles. The size of these patches that are going to be selected can be changed and adjusted. For big patches like the upper yellow one, the size should be increased. Otherwise, only the smaller ones will be selected.

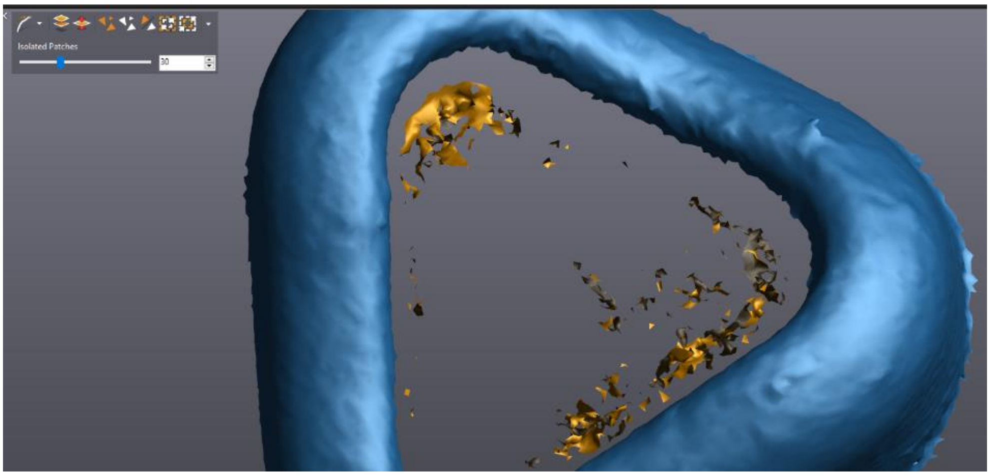

Figure 34: Patch size selection on Mask B

Figure 34 shows the last patches selected and ready to be deleted.

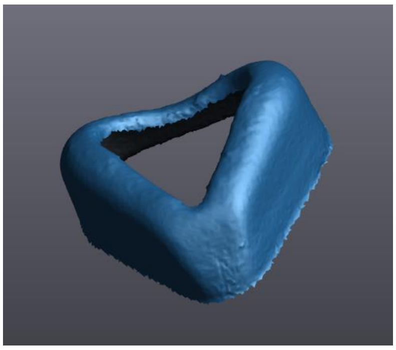

Figure 35: Mask B cut and clean for the comparisons

Figure 35 shows the resulting image. The same process should be followed with the 10 repetitions of each mask obtained with the scanner.

Mask A implies one step that is not necessary in the case of Mask B. The inner part of the mask presents spikes that if selected to then delete them, they create holes or take with them information that could be relevant for the comparison. Thus, they should be smoothed and clean in a different way. To achieve this, select the "Remove Spike" button on the area named "Improve" in the displayed options.

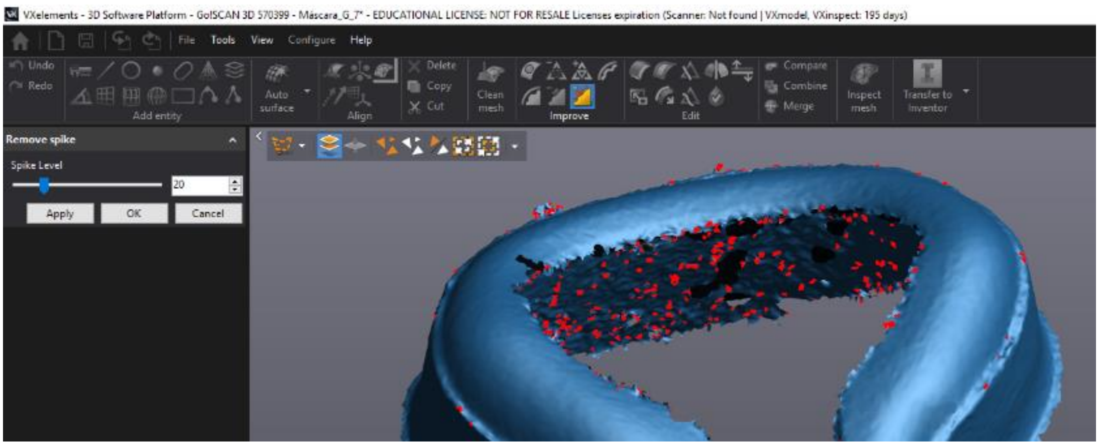

Figure 36: Removing spikes on Mask A

The number selected for "Remove Spikes" should be carefully selected. If a big one is selected, the spikes will be gone but they probably left a big hole in their place. For this mask, a number between 10-25 is adequate. Once this is applied, the mask should look like this:

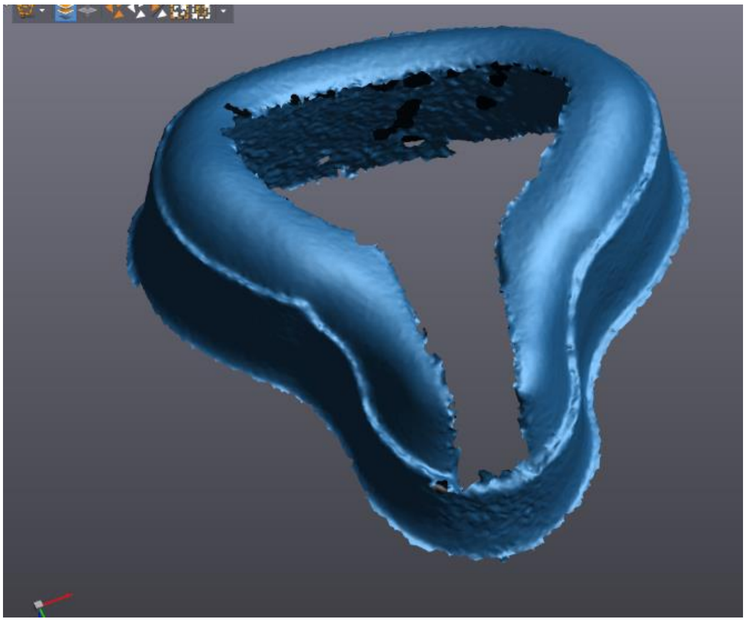

Figure 37: Mask A cut, clean and ready for the comparisons

- Post-processing via GOM Inspect

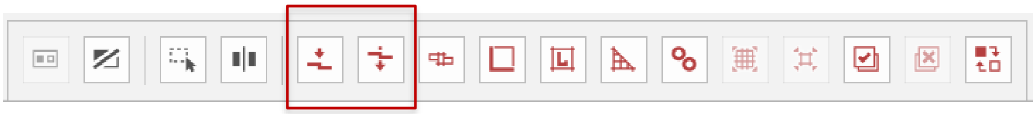

Figure 38: Bar in the lower part of GOM Inspect software tool

Figure 38 shows the bar located in the GOM in the lower part of the screen. The 5th and the 6th icons are the ones related to selecting a determined area of the object. The latter selects 'through surface', which means that the points belonging to every face of the object encircled by the selection will be included.

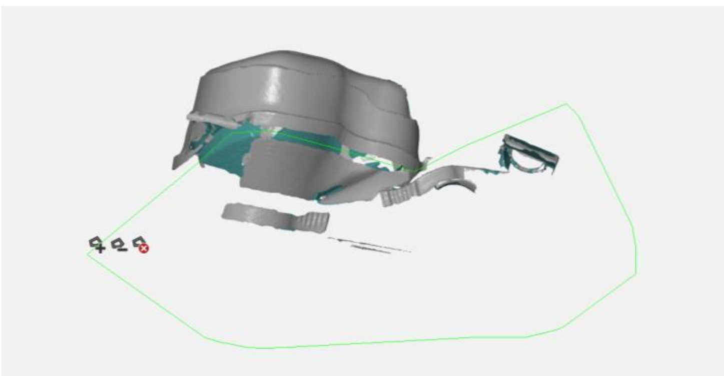

Figure 39: Green line encircling selection

The area of interest must be selected encircling it inside the green area, as can be observed in Figure 39, by clicking repeateadly with the left button of the mouse.

Once the limits are set, the right button of the mouse must be pressed and released while maintaining the cursor on the '+' icon. Then, the selected area will be shown in red, as can be observed in Figure 40. To delete the selection: Ctrl + Del.

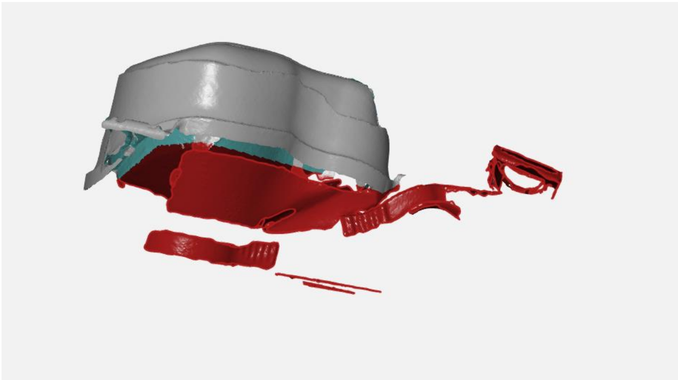

Figure 40: Selected area on Mask A

The same steps as in the VX Elements must be followed till the volume of interest is isolated. While using this programme to post-process the masks it is not necessary to make the spikes smoother. It is enough with cutting the 3D image carefully following its geometry.

❖ Alignment and Comparison via VX Elements

The first step is to import the two meshes that are going to be compared.

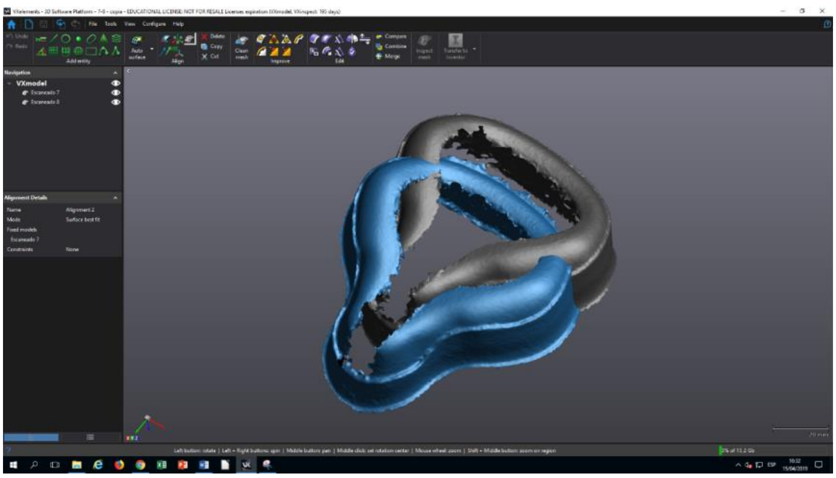

Figure 41: 2 different Mask A scans imported to VXElements

Then in the option 'Best fit' must be selected. A 'Best Fit' alignment causes a group of measured points to match as accurately as possible to their nominal position or theoretical equivalent. In some particular cases there is the possibility to align a set of points to a CAD curve or surface. In the case of this masks, it aligns the mask chosen as the reference to the other mask scan.

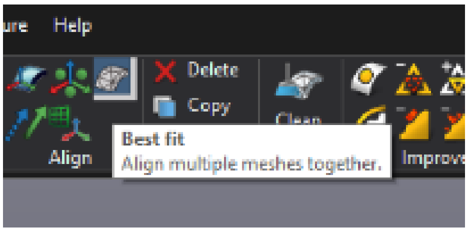

Figure 42: Best fit on VXElements

Figure 42 shows the exact place where the tool can be found. In this project, the alignment has been carried out manually. This option must be selected in the options that appear on the left, in the menu that opens right after selecting 'Best fit'.

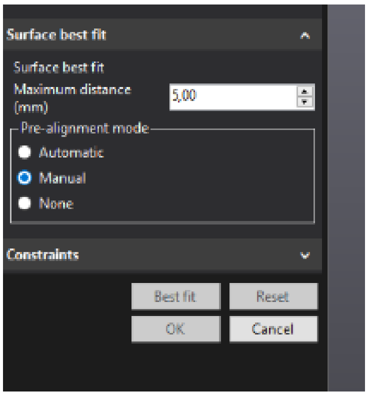

Figure 43: Box in VXElements with Best Fit options

At this moment, several points must be equally selected in both images. Thus, it is important to choose a determined number of points that can be easily found in every mask. In the case of the Mask A, 6 points have been chosen that follow the 'S' printed on the mask as part of its logo. The selection of these points must be carried out carefully and in the same order.

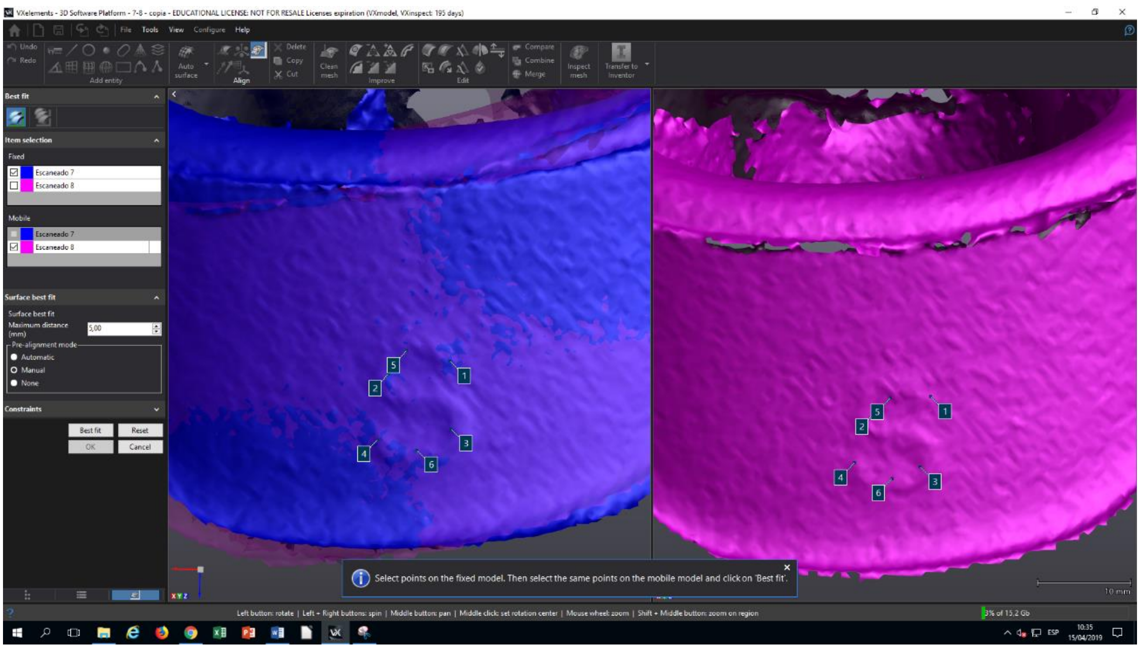

Figure 44: Point selection and order followed

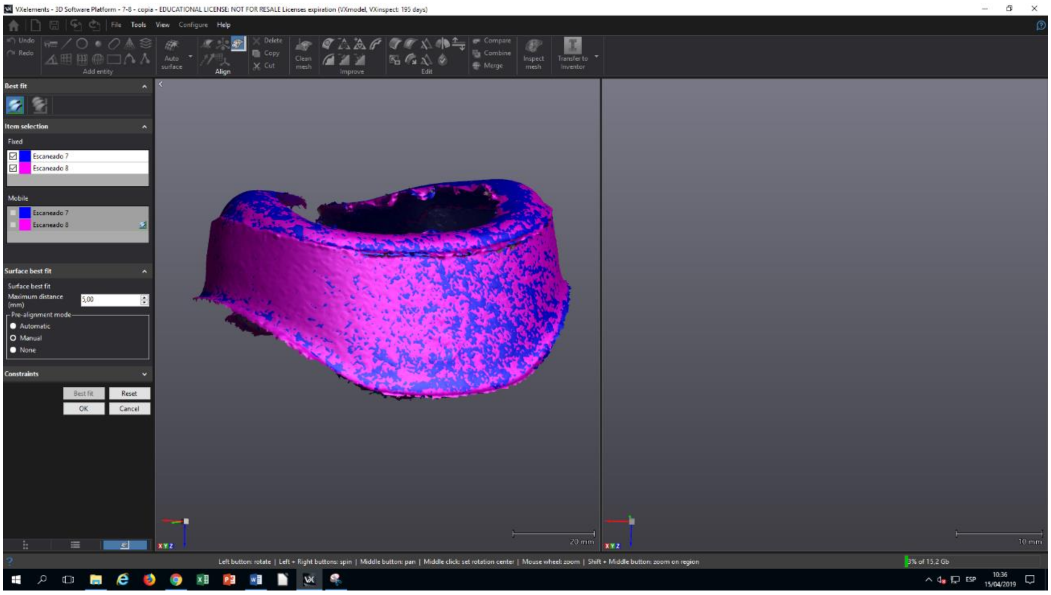

Figure 45: Preview of the alignment between the 2 scans of Mask A

Figure 45 provides a preview of the alignment. At first sight, the alignment obtained is satisfactory, so it is enough to press OK in the menu on the left and the two masks would be finally aligned. Nevertheless, it is not possible to know if the alignment is truly good or not until the data is obtained. If the standard deviation obtained from the data on the left-hand side of the screen is too big, a new alignment will need to be obtained, until the best result possible is obtained.

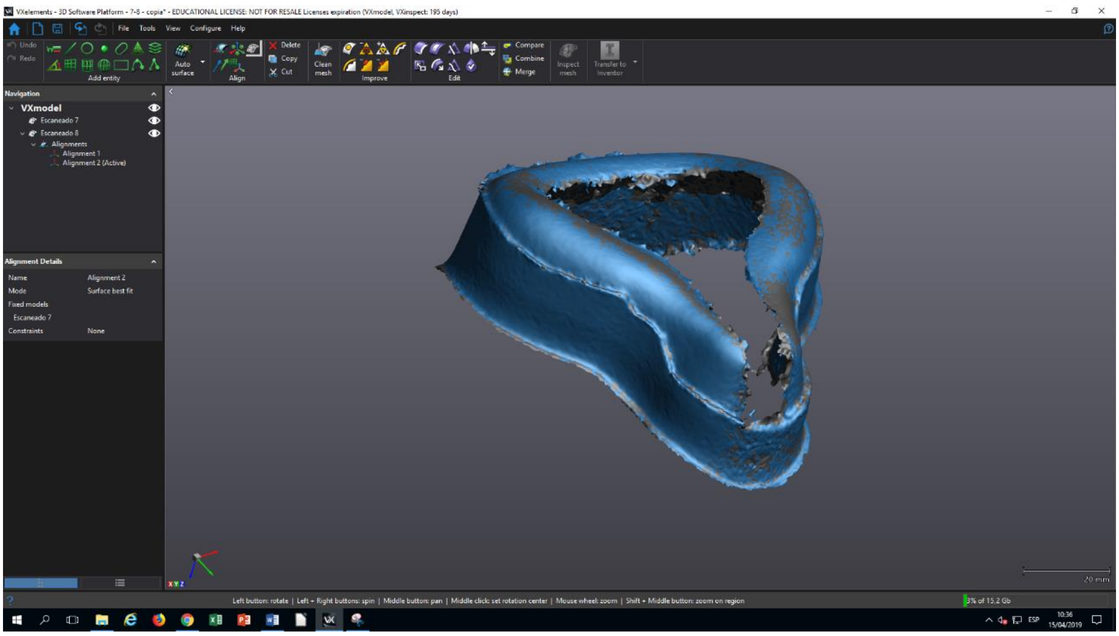

Figure 46: Result of the alignment between the 2 different scans of Mask A

Now, going on to the comparison phase, it is important to select in the menu on the left the correct image. The image **not** defined as the reference should be selected, to then click 'Compare to' the reference 3D image.

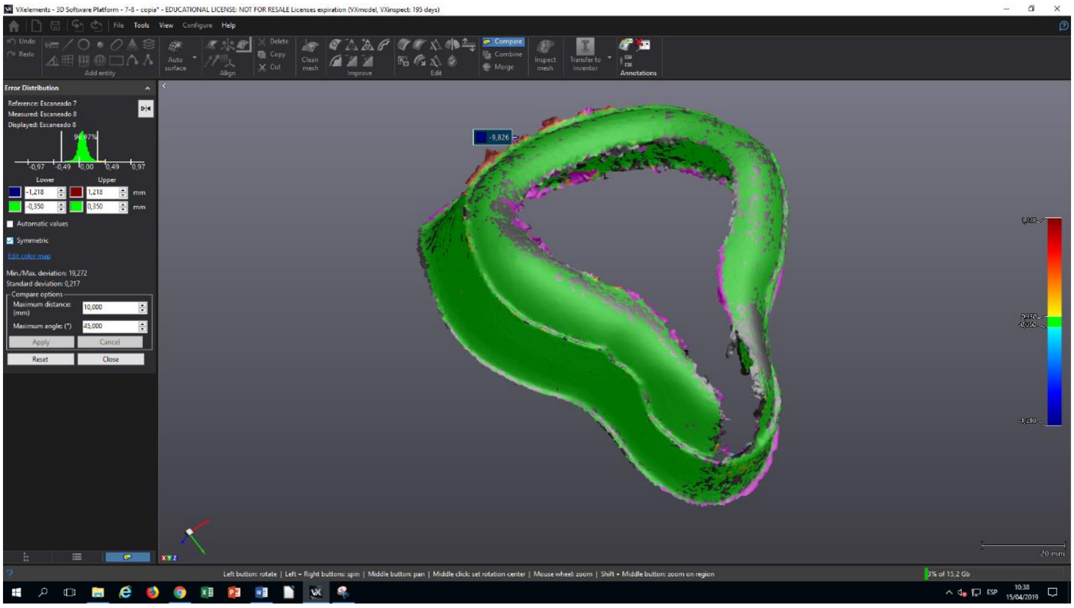

Figure 47: Colour map of the alignment

Figure 47 shows a colour map of the comparison. In order to ensure the uniformity of the data collected, the limits of the green volume are manually selected by deciding on a value. In case of Mask A, the limit chosen has been ±0,350mm. Then, data about the standard deviation should be collected and examined. The error distribution is also provided, whose result percentage and curve are shown in the top-left side of the screen.

In the case of Mask B, the point selection is more complicated, as there is no characteristic shape or reference point. The following points have been selected. Human error, in this comparison process, is inevitable.

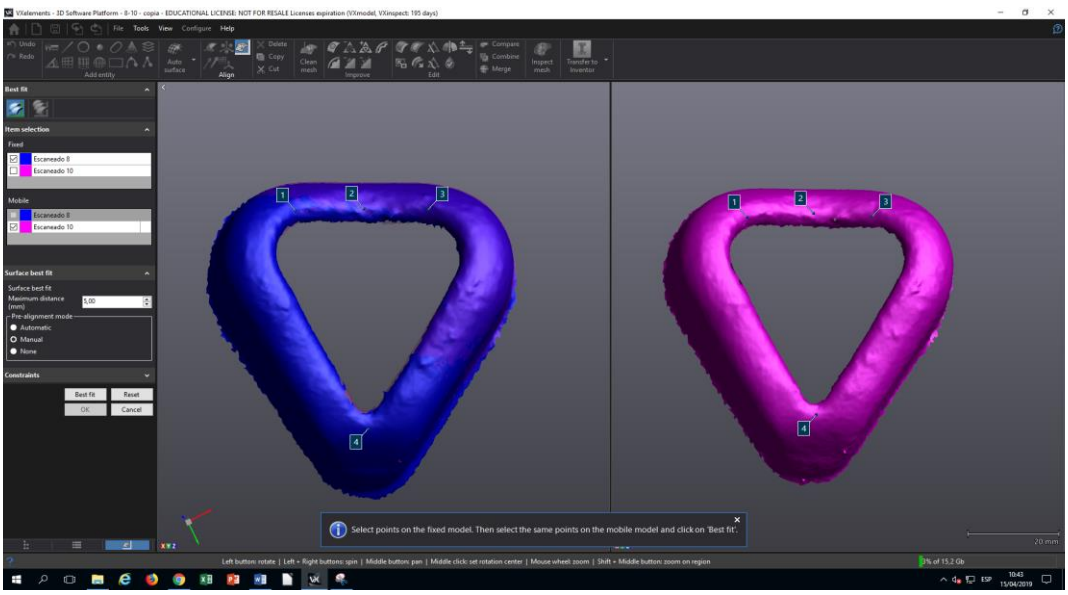

Figure 48: Point selection in Mask B and order followed

In this case, as the mask is smaller and more uniform, a limit of ±0,2mm is to be introduced in manually for the colour map and the comparison results.

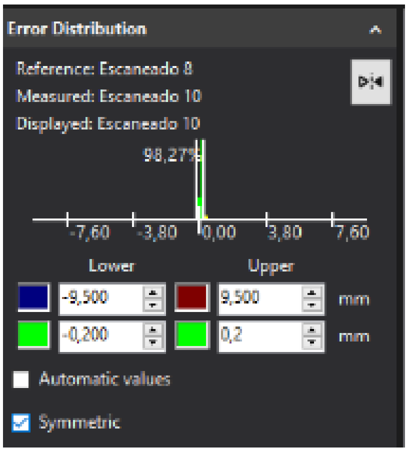

Figure 49: Results window with relevant data for the comparison

❖ Alignment and Comparison via GOM Inspect

In this case, to compare with the GOM, the object is imported in a different way depending on if it is the reference or not. The mesh considered as the reference has to be imported as a CAD body, whereas the other one will be imported as a mesh. This options can be selecting in the box below.

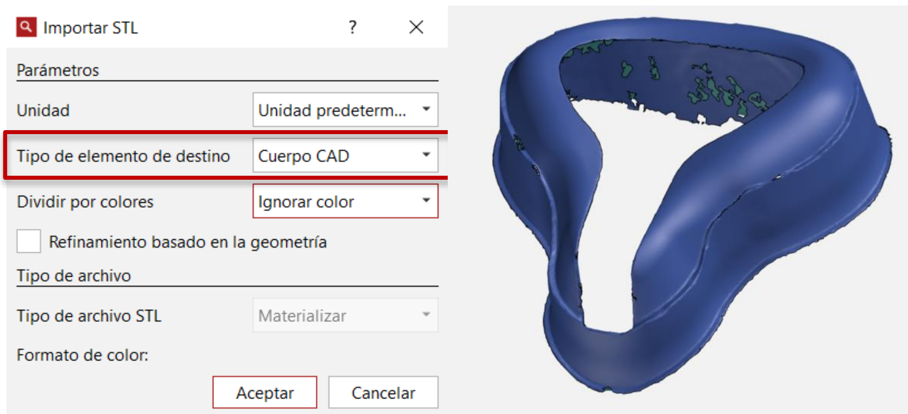

Figure 50: Importing a CAD Body

Once the CAD object is imported, it will be easily distinguishable, as it always appears in a characteristic blue colour, as can be observed in Figure 50.

The other scan of the mask must be imported in a different way. The CAD object is the reference and the other scan will only be imported as a 'Mesh'.

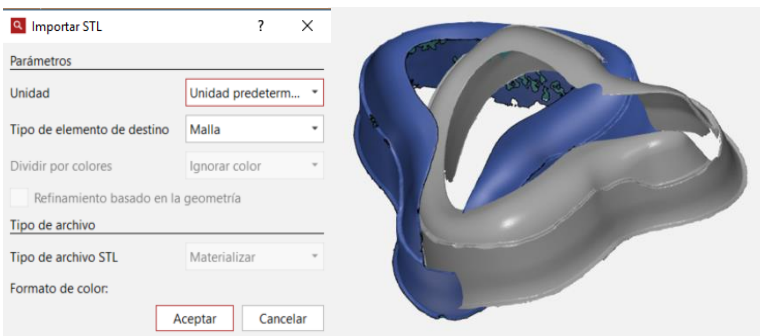

Figure 51: Importing a 'Mesh'

Figure 51 shows the way to import the second scan as a 'Mesh'.

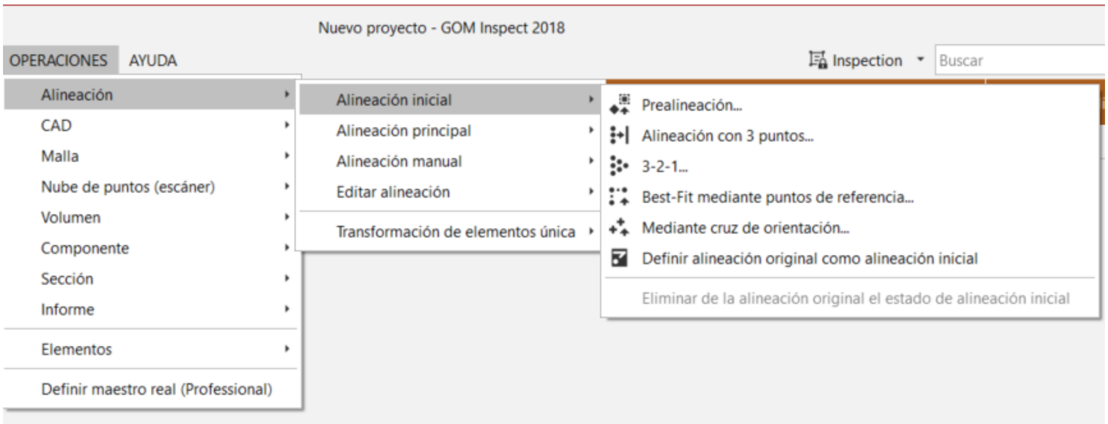

Figure 52: Location of pre-alignment option in bar at the top of GOM Inspect

It is not possible to perform a 'Best Fit' alignment right away, so a prealignment is carried out.

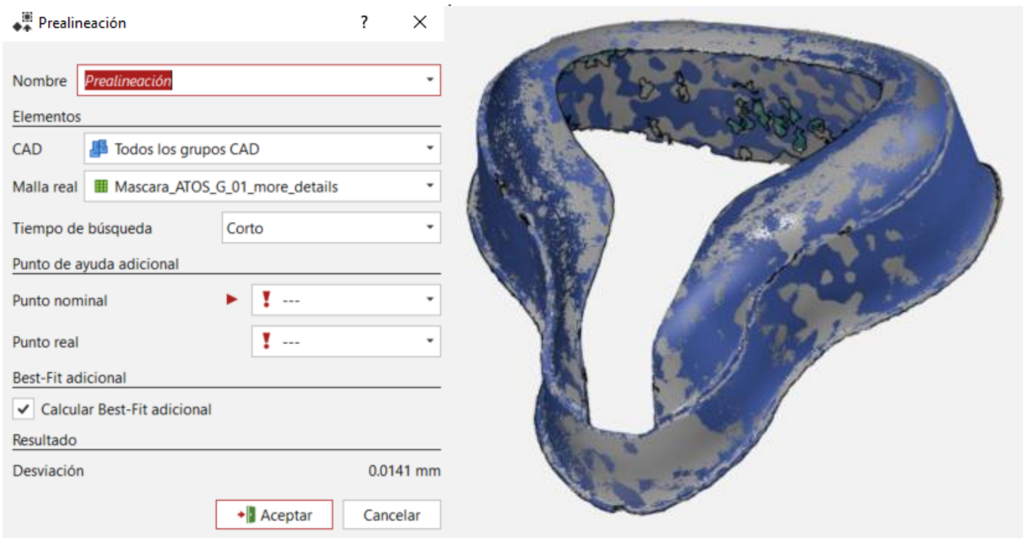

Figure 53: Pre-alignment option window and result

Nevertheless, the pre-alignment includes, by default, an 'Additional Best Fit', as Figure 53 shows. After pressing 'Accept', the pre-alignment result is displayed. When applying any other alignment method to this initial one, the results do not change. Therefore, it is possible to start the comparison.

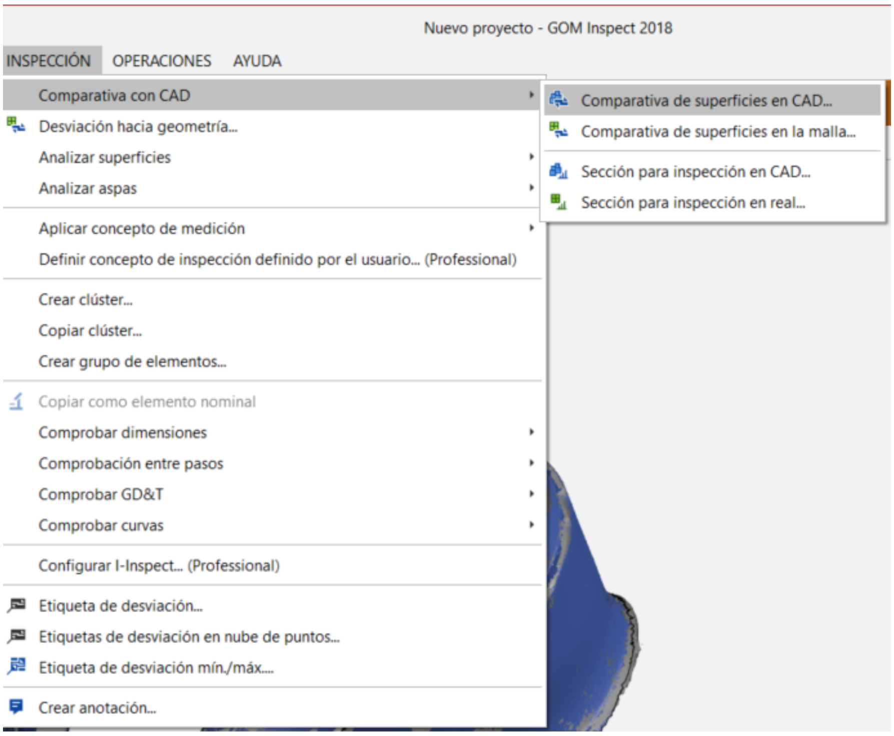

Figure 54: Location of 'Comparison of surfaces on CAD'

Figure 54 shows the place in the top bar where the comparison option can be found. It is important to choose this comparison option because the different scans are all compared to the same CAD object, which is the reference. If the comparison is carried out on the Mesh the results will change completely, as it would take the Mesh as the reference.

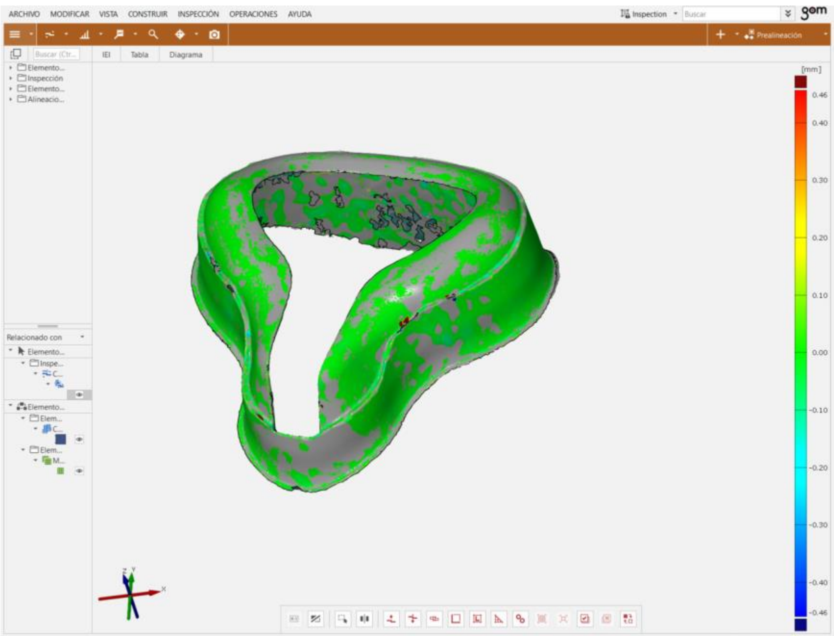

Figure 55: Colour map of the comparison of Mask A

Once the colour map is obtained, it is time to collect the data.

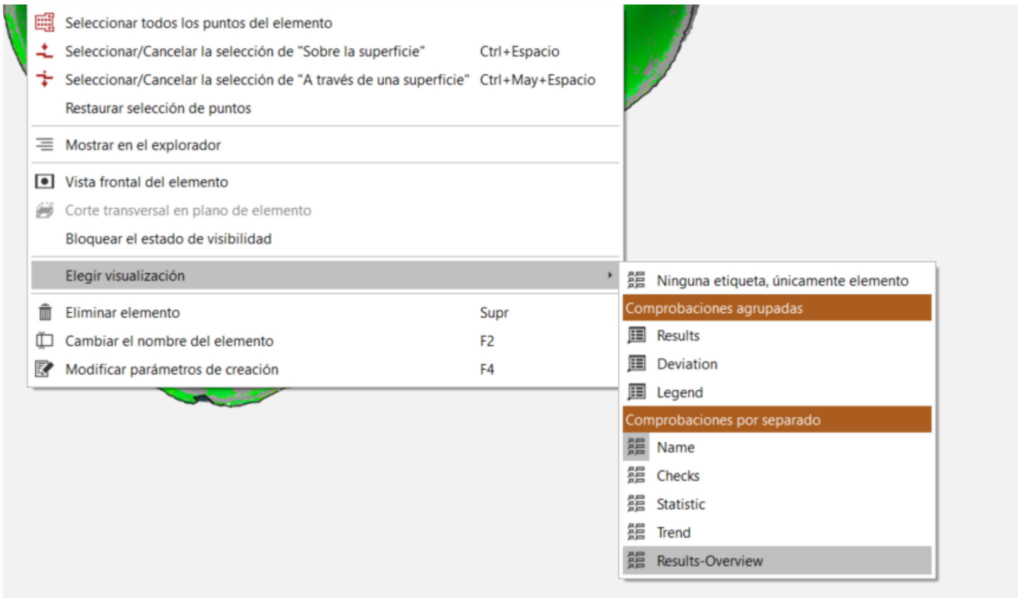

Figure 56: Location of Results-Overview when pressing the right button of the mouse

Figure 56 shows the way to find the data needed to compare the different scans. To get there, first, place the cursor on the masks and then right click.

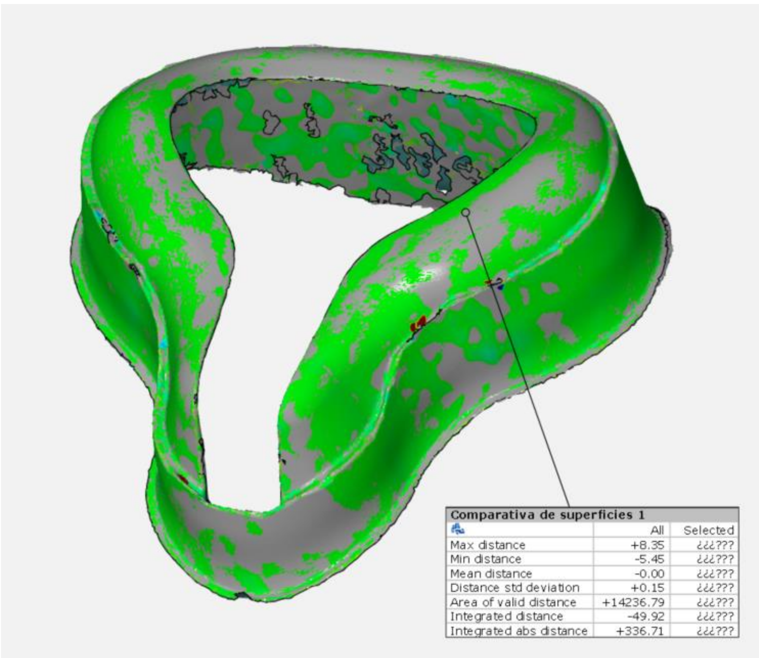

Figure 57: Data Box for the Comparison

Figure 57 shows the box where all the information and data needed about the alignment and comparison can be found.

The exact same procedure has to be followed with every pair of scans and with Mask B.

❖ Adding an Offset layer and Shell → Creating the final prototype

The first step to create the adaptor is to cut the area relevant to create the adaptor.

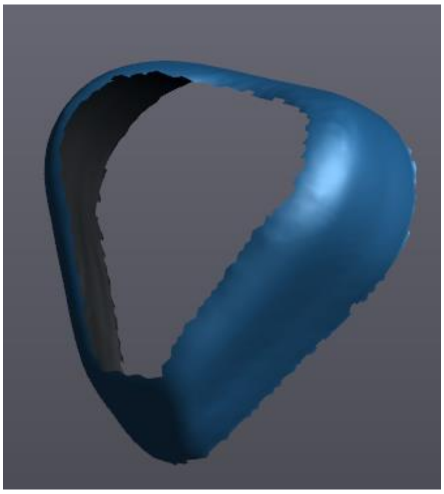

Figure 58: Cut of relevant part for adaptor of Mask B

Figure 58 shows the new cut for Mask B, ready to create the adaptor.

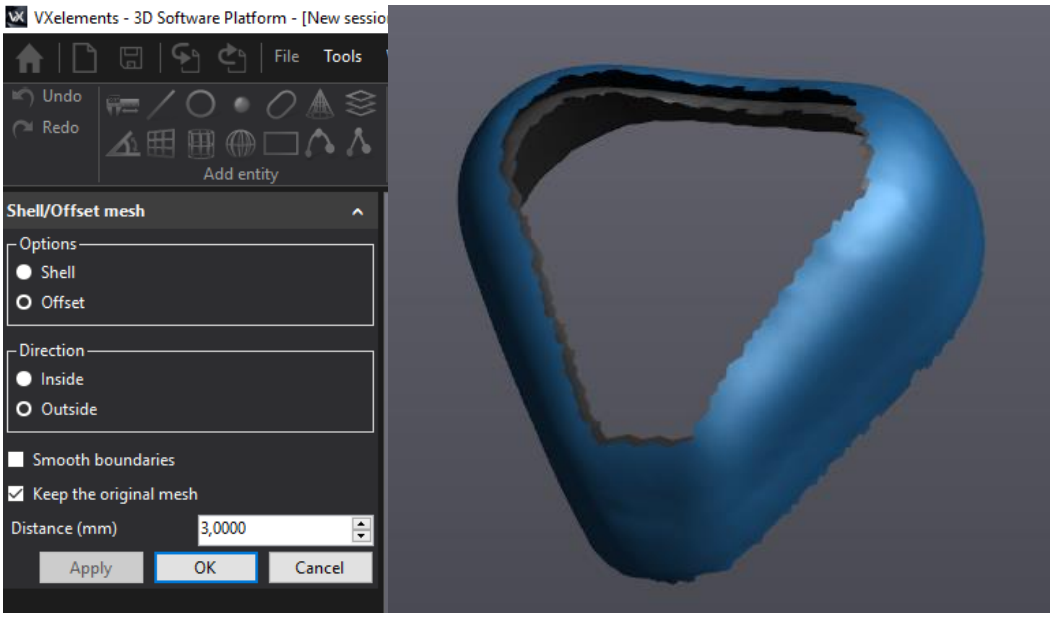

Figure 59: Addition of Offset layer to Mask B

Figure 59 shows the different options available when creating the 'Offset'. The direction must be, of course, outwards, as the adaptor is meant to cover the oxygen masks. An initial 3mm offset was chosen. This number can be changed at will, depending on the thickness wanted.

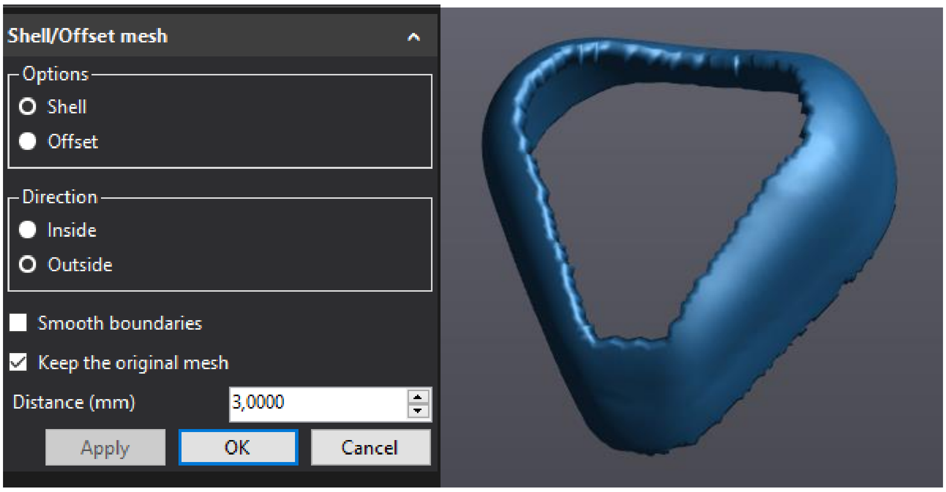

Figure 60: Shell Options and Final Adaptor of Mask B

Figure 60 shows the options available when creating the Shell. It is the same menu as the one displayed for the Offset. The shell joins both surfaces seen in the previous figure, while keeping the inside empty. Once this step is finished, the adaptor will have finally been achieved. The exact same procedure has to be followed to obtain the adaptor for Mask A.

8. RESULTS

8.1 Comparison between VX Elements and GOM Inspect

Table 2: Mask A Comparison Data performed with VXElements

VX Elemets										
	1	2	3	4	5	6	7	8	9	10
upper and lower limits ±0,350	96,01%	96,56%	97,13%	96,56%	96,26%	95,72%	Reference	96,48%	97,61%	97,00%
Min/max deviation	10,024	10,982	10,356	8,852	11,377	13,855	Reference	19,272	15,947	12,937
Standard deviation (mm)	0,174	0,177	0,153	0,127	0,197	0,213	Reference	0,217	0,184	0,203

Table 3: Mask A Comparison Data obtained from GOM Inspect

Tabla GOM										
	1	2	3	4	5	6	7	8	9	10
Min/max distance	9,99	-9,95	-9,94	-9,96	-9,97	9,99	Reference	9,99	-9,96	10,00
Mean Distance (mm)	0,04	0,05	0,08	0,07	0,10	-0,02	Reference	0,06	0,01	0,07
Distance stn deviation (mm)	0,85	0,79	0,63	0,89	0,71	0,77	Reference	0,68	0,65	0,75

Table 4: Mask B Comparison Data obtained from VX Elements

VX Elemets										
	1	2	3	4	5	6	7	8	9	10
upper and lower limits ±0,2mm	98,15%	96,60%	98,69%	98,25%	98,88%	98,38%	97,85%	Reference	98,28%	98,81%
Min/max deviation	2,772	2,921	2,995	3,082	1,542	1,542	1,353	Reference	11,352	1,765
Standard deviation (mm)	0,056	0,065	0,050	0,080	0,049	0,049	0,055	Reference	0,090	0,054

Table 5: Mask B Comparison Data obtained from GOM Inspect

Tabla GOM										
	1	2	3	4	5	6	7	8	9	10
Min/max distance	-9,88	9,82	9,32	9,4	8,94	9,27	8,81	Reference	9,21	9,44
Mean Distance (mm)	0,04	0,02	-0,03	-0,01	-0,02	-0,03	-0,04	Reference	-0,05	-0,04
Distance stn deviation (mm)	0,22	0,26	0,16	0,23	0,21	0,14	0,18	Reference	0,16	0,2

8.2 Results obtained for each scanner separately with GOM Inspect

- GO!SCAN

Table 6: Mask A Comparison Data obtained from GOM Inspect using the GO!Scan

	1	2	3	4	5	6	7	8	9	10
Mean Distance (mm)	0,04	0,05	0,08	0,07	0,10	-0,02	Reference	0,06	0,01	0,07
Distance stn deviation (mm)	0,85	0,79	0,63	0,89	0,71	0,77	Reference	0,68	0,65	0,75

Table 7: Mask B Comparison Data obtained from GOM inspect using the GO!Scan

	1	2	3	4	5	6	7	8	9	10
Mean Distance (mm)	0,04	0,02	-0,03	-0,01	-0,02	-0,03	-0,04	Reference	-0,05	-0,04
Distance stn deviation (mm)	0,22	0,26	0,16	0,23	0,21	0,14	0,18	Reference	0,16	0,2

- Handy REVSCAN

Table 8: Mask A Comparison Data obtained from GOM Inspect using the Handy REVSCAN

	1	2	3	4	5	6	7	8	9	10
Mean Distance (mm)	-0,02	-0,02	-0,01	-0,01	-0,03	Reference	0,01	-0,01	-0,02	-0,02
Distance stn deviation	0,35	0,40	0,35	0,41	0,45	Reference	0,45	0,36	0,41	0,38

Table 9: Mask B Comparison Data obtained from GOM Inspect using the Handy REVSCAN

	1	2	3	4	5	6	7	8	9	10
Mean Distance (mm)	0,02	0,03	0,02	0,02	0,02	0,00	0,03	0,01	Reference	0,00
Distance stn deviation	0,28	0,24	0,12	0,43	0,07	0,22	0,11	0,32	Reference	0,15

- ATOS COMPACT

Table 10: Mask A Comparison Data obtained from GOM Inspect using ATOS scan

	1	2	3	4	5	6	7	8	9	10
Mean Distance (mm)	0,00	Reference	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	0,00
Distance stn deviation	0,15	Reference	0,15	0,18	0,17	0,17	0,14	0,17	0,18	0,15

Table 11: Mask B Comparison Data obtained from GOM Inspect using ATOS scan

	1	2	3	4	5	6	7	8	9	10
Mean Distance (mm)	-0,01	-0,02	0,01	-0,01	-0,02	Reference	0,01	-0,02	0,01	-0,01
Distance stn deviation	0,14	0,07	0,15	0,16	0,13	Reference	0,11	0,14	0,12	0,16

8.3 Comparison between Reference scans

Table 12: Final Comparison data between ATOS scan and GO!Scan. Mask A.

ATOS with GO!SCAN		
Mask A 2-7	Min/Max Distance	10,00
	Mean Distance	-0,06
	Distance stn deviation	0,62

Table 13: Final Comparison Data between ATOS and Handy REVSCAN. Mask A.

ATOS with Handy REVSCAN		
Mask A 6-6	Min/Max Distance	-9,97
	Mean Distance	-0,07
	Distance stn deviation	0,45

Table 14: Final Comparison Data between ATOS scan and GO!Scan. Mask B.

ATOS with GO!SCAN		
Mask B 2-8	Min/Max Distance	9,81
	Mean Distance	0,03
	Distance stn deviation	0,34

Table 15: Final Comparison Data between ATOS and Handy REVSCAN. Mask B.

ATOS with Handy REVSCAN		
Mask B 6-9	Min/Max Distance	8,99
	Mean Distance	-0,04
	Distance stn deviation	0,24

8.4 Final Adaptors

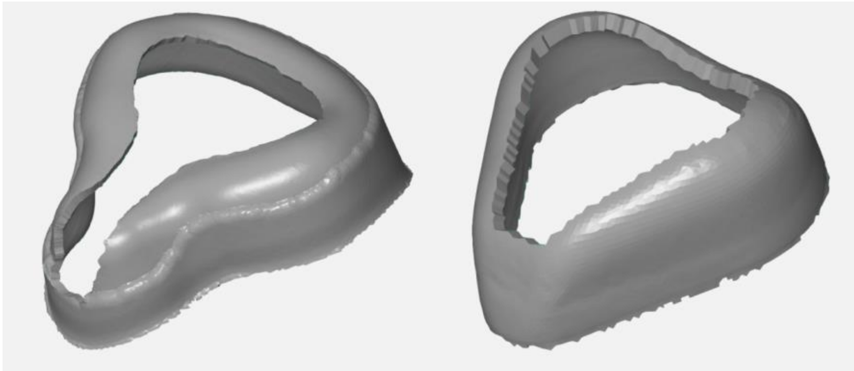

Figure 61: Final adaptors as *.stl files

Figure 62: Final Result - Mask A

Figure 63: Final Result - Mask B

9. DISCUSSION

9.1 Comparison between VXElements and GOM Inspect software tools

Tables 2-5 represent all available information that VXElements and GOM Inspect provide when comparing the scans from GO!Scan. It is important to point out that the figures obtained are different even though the alignment is performed in both cases using a 'Best Fit'. This difference can be attributed to the fact that the aligning process was performed manually in the VXElements. So, a matching result will be considered when the pair of masks that present the lowest standard deviation is the same in VXElements and in GOM Inspect. Nevertheless, and even though the alignments where performed manually in VXElements, the results obtained are better (lower standard deviation) than in the GOM, where the alignment was automatic. The human error committed is, thus, acceptable enough to consider the obtained results reliable and to compare both software tools.

Another reason to consider the manual alignment reliable is the error distribution provided by VXElements. It indicates the percentage of points that have an error contained between the introduced upper and lower limits. These limits are first provided automatically by the program, but they are different in every case. After examining all the results obtained, a common limit was chosen so that the results are comparable. In the case of Mask A, a limit of ±0,35mm was chosen and in the case of Mask B, ±0,2mm. The results obtained are all above 95%, which indicates that the majority of the points have an error smaller than approximately a third of a millimetre, in the case of Mask A, and a fifth of a millimetre in Mask B.

Going on to analysing the figure, when examining tables 4 and 5, it can be easily observed that the results for the best pair of masks match. The one with the lowest standard deviation is, in both cases, the comparison between scan 6 and 8 (being the latter the reference). Nevertheless, when examining tables 2 and 3, the results do not match completely. The best comparison in the VXElements is 4-7, whereas the best one in GOM Inspect is 3-7, which matches the second best in VXElements. This difference in the results can be attributed to the human error introduced, that in this case benefits the results in the VXElements.

As for program use, the GOM is considerably faster in the alignment and comparison process, as it is performed automatically. Plus, it allows to import *.stl files obtained with any scanner, whereas the VXElements only allows to work with scans obtained with the scanners by Creaform (GO!Scan and Handy REVScan). However, the VXElements allows to create an offset layer and a shell to create the final adaptor, function that GOM Inspect did not include in the version of the program used.

In the end, and taking into account the reasons stated above, both programs provide with satisfactory results regarding the aligning and comparing process. Nevertheless, the only program that allows to create the adaptor is the VXElements, making this program the most suitable option to carry out the subject of this work.

9.2 Comparison between GO!Scan, Handy REVScan and ATOS Compact Scan

The comparison was carried out using the GOM Inspect software tool, as it allows to import *.stl files for all 3 scanners.

The first aspect to mention is that the difference in the precision between the 3 scanners is reflected on the results obtained from the comparisons, being the GO!Scan the one providing the worst results (higher standard deviation) and the ATOS Compact Scan the one that provides the best.

As for the quality of the image, the GO!Scan is also the one that provides the worst results, as the borders of the masks in the 3D images obtained are not well defined and are full of spikes. These spikes have to be corrected in order to compare the results, which can cause holes to appear. In addition to that, the HandyScan and the ATOS Compact provide with images of the mask whose surface is much smoother and cleaner than in the GO!Scan.

Having a look at tables 8-11, in the case of Mask A the results are considerably better when the images are obtained with the ATOS scan (lower standard deviation). But, when examining the results for Mask B, the best result in both cases coincide in number, meaning that the Handy REVScan is capable of providing the same quality of results when used carefully and properly as the ATOS scan (which is more expensive and difficult to use).

Thus, the scanner that combines easiness of use and quality of the obtained image is the Handy REVScan, becoming the most suitable scanner to use for this work.

9.3 Comments on Final Adaptor

The adaptors have been printed in silicone by means of a 3D printer. When trying them on the breathing masks, the fitting was correct.

The offset was chosen to be 3mm when creating the adaptor for both masks. In the case of Mask B, this thickness can be considered to be a bit excessive, as the dimensions of the mask are smaller than the ones of Mask A. The offset distance can be changed at will if necessary, to get the desired thickness and fitting.

10. PLANNING AND SCHEDULE

10.1 Task Description, Phases and Procedures

Task 1: Pre-Scanning Phase (10 days)

- Description: Cut irrelevant parts of Mask A. Addition of Powder. Positioning of Targets. Calibration of the scanners.
- Milestones: Set-up of the scanning environment.
- Outcome: State of the Art section included in this document. Pictures of the pre-scanning process.

Task 2: Scanning Process (30 days)

- Description: Obtention of 10 scans per Mask with each of the 3D scanners.
- Milestones: Obtention of all the files necessary for the post-processing and comparing process.
- Outcome: Scanning methodology and pictures included in this document.

Task 3: Post-Processing (15 days)

- Description: Cutting and cleaning every 3D image obtained in the previous task.
- Milestones: *.stl files ready for the alignment and comparison process.
- Outcome: Post-processing report and pictures of the process.

Task 4: Alignment and Comparison (30 days)

- Description: Alignment of the scans to the reference in each case. Comparison between these scans to the reference. Comparison between the references of the 3 scanners.
- Milestones: Excel data sheet with comparison data.
- Outcome: Excel data and report on the alignment and comparison procedures as well as pictures of the process included in this document.

Task 5: Analysis of Results (22 days)

- Description: Analysis of the excel data obtained in the previous task. Obtention of most suitable scanner for this work and of the files that will be used to create the adaptor.
- Milestones: Conclusions on best scanner for the adaptor.
- Outcome: Discussion of the results section included in this document.

Task 6: Creation of Adaptor (20 days)

- Description: Creation of offset layer and shell that forms the adaptor.
- Milestones: Achievement of the objective of this work.
- Outcome: 3D prints of both prototypes and definitive *.stl files.

Task 7: Documentation (35 days)

- Description: Writing the document. It is carried out one the methodology has come to an end and the conclusions have been obtained.
- Milestones: Document the project
- Outcome: Bachelor's Thesis Document.

10.2 Gantt Diagram

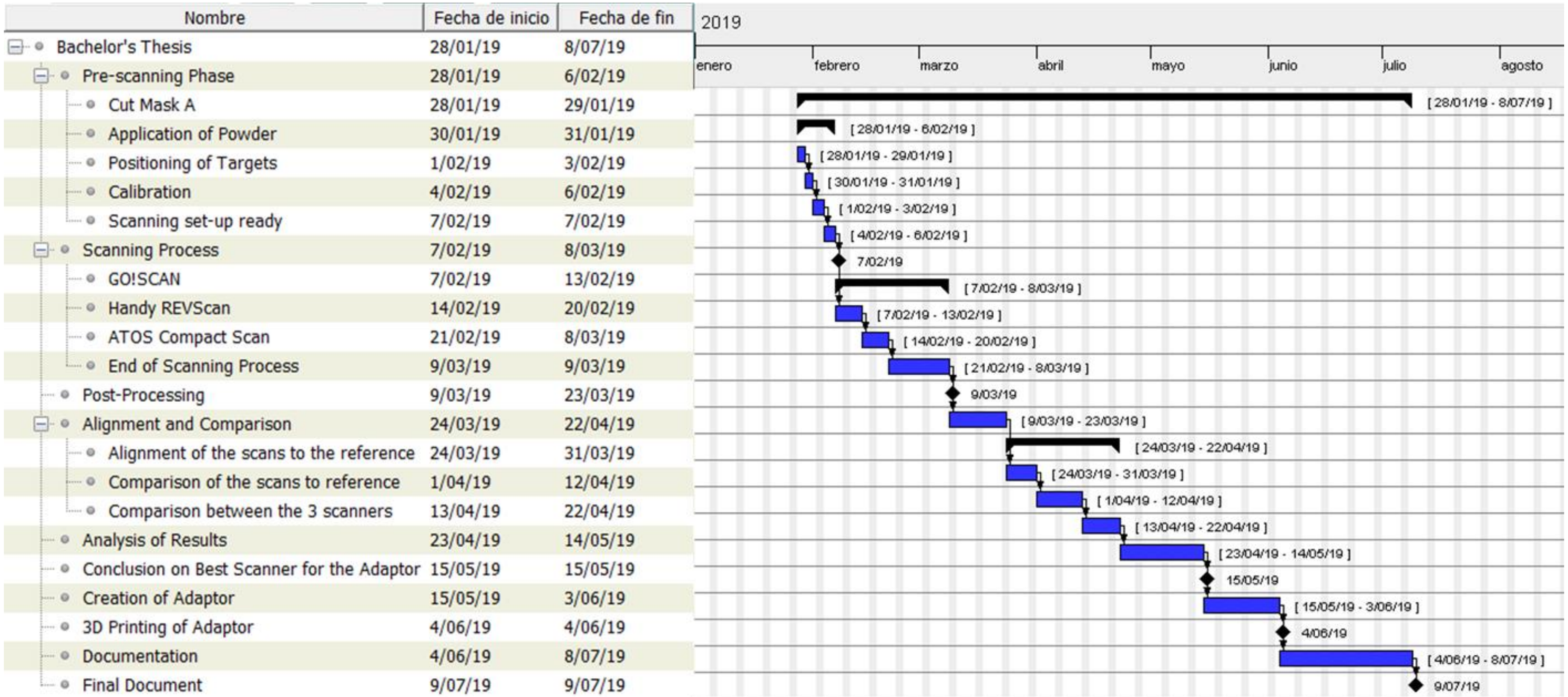

Figure 64: Gantt Diagram

The total duration of the project is 162 days, starting on January 28 and finishing on July 9, 2019.

11. Economical Aspects

Table 16: Budget

INTERNAL HOURS			
	Number of hours employed	Unit Cost (€/h)	Cost (€)
Junior Engineer	300h	25 €/h	7.500,00 €
Thesis Director	50h	60 €/h	3.000,00 €
		Total	10.500,00 €

AMORTIZATION				
	Initial Cost	Lifetime	Use in the project	Amortization
Personal Computer	1.200,00 €	5 years	6 months	120,00 €
GO!SCAN 3D	30.000,00 €	10 years	7 days	58,10 €
Handy REVScan	40.000,00 €	10 years	7 days	77,70 €
ATOS Compact Scan	70.000,00 €	10 years	16 days	311,10 €
White Powder	6,00 €			6,00 €
Positioning Targets	10 ct/unit	Single use	60 units	6,00 €
Office Pack	150,00 €	1 year	6 months	75,00 €
			Total	653,90 €

OTHER EXPENSES			
	€/kWh	Number of Hours	Cost (€)
University Room Rental			1.000,00 €
Internet Conection			50,00 €
Electricity	0,115 €/kWh	300h	34,50 €
		Total	1.084,50 €

Unforseen Expenses (5%)	611,92 €
SUBTOTAL	12.850,32 €

TAXES (21%)	2.698,57 €
TOTAL	15.548,89 €

12.CONCLUSIONS AND FUTURE PROSPECTS

Conclusions

- The main objective of this work was achieved, as the adaptors were obtained, printed in silicon and tested.
- The best scanner to obtain the 3D digital image for this work is the Handy REVScan, as it joins quality, quickness and easiness of use.
- The most suitable program for this work is VXElements. It is the native program of the Handy REVScan and it provides with the necessary tools to align and compare the masks, and allows to add an offset and create the shell to form the adaptor.
- The thickness in Mask B was found to be slightly excessive in the silicon-printed model. This may be changed at will by varying the Offset value when creating future prototypes or adaptors.

Future Prospects

- This work was one of the halves of a bigger project whose objective is to create a personalized adaptor for these breathing masks. Once the other half of the project is achieved, both parts can be joined to produce the first complete prototype of the adaptors.
- If the project is successful and the production process standardized, it will be possible to provide adaptors for the individual patients in need, creating a personalized piece in a matter of hours when requested.

13.REFERENCES

[1] **Haleem, Abid. Javaid, Mohd.** (May 6, 2018) 3D Scanning Applications in Medical Field: A literature-based review. Recovered from*: ScienceDirect*. [Access date: 03/02/2019] (https://www.sciencedirect.com/science/article/pii/S2213398418300952#fig0005)

[2] **A-B Ebrahim, Mostafa.** (October 14) 3D Laser Scanners: History, Applications and Future. Recovered from: *ResearchGate*. [Access date: 03/02/2019] (https://www.researchgate.net/publication/267037683_3D_LASER_SCANNERS_HISTORY_APPLICATIONS_AND_FUTURE)

[3] **Trimaker** (2016) Adiós al Yeso: Férulas Impresas en 3D. Recovered from: *trimaker.com*. [Access date: 23/03/2019] (https://trimaker.com/adios-al-yeso-ferulas-impresas-en-3d/)

[4] **Campillo, Santiago** (October 14, 2018) Esta empresa malagueña quiere revolucionar la traumatología con escayolas impresas en 3D. Recovered from: *xataka.com*. [Access date: 25/03/2019] (https://www.xataka.com/medicina-y-salud/esta-empresa-malaguena-quiere-revolucionar-traumatologia-escayolas-impresas-3d)

[5] **García, Leonor** (December 3, 2016) Instrumental hecho con impresoras 3D. Recovered from: *malagahoy.es*. [Access date: 27/03/2019] (https://www.malagahoy.es/malaga/Instrumental-hecho-impresoras_0_1087091428.html)

[6] **impresiontresde** (2018) Ventajas médicas del instrumental quirúrgico personalizado con impresión 3D. Recovered from: *impresiontresde.com*. [Access date: 29/03/2019] (https://impresiontresde.com/instrumental-quirurgico-personalizado-impresion-3d/)

[7] **López, Miguel** (November 24, 2018) Órganos de plástico, prototipos y prótesis: para qué se está usando hoy la impresión 3D. Recovered from: *xataka.com*. [Access date: 04/04/2019] (https://www.xataka.com/otros/organos-plastico-prototipos-protesis-se-esta-usando-hoy-impresion-3d)

[8] **Motley, Darryl**. (May 30, 2017) How Structured-Light 3D Scanners Work (With Video Demonstrations). Recovered from: *gomeasure3d.com*. [Access date: 07/04/2019] (https://gomeasure3d.com/blog/how-structured-light-3d-scanners-work-video/)

[9] **Motley, Darryl** (July 26, 2018). Understanding 3D Scanners: Field of View Explained and How It Impacts Scan Quality. Recovered from: *gomeasure3d.com*. [Access date: 09/04/2019] (https://gomeasure3d.com/blog/understanding-3d-scanners-field-of-view-explained-and-how-it-impacts-scan-quality/)

[10] **Marta** (2018) Media Aritmética. Recovered from: *superprof.es*. [Access date: 15/04/2019] (https://www.superprof.es/apuntes/escolar/matematicas/estadistica/descriptiva/media-aritmetica.html)

[11] **Disfruta Las Matemáticas** (2011) Varianza y Desviación Estándar. Recovered from: *disfrutalasmatematicas.com*. [Access date: 19/04/2019] (http://www.disfrutalasmatematicas.com/datos/desviacion-estandar.html

[12] **Roberts, Donna** (2012-2019) Variance and Standard Deviation. Recovered from: *mathbitsnotebook.com*. [Access date: 22/04/2019] (https://mathbitsnotebook.com/Algebra1/StatisticsData/STSD.html)

[13] **Chegg Study** (2003-2019) Normal Curve. Recovered from: *chegg.com*. [Access date: 25/04/2019] (https://www.chegg.com/homework-help/definitions/normal-curve-31)

[14] **VITUTOR** (2015) Distribución normal. Recovered from: *vitutor.net*. [Access date: 27/04/2019] (https://www.vitutor.net/1/55.html)

[15] **Varsity Tutors** (2007-2019). Normal Distribution of Data. Recovered from: varsitytutors.com. [Access date: 28/04/2019] (https://www.varsitytutors.com/hotmath/hotmath_help/topics/normal-distribution-of-data)

[16] **Philips Breathing Masks** (2012). Pediatric Mask Brochure. Meeting the big challenge of little faces. [Access date: 10/07/2019] (http://incenter.medical.philips.com/doclib/enc/9027750/Pediatric_Mask_Brochure_EMAIL_8_12.pdf%3ffunc%3ddoc.Fetch%26nodeid%3d9027750)

[17] **Creaform** (2012). Go!SCAN 3D G1 Scanner. Recovered from: *creaform3d.com*. [Access date: 01/05/2019] (https://www.creaform3d.com/en/customer-support/legacy-products/goscan-3d-g1-scanner)

[18] **Creaform** (December 2005) REVSCAN SCANNER. Technical Specifications. Recovered from: *creaform3d.com*. [Access date: 04/05/2019] (https://www.creaform3d.com/en/customer-support/legacy-products/revscan-scanner)

[19] **Creaform** (2005) Handy Scan 3D. Los escáneres 3D portátiles para aplicaciones industriales. Recovered from: *creaform3d.com*. [Access date: 09/05/2019] (https://www.creaform3d.com/sites/default/files/assets/brochures/files/handyscan/Handyscan3D_Brochure_SPA_22052012.pdf)

[20] **GOM** (2010) ATOS Compact Scan. Precise. Flexible. Affordable. Recovered from: *gom.com*. [Access date: 11/05/2019] (https://www.gom.com/metrology-systems/atos/atos-compact-scan.html)

[21] **Metronicnet** (2012) ATOS Compact Scan. La gama de escáneres compactos. Recovered from: *metronicnet.com*. [Access date: 14/05/2019] (http://www.metronicnet.com/uploads/archivos/ATOS-Compact.pdf)

[22] **Proto3000** (2019) Positioning Targets for 3D Scanning. [Access date: 10/07/2019] (https://store.proto3000.com/collections/positioning-targets-for-3d-scanninghttps://store.proto3000.com/collections/positioning-targets-for-3d-scanning)

[23] **Twilight Instrumentos de Medición Industrial** (2019) Aerosol Revelador, NORD-TEST U89, Helling, HI-U89 [Access date: 10/07/2019] (https://twilight.mx/instrumentos/pruebas-no-destructivas/48/872/hi-u89-aerosol-revelador-nord-test-u89-500ml-helling.html)

[24] **3D Scan Spray** (2019) About 3D Scan Spray [Access date: 9/07/2019] (https://3dscanspray.com/3d-spray-features/)

[25] **Doiron, Cody** (April 20, 2018) Calibrating your GO!SCAN 3D Scanner. Recovered from: *cati.com*. [Access date: 16/05/2019] (https://www.cati.com/blog/2018/04/calibrating-goscan-3d-scanner/)

[26] **Hexagon Manufacturing Intelligence** (2019) Understanding Best Fit Alignments. Recovered from: *support.hexagonmi.com*. [Access date: 20/05/2019] (https://support.hexagonmi.com/s/article/Understanding-Best-Fit-Alignments-1527312042816)