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BACHELOR THESIS

Biomedical & Mechanical Engineering

VIRTUAL REALITY APPLIED TO BIOMEDICAL ENGINEERING

Conversion of medical images to 3D models and their implementation to a virtual reality app designed for surgical planning of congenital cardiac defects

Project & Annex

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ABSTRACT

Nowadays, virtual reality is on trend and it is spreading throughout the medical field, making possible the creation of huge amounts of applications designed to train doctors and treat patients in a more efficient way, as in optimizing the surgical planning processes. The medical need and the aim of this project is to optimize the surgical planning process for congenital heart defects, which comprised the 3D reconstruction of the patient's heart and its integration in the VR app. Following this line, it has been a combination of 3D modelling images of hearts thanks to the *Hospital Sant Joan de Déu* and the application design with the software Unity 3D thanks to the company VISYON. Improvements were accomplished regarding the used software for the segmentation and reconstruction, and basic functionalities where achieved, such as import, move, rotate, 3D screenshots of the cardiac organ and, thus, have a better understanding of the treated congenital heart disease. The result has been the creation of an ideal process, in which the 3D reconstruction has achieved its rapidity and accuracy, the very simple importing method to the designed app, and the Virtual Reality app which allows an attractive and intuitive interaction, thanks to an immersive and realistic experience to adjust to the efficiency and precision requirements demanded in the medical field.

RESUM

Actualment, la realitat virtual esta sent tendència i s'està expandint a l'àmbit mèdic, fent possible l'aparició de nombroses aplicacions dissenyades per entrenar metges i tractar pacients de forma més eficient, així com optimitzar els processos de planificació quirúrgica. La necessitat mèdica i objectiu d'aquest projecte és fer òptim el procés de planificació quirúrgica per a cardiopaties congènites, que compren la reconstrucció en 3D del cor del pacient i la seva integració en una aplicació de realitat virtual. Seguint aquesta línia s'ha combinat un procés de modelat 3D d'imatges de cors obtinguts gracies al Hospital Sant Joan de Déu i el disseny de l'aplicació mitjançant el software Unity 3D gracies a l'empresa VISYON. S'han aconseguit millores en quant al software emprat per a la segmentació i reconstrucció, i s'han assolit funcionalitats bàsiques a l'aplicació com importar, moure, rotar i fer captures de pantalla en 3D de l'òrgan cardíac i així, entendre millor la cardiopatia que s'ha de tractar. El resultat ha estat la creació d'un procés òptim, en el que la reconstrucció en 3D ha aconseguit ser ràpida i precisa, el mètode d'importació a l'app dissenyada molt senzill, i una aplicació que permet una interacció atractiva i intuïtiva, gracies a una experiència immersiva i realista per ajustar-se als requeriments d'eficiència i precisió exigits en el camp mèdic.

RESUMEN

Actualmente, la realidad virtual está siendo tendencia y se está expandiendo en el ámbito médico, haciendo posible la aparición de numerosas aplicaciones diseñadas para entrenar médicos y tratar pacientes de forma más eficiente, así como optimizar los procesos de planificación quirúrgica. La necesidad médica y objetivo de este proyecto es hacer óptimo el proceso de planificación quirúrgica para cardiopatías congénitas, que comprende la reconstrucción en 3D del corazón del paciente y su integración en una aplicación de realidad virtual. Siguiendo esta línea se ha combinado un proceso de modelado 3D de imágenes de corazones obtenidos gracias al Hospital Sant Joan de Déu y el diseño de la aplicación mediante el software Unity 3D gracias a la empresa VISYON. Se han logrado mejoras en cuanto al software empleado para la segmentación y reconstrucción, y se han logrado funcionalidades básicas en la aplicación como importar, mover, rotar y hacer capturas de pantalla en 3D del órgano cardíaco y así, entender mejor la cardiopatía que se debe tratar. El resultado ha sido la creación de un proceso óptimo, en el que la reconstrucción en 3D ha conseguido ser rápida y precisa, el método de importación a la app diseñada muy sencillo, y una aplicación que permite una interacción atractiva e intuitiva, gracias a una experiencia inmersiva y realista para ajustarse a los requerimientos de eficiencia y precisión exigidos en el campo médico.

AKNOWLEDGEMENTS

We would like to thank all the people that has helped this project become real, despite all the issues that have appeared during the process.

In first place, thanks to Visyon for providing us with the HTC Vive set so that we could work with it and test with ease any improvement in the app. From there thanks to Iñigo Gainza for managing and helping us direct the project, as well as Josep Lorente for his tireless patience and kindness towards to programming part.

Thanks to our tutors Jordi Torner and Francesc Alpiste for devoting time and helping to guide us throughout the project.

In the other hand, thanks for the help from Hospital Sant Joan de Déu by Alex Perez and Joan Sanchez, for lending us the DICOM images for the project, and also inviting us to the hospital to observe and ask for possible needs for the doctors.

Finally, thanks to family and friends that have been there in the hardest moments, giving us strength to carry on and finish our job.

Index

Figure Index

1. INTRODUCTION

1.1. Context

In a constantly growing world, technology evolves at vertiginous speeds. Every time a question appears, there's an answer to be discovered, and this has been happening for a long time. During human existence, there have been innumerable amounts of inventions that have represented a huge step for humanity. This has never stopped happening yet, but it is true that every time it gets harder to innovate and be creative.

Many of those inventions were considered impossible or unimaginable before they became a real thing, just like in the case of Virtual Reality. This term appeared with the idea to create a virtual space where the user could see objects in a simulated 3D world and interact with them, with the sensation of being immersed in it.

In this last decade, Virtual Reality has become one of the most important advances in a world totally digitalized. More and more, digital devices are taking control over every little thing surrounding people, and this is also a clear opportunity to invest in this field.

So, it is its spreading, that this technology has reached medicine and science subjects. With many innovating ideas like surgery training or rehabilitation programs, Virtual Reality has become an attractive investment for hospitals and clinics, which search to give the best conditions to patients that everyday can be treated of more dangerous operations. This is also reaching educational ambits, that make learning easier and clearer for future professionals.

1.2. Motivation

Currently there is really a need in medicine to contribute with new ideas to optimize surgeries. It is true that each day new ideas and devices are brought to perform harder processes, but it is still hard to lower the invasion needed to carry through many of these. The aim of this project is to have more than an educational use. It can become a useful tool for surgeons or for future investigators, to create new applications with the base extracted from this project.

Apart from this, to bring this idea to life it will be required to search for better tools for image segmentation, because actual results do not give a proper idea of what could be their representation. This can suppose an advance in 3D imaging and model formation, a real need for investigation.

1.3. Project objectives

The main objective of this project is to make a Virtual Reality application for use in surgery planning by achieving the following:

- To create an application that gives the ability to load 3D models of hearts and interact with them inside a virtual space.
- To find an optimal way to make 3D models by using DICOM images from the hospital. These models have to be easy to modify as also easy to cut, to extract all the non-important parts appearing in the objects.
- To get high resolution models to make the experience inside the virtual world more realistic. This brings the sensation of immersion to the user and improves comparations with real objects.
- To find an optimal system to load images to the Virtual Reality application. Making an effective path for users to take an image and charge see and interact with it in 3D.
- To make the application intuitive and easy-to-use. It needs the required interactions to function and each element of distraction alters the functionality of the project.

1.4. Significance of the project

Even though the intention is to bring a ready-to-use application, it is known that there are still many steps to carry through before this idea can become a real useful tool in medicine. The most important need to make this real is the upgrade in image taking from the patients. The models created from radiographies do not give the best resolution to be trusted if compared to real cases. The worst thing right now is the inability to get a clean shape in the interior faces of the models. This makes image section tool inside the application still a not so useful and might not be required for the aim of this project.

Moreover, there is no easy way to transfer images from the 3D reconstruction to a Virtual Reality environment, being one of our objectives.

2. STATE OF THE ART: VIRTUAL REALITY

2.1. Definition

The meaning of virtual reality appears from the union of the terms virtual, which means “near”, and reality. Knowing this, the composite obtained would be “near-reality”, something that tries to simulate what we call the real world. Virtual reality in itself is still a concept hard to specify, because in the last years this technology has suffered a big upgrade and many different branches have appeared.

Even though the real definitions may vary, what is known as virtual reality is a computer created environment that the user can watch as if it was real with the help of a headset. This must not be confused with Augmented Reality, which uses the real world to incorporate objects and illusions just like if they were there, by using special glasses. In Virtual Reality, the space is created as an illusion in 360º so it feels like everything is happening in reality but only because the vision sees something that seems to be there.

So, the basic configuration of modern immersive virtual reality devices usually is a headset, which can also incorporate a pair of controllers. With these components, the user is tricked by what his vision sense is perceiving, but the other senses are still outside the game. To increase immersion, there are many components, such as headphones or audio systems that can reproduce sounds like if they were coming from any direction. For example, a sound that appears in the back and as the user turns it seems like it is still in the same position and he/she ends up hearing the sound in the front. There are many other gadgets to increase perception of virtual reality games, like platforms or even representations of vehicles and many more. Despite all of these there’s still a long trip to travel, because this trickiness of human senses usually produces dizziness and sickness in many users and has to be taken in count when thinking of the popularization of the technology.

To get things clear, immersion is defined as the feeling or sensation that one is inside a space or world. The more interactions the user gets, the more real it feels.

2.2. History

Although the Virtual Reality that is known nowadays might always relate to the small headset and some other gadgets, the concept itself has existed for a long time now.

Back to the XIX century, the first attempts to create the illusion of being in another place appeared with the called *panoramic paintings.* These murals showed the 360º vision of an environment and tried to simulate what could someone watch standing there. Later then appeared the stereoscopic photos, to create the illusion of depth and at the start of the XX century the idea was transformed into something more attractive and turned into a tourist attraction, the *View-Master.* Quite before that, in 1929 appeared the first commercial flight simulator, that used electromechanical systems and simulated movement and turbulences with a motor device. This one was highly used by the US military by the need to train futures pilots in a safe way.

Figure 1 Example of panoramic painting (Source: Virtual Reality Society)

Reaching the 50s decade, appeared the *Sensorama*, an arcade-style cabinet that showed films so that the user would feel more immersed by stimulating vision and sound in a more closed space.

In the 60s the first idea of a present headset was invented. Also, the first motion control platforms that were mainly used for training too by the use of displayed videos. As its popularity grew, the concept of *Ultimate Display* appeared. It meant the first approximation to what is known nowadays as Virtual Reality, by the need of a computer constructed 3D world, interaction with virtual objects and realistic sense perception. By 1968 it was published the first head mount connected to a computer, instead of a camera. It was called Sword of Damocles and it yet had many problems such as its weight or the need to strap it to the user's head.

Figure 2 The Sensorama (Source: Virtual Reality Society)

It was at 1987 when the term of Virtual Reality finally appeared and started to become a real thing to invest in.

Reaching the 90s many gaming companies started developing their own VR devices, like *Virtuality's* arcade games, *Sega's Genesis* console and *Nintendo's Virtual Boy*.

Figure 3 Virtuality: VR arcade (Source: Teslasuit)

Many other complements appeared during the first decade of this century, and also the 3D technology suffered its biggest upgrade in history. It has been though in the last years when the first actual VR prototypes appeared and started becoming popular outside the arcade world because of its affordability and commodity.

2.3. Present

As explained before, there are many branches now that come from the Virtual Reality world, and so it is possible to separate and define some of them:

2.3.1. Non-Immersive Virtual Reality Environments

Being the first one of the spaces existing, this kind of environment does not give a real sensation of immersion more than interaction with a keyboard or joysticks mainly. The nice thing about this kind of technology is that since it does not require many gadgets or complements to work, it is also the low-budget system for users who might only have a personal computer to experience with. The hardware needed is not really expensive and does not need to have high resolution or processors to work well.

2.3.2. Semi-Immersive Virtual Reality Environments

What is known as a semi-immersive environment usually consists in a slightly curved screen that projects three dimensional images. In these spaces, the user still sees and is aware of what is happening around, but it is not required to use virtual reality gear to enjoy the experience. This kind of experience can be upgraded with the use of a mechanical system that is consequent with what the user is seeing, so the sensation of immersion gets increased. An example for this could be a flight simulator.

2.3.3. CAVE Fully Immersive Virtual Reality

Even though it may vary in some occasions, the main set up of a CAVE system includes: projections in every direction, immersive speaker system from many angles and so sound or music, tracking sensors and video display. This also often happens inside a cube-like space. With the help of a head mounted display, the user's motion inside the space is captured and transferred to what is seen in the glasses.

Figure 4 CAVE VR space (Source: Avicvision)

The ability to capture the motion of the player gives an incredible sensation of immersion to the person which can isolate he or she totally inside the virtual world. This also includes the option to let the user interact with the environment, usually done with a controller, glove or another device, which gives the player the ability to perform actions inside the virtual world, also known as haptics.

2.3.4. Collaborative Virtual Environments

As its name says, the idea of these environments is to create a space where a certain number of people can join and interact with themselves, no matter where they are in reality. Used by users from many disciplines such as scientists, researchers, artists or developers there are many environments existing for marketing, medicine, education, training and many more.

2.4. Device election

The device for which this project has been developed is the HTC Vive, which can be defined as a fully immersive gadget. Being the first of its kind, this system included the first tracking system within a certain space, giving the ability to the user to move around and explore while its motions are tracked by to sensors in a room-scale space.

The HTC configuration is made by the head mount or headset, two controllers that allow interaction with the environment and objects and two base stations placed with some separation that mark the tracking space of the device by the use of infrared detection. There is also the possibility to attach Vive trackers to real life objects, so they can be used in the virtual world and make the sensation of, for example grabbing the object seen in the display instead of the controller. Also, it can be attached to the hands or feet depending on the use.

With a variety of interactions available, the controllers have four different buttons and sensors to get the inputs from the user, apart from the steam home button.

Figure 5 HTC Vive main configuration (Source: Mighty Ape)

2.4.1. Competitors

There are many other companies and devices existing that work with virtual reality, although not all of them are focused in the same type of applications. The advantages and disadvantages of each one may vary a lot yet because the last developments made put a great difference between them, but it is still important to keep the important ones in mind.

Since the possible engines chosen for developing this project were Unreal Engine and Unity 3D, the competitors study developed below has focused in the four virtual reality devices recommended and supported by these two engines, one of which is the HTC Vive described above.

2.4.1.1. Oculus Rift

Released on March of 2016, this project was the first big upgrade in immersive virtual reality devices. With a very similar configuration to the HTC Vive, the Oculus is available to use in computer as also in mobile devices, with some differences in the model. A high-resolution display and the ergonomic controllers make this device a huge potential source for future releases. The last model also includes position trackers, but the space covered and possible to move is lower than the made by HTC.

Figure 6 Oculus Rift set (Source: VR Heads)

2.4.1.2. Samsung Gear VR

Right in the top of virtual reality devices, it is found the Gear VR system. Developed in collaboration with Oculus, this headset offers the best quality and resolution for mobile applications. To use this device, it is required to have certain applications installed in the phone. Despite that, the Gear VR achieves a high immersive result and is also really accepted because of its lower price.

Figure 7 Samsung's Gear VR (Source: Samsung)

2.4.1.3. Google Cardboard

For the low budget customers, google decided to develop a the most low-cost head mount for virtual reality users. By using a piece of cardboard, people can fold their own head mount with the given instructions, and use virtual reality applications. Despite the fact that immersion is highly reduced in this component in comparation with its competitors, this one achieves the objective of reaching nearly anyone who has a VR supporting smartphone. This was meant to increase interest in virtual reality development and so improve the sensations received about it. To even help more users, there are many free software options to develop applications for the Google Cardboard VR system.

Figure 8 Google Cardboard (Source: Google Store)

2.4.1.4. Specification comparation

	HTC VIVE	OCULUS RIFT	SAMSUNG GEAR VR	GOOGLE CARDBOARD
SUPPORTED SYSTEM	PC	PC	Mobile phone	Mobile phone
PRICE (€)	699.00	449.00	110.00	7.00 to 63.00
RESOLUTION (PER EYE)	1080x1200	1080x1200	1280x1440 (Depends on phone)	Depends on phone
FIELD OF VIEW	110º	110º	101º	90º
REFRESH RATE (HZ)	90	90	60	~ 58
WEIGHT (G)	470	470	318 + phone	75 + phone
POSITION TRACKING	Yes	Yes	No	No
CONTROLLERS	Yes	Yes	Yes	No
WIRELESS	No	No	Yes	Yes
ADJUSTABLE	Yes	Yes	Yes	No

Table 1 VR Device comparation

2.5. Uses of Virtual Reality

The use of virtual reality nowadays is extended in more themes than it is known for sure. The characteristics of its technology provide something exclusive and hard to compare with any other systems existing. So it is, that as explained above virtual reality can be find in aspects like art, architecture, science, sports, media and many, many more.

The key of its fame is the ability to really show 3D images with simulated volume. It cannot be compared to a 3D object seen through a 2D screen. It is true that this technology still needs a lot of work to be put on, nevertheless it is what future is aiming for now.

This ability to see and interact with 3D models is being used gradually more in medical applications. Offering high resolution constructed organs, without the need to understand and interpret the sum of plane images dynamizes surgery planning processes as well as many other purposes. This all appears thanks to the need of society to have better solutions for its problems. The more optimal they are, the better results and longer application they have.

2.6. Medical use of Virtual Reality

Apart from the project explained here, there are many projects that have been developed through this last years and a lot more that are being created for medical uses:

- Personnel training: just like with the flight simulators for the militaries, Virtual Reality can be and is used to train future surgeons and doctors. The possibility to perform some processes before doing them in reality, helps people focus and learn new abilities without taking the risk of a real intervention.
- Education: same as the training, but for a more theoretical use. Interactive games or 3D videos help understand concepts faster and easier in a world where everyday knowledge increases at high speed.
- Rehabilitation: many diseases can be fatal or traumatic. Nevertheless, some applications are made to help people with neurodegenerative problems to train their memory, or just stimulate the use of the brain and thoughts to lower the effects that these could have.

- Surgery planning: even though this is a still very primal idea, the use of 3D modeled organs is becoming a high requisite for future processes. Not only because this lets surgeons prepare better before surgeries, but also because this will lower the invasion required to perform some of these processes, and so lower the risk for the patients operated.

Figure 9 Medical training with VR device (Source: Medical Futurist)

3. MEDICAL NEEDS: SURGICAL PLANNING FOR CONGENITAL HEART DEFECTS

3.1. Human heart anatomy

The human heart is an organ that pumps blood throughout the body via the circulatory system, supplying oxygen and nutrients to the tissues and removing carbon dioxide and other wastes.

"The tissues of the body need a constant supply of nutrition in order to be active," said Dr. Lawrence Phillips, a cardiologist at NYU Langone Medical Center in New York. "If the heart is not able to supply blood to the organs and tissues, they'll die."

In humans, the heart is roughly the size of a large fist and weighs between 280 to 340 grams in men and 230 to 280 grams in women, according to Henry Gray's "Anatomy of the Human Body".

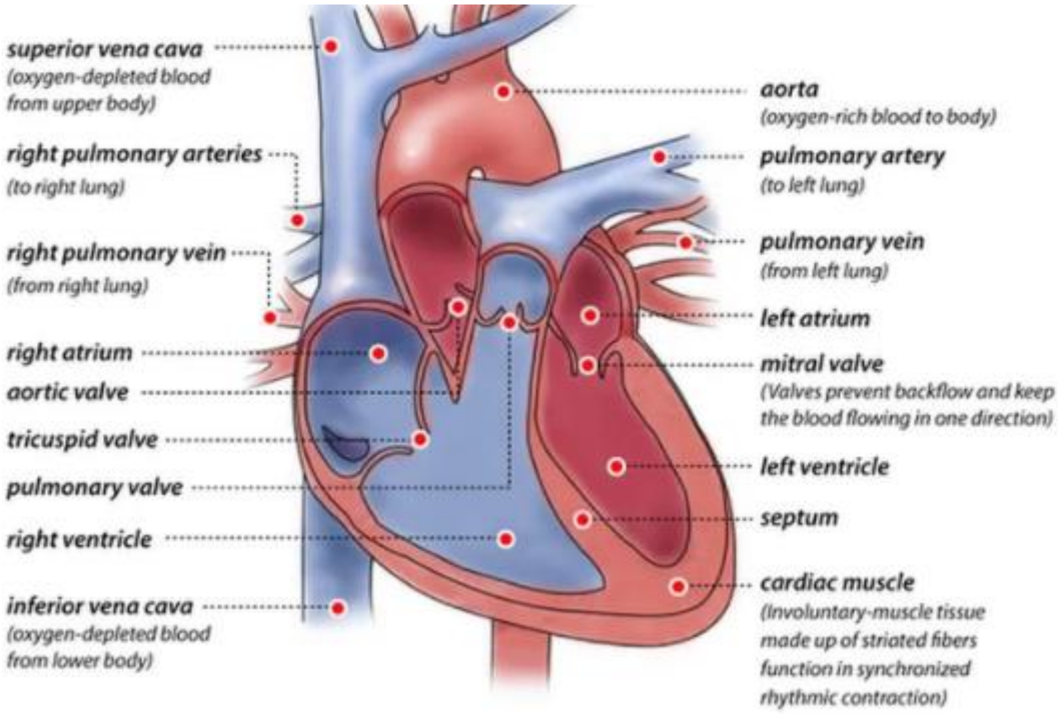


Figure 10 Heart Anatomy (Source: livescience)

The human heart has four chambers: two upper chambers (the atria) and two lower ones (the ventricles), according to the National Institutes of Health. The right atrium and right ventricle together make up the "right heart," and the left atrium and left ventricle make up the "left heart." A wall of muscle called the septum separates the two sides of the heart.

A double-walled sac called the pericardium encases the heart, which serves to protect the heart and anchor it inside the chest. Between the outer layer, the parietal pericardium, and the inner layer, the serous pericardium, runs pericardial fluid, which lubricates the heart during contractions and movements of the lungs and diaphragm.

The heart's outer wall consists of three layers. The outermost wall layer, or epicardium, is the inner wall of the pericardium. The middle layer, or myocardium, contains the muscle that contracts. The inner layer, or endocardium, is the lining that contacts the blood.

The tricuspid valve and the mitral valve make up the atrioventricular (AV) valves, which connect the atria and the ventricles. The pulmonary semi-lunar valve separates the right ventricle from the pulmonary artery, and the aortic valve separates the left ventricle from the aorta. The heartstrings, or chordae tendineae, anchor the valves to heart muscles. And the sinoatrial node produces the electrical pulses that drive heart contractions.

3.2. Human heart function

The heart circulates blood through two pathways: the pulmonary circuit and the systemic circuit.

In the pulmonary circuit, deoxygenated blood leaves the right ventricle of the heart via the pulmonary artery and travels to the lungs, then returns as oxygenated blood to the left atrium of the heart via the pulmonary vein.

In the systemic circuit, oxygenated blood leaves the body via the left ventricle to the aorta, and from there enters the arteries and capillaries where it supplies the body's tissues with oxygen. Deoxygenated blood returns via veins to the venae cava, re-entering the heart's right atrium.

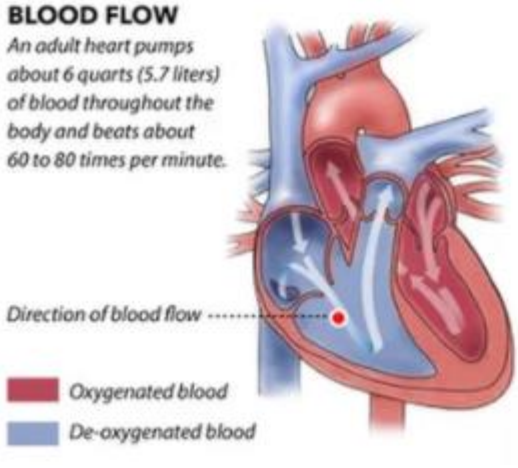


Figure 11 Heart Function (Source: livescience)

3.3. Congenital heart defects

Congenital heart defects are structural problems arising from abnormal formation of the heart or major blood vessels. The word "congenital" means existing at birth.

They can be classified as follows:

- Those that produce left-to-right shunts (passage of blood from the systemic circulation to the pulmonary circulation).
- Those that produce obstruction to blood flow.
- Congenital cyanotic heart diseases, in which abnormal blood flow goes from the pulmonary to the systemic circulation, passing non-oxygenated blood adequately to the tissues, causing what is known as cyanosis (purple colour of lips)

3.3.1. Aortic Valve Stenosis (AVS)

A valve from the heart to the body that does not properly open and close and may also leak blood. When the blood flowing out from the heart is trapped by a poorly working valve, pressure may build up inside the heart and cause damage.

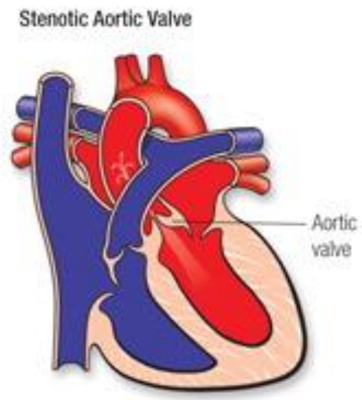


Figure 12 Aortic Valve Stenosis (Source: American Heart Association)

3.3.2. Atrial Septal Defect (ASD)

A "hole" in the wall that separates the top two chambers of the heart.

This defect allows oxygen-rich blood to leak into the oxygen-poor blood chambers in the heart. ASD is a defect in the septum between the heart's two upper chambers (atria). The septum is a wall that separates the heart's left and right sides.

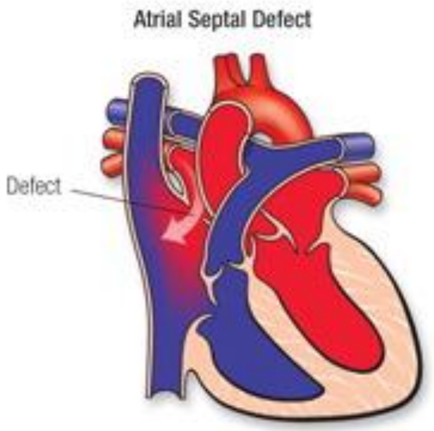
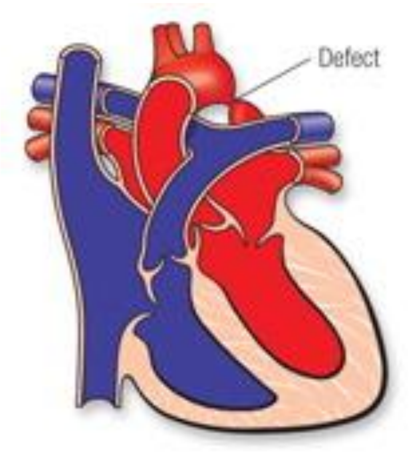


Figure 13 Atrial Septal Defect (Source: American Heart Association)

3.3.3. Coarctation of the Aorta (CoA)

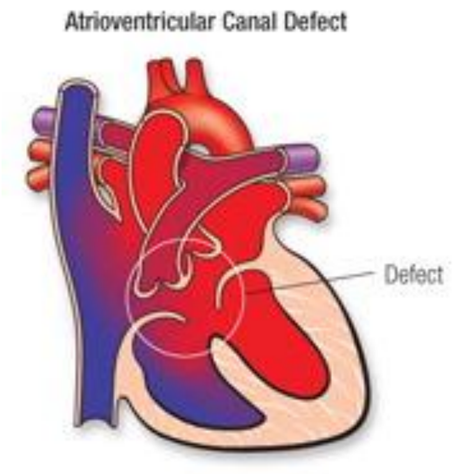


A narrowing of the major artery (the aorta) that carries blood to the body.

This narrowing affects blood flow where the arteries branch out to carry blood along separate vessels to the upper and lower parts of the body. CoA can cause high blood pressure or heart damage.

Figure 14 Coarctation of the Aorta (Source: American Heart Association)

3.3.4. Complete Atrioventricular Canal defect (CAVC)



A large hole in center of the heart affecting all four chambers where they would normally be divided. When a heart is properly divided, the oxygen-rich blood from the lungs does not mix with the oxygen-poor blood from the body. A CAVC allows blood to mix and the chambers and valves to not properly route the blood to each station of circulation.

Figure 15 Complete Atrioventricular Canal defect (Source: American Heart Association)

3.3.5. Patent Ductus Arteriosus (PDA)

An unclosed hole in the aorta.

Before a baby is born, the fetus' blood does not need to go to the lungs to get oxygenated. The ductus arteriosus is a hole that allows the blood to skip the circulation to the lungs. However, when the baby is born, the blood must receive oxygen in the lungs and this hole is supposed to close. If the ductus arteriosus is still open (or patent) the blood may skip this necessary step of circulation. The open hole is called the patent ductus arteriosus.

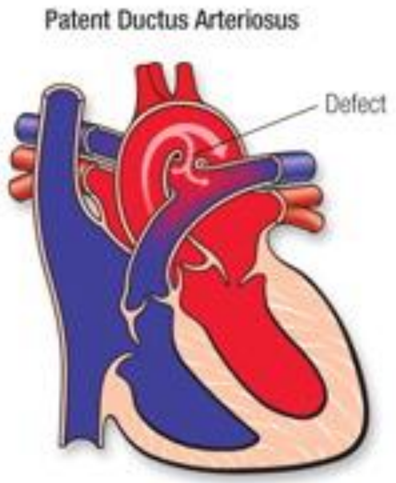


Figure 16 Patent Ductus Arteriosus (Source: American Heart Association)

3.3.6. Tetralogy of Fallot (ToF)

A heart defect that features four problems.

They are:

- a hole between the lower chambers of the heart
- an obstruction from the heart to the lungs
- The aorta (blood vessel) lies over the hole in the lower chambers
- The muscle surrounding the lower right chamber becomes overly thickened

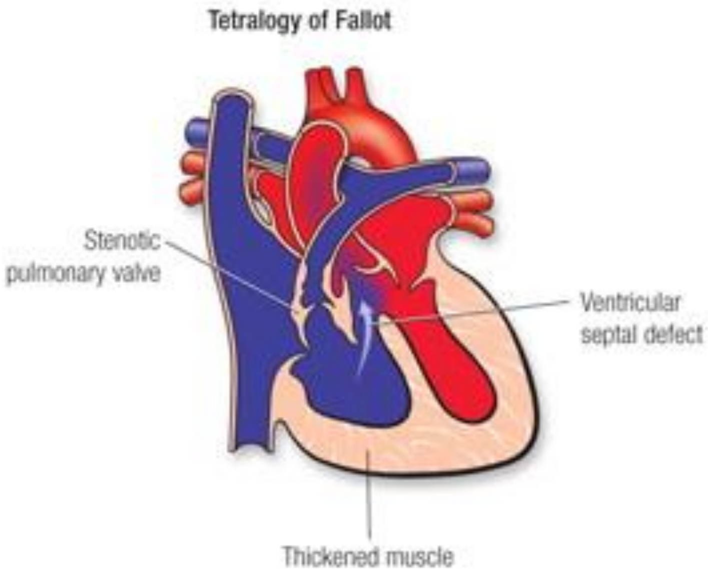


Figure 17 Tetralogy of Fallot (Source: American Heart Association)

4. MEDICAL IMAGES RECONSTRUCTION

The reconstruction of medical images allows transforming the images obtained with techniques of data acquisition into numerical and geometrical format dates.

A good result of the project is based on the quality and adequacy of these medical images, from which the 3D models of the hearts are obtained. For the project it is necessary that both the ventricles, the atria and the blood vessels that are connected to the heart are well represented, since most of the diseases are related to them.

Every process of reconstruction of medical images is made up of several parts:

1. - Obtaining medical images

Figure 19 Doctor looking medical images (Source: IBM)

2. - Segmentation of the images

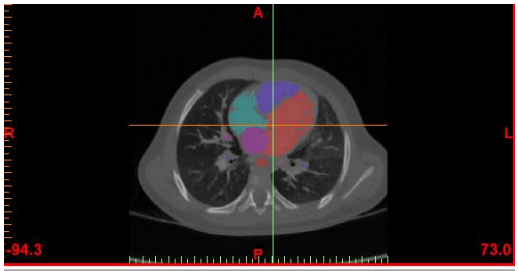


Figure 18 Heart segmentation (Source: Screenshot Mimics Medical)

3. - Geometric reconstruction

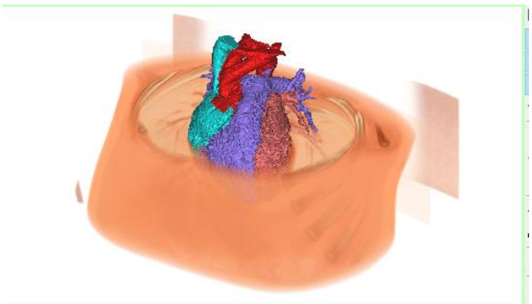


Figure 20 3D reconstruction (Source: Screenshot Mimics Medical)

4. - Mesh processing

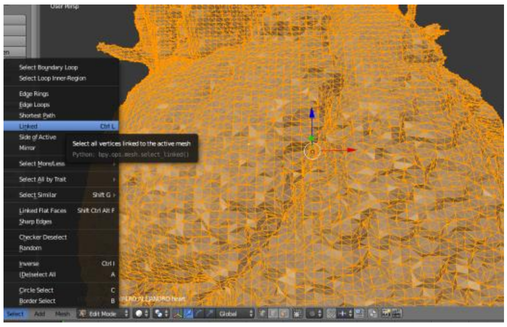


Figure 21 Mesh (Source: Screenshot Blender)

4.1. Medical imaging

This project has been realized thanks to the medical images obtained by the Hospital Sant Joan de Déu. For better understanding, it is necessary to know what a medical image is and the different obtaining techniques.

Medical imaging encompasses different imaging modalities and processes to image and represent the interior of the human body for diagnostic and treatment purposes.

Medical imaging is crucial in a variety of medical setting and at all major levels of health care. It is also a non-invasive procedure where no instrument is introduced into a patient's body which is the case for most imaging techniques used.

Though medical/clinical judgment may be sufficient prior to treatment of many conditions, the use of diagnostic imaging services is paramount in confirming, correctly assessing and documenting courses of many diseases as well as in assessing responses to treatment. Furthermore, medical imaging is frequently justified in the follow-up of a disease already diagnosed and/or treated.

With improved health care policy and increasing availability of medical equipment, the number of global imaging-based procedures is increasing considerably. Effective, safe, and high-quality imaging is important for much medical decision-making and can reduce unnecessary procedures.

Each type of technology gives different information about the area of the body being studied or treated, related to possible disease, injury, or the effectiveness of medical treatment. Therefore, both the quality and the content of the image is largely influenced by the technique used to obtain it.

4.1.1. Conventional radiography

Radiography is the use of x-rays to visualize the internal structures of a patient. X-Rays are a form of electromagnetic radiation, produced by an x-ray tube. The x-rays are passed through the body and captured behind the patient by a detector. There is variance in absorption of the x-rays by different tissues within the body, dense bone absorbs more radiation, while soft tissue allows more to pass through. This variance produces contrast within the image to give a 2D representation of all the structures within the patient.

4.1.2. Computed tomography (CT)

Also known as Computed axial tomography (CAT) is an imaging modality that utilizes x-ray photons for image production, with digital reconstruction. An x-ray tube produces an x-ray beam that passes through the patient. This beam is captured by the detectors and reconstructed to create a two or three dimensional image.

The data captured by the scanner is digitally converted by various algorithms into reconstructed images, which represent a cross-sectional slice through the patient at that level. Each image is acquired at a slightly different angle and results from a different reconstruction algorithm. The individual volume elements that make up the image are each displayed as a two-dimensional pixel, each of which carries a designation of density or attenuation.

Figure 22 Computed Tomography (Source: LifeBridge Health)

4.1.3. Magnetic resonance imaging (MRI)

Magnetic resonance imaging (MRI), is a medical imaging technique used in radiology to visualize detailed internal structures using magnetic radiation. MRI provides real-time, three-dimensional views of body organs with good soft tissue contrast, making visualization of brain, spine, muscles, joints and other structures excellent. It is multiplanar, which means that images can be obtained in multiple body planes without changing positions.

4.1.4. 3D angiography

Angiography is a diagnostic imaging test whose function is the study of blood vessels that are not visible by conventional radiology. The process is based on intravenous injection of a contrast media into the blood vessels for the study. X-rays cannot pass through the compound, so the morphology of the arterial tree is revealed on the radiographic plate.

Angiography can be divided into two phases: the first consists in introducing the contrast, and the second phase is to use one of the three previous diagnostic technique to obtain an image.

It is commonly used to assess the coronary arteries of the heart.

4.1.5. Echocardiogram

An echocardiogram is an image obtained by applying ultrasound to the interior of the heart. To perform this technique, it is necessary to place electrodes on the patient's chest. The doctor passes the probe through the chest area to record the images. The time it takes to perform the echocardiogram is between 40 and 60 minutes. Echocardiograms can detect any cardiac defect and malfunction in the muscle.

4.2. Medical image file formats

Image file formats provide a standardized way to store the information describing an image in a computer file.

A medical image data set consists typically of:

- One or more images representing the projection of an anatomical volume onto an image plane (projection or planar imaging)
- A series of images representing thin slices through a volume (tomographic or multislice two-dimensional imaging)
- A set of data from a volume (volume or three-dimensional imaging)
- A multiple acquisition of the same tomographic or volume image over time to produce a dynamic series of acquisitions (four-dimensional imaging)

The file format describes how the image data are organized inside the image file and how the pixel data should be interpreted by a software for the correct loading and visualization.

Medical image file formats can be divided in two categories. The first is formats intended to standardize the images generated by diagnostic modalities, e.g., Dicom. The second is formats born with the aim to facilitate and strengthen post-processing analysis, e.g., Analyze, Nifti, and Minc.

In this project, the firsts ones are going to be used. Digital Imaging and Communications in Medicine (DICOM) is a standard for storing and transmitting medical images. DICOM has been central to the development of modern radiological imaging and incorporates standards for imaging modalities such as radiography, ultrasonography, computed tomography (CT), magnetic resonance imaging (MRI), and radiation therapy.

4.3. Image segmentation

Segmentation is the partition of a digital image in multiple regions according to a given criterion.

The methods to carry out the segmentation process vary widely depending on the specific need for visualization, type of image, and other factors. For example, the segmentation of heart tissue has different requirements than that of other organs of the human body.

It has been found that specialized methods for particular applications of segmentation can get better results than general methods.

The purpose of segmentation is to locate objects and regions of interest (ROI).

Unfortunately, many of the existing segmentation algorithms are still too simple to get accurate results, so this part has to be done manually or semi-automatically.

4.3.1. Thresholding

The simplest method of image segmentation is called the thresholding method. This method is based on a clip-level (or a threshold value) to turn a gray-scale image into a binary image.

The key is to select the threshold value (or values when multiple-levels are selected) from the radiographs and DICOM images.

A threshold can be applied to segment the object and background. Mathematically the threshold can be defined as follows:

$$ri,j = \begin{cases} 1 & pi,j \geq T \\ 0 & pi,j < T \end{cases}$$

Where ri, j is the resulting pixel at co-ordinate (i, j), pi, j is the pixel of input image and T is the value of threshold.

4.3.2. Region based segmentation (Region Growing)

Region based methods are based on the principle of homogeneity - pixels with similar properties are clustered together to form a homogenous region. The criteria for homogeneity is most of the time gray level of pixels and this criterion can be specified by following conditions:

$$R_1 \cup R_2 \cup R_3 \cup \ldots \cup R_i = I$$

where R_1, R_2, R_3, ...R_i are the region in the image I, and further:

$$R_1 \cap R_2 \cap R_3 \cap \ldots \cap R_i = 0$$

This is as per the set theory of homogeneity.

Region based segmentation is further divided into three types based on the principle of region growing:

- Region merging
- Region splitting
- Split and merge

4.3.2.1. Region merging

In this method some seeding points are required to initialize the process, the segmentation results are dependent on the choice of seeds.

Regions are grown iteratively by merging the neighboring pixels depending upon the merging criterion.

This process is continued until all pixels are assigned to their respective regions as per merging criterion.

4.3.2.2. Region splitting

Its principle is just opposite to region merging and whole image is continuously split until no further splitting of a region is possible.

4.3.2.3. Split and merge method

This is the combination of splits and merges utilizing the advantage of the two methods. This method is based on quad quadrant tree representation of data where by image segment is split into four quadrants provided the original segment is non-uniform in properties. After this the four neighboring squares are merged depending on the uniformity of the region (segments). This split and merge process is continued until no further split and merge is possible.

4.4. Geometric reconstruction & volume rendering

The term volume rendering comprises a set of techniques for rendering discrete 3D data sets. With respect to medical imaging, such data is acquired from the different sources explained in section 5.1. Each 2-dimensional subset had to be visualized and interpreted separately. Although visualizing a volumetric data set as 3-dimensional entities is not an easy task, it is both worthwhile and rewarding. To summarize succinctly, volume rendering is a very powerful way for visualizing such 3-dimensional scalar fields. It also helps in the interpretation of the contained data values.

The 3D reconstruction of tissues is performed with digital processing techniques. A 3D medical image in grey scale is represented by a matrix of dimensions mxnxz, formed by the parallel stacking of z cuts of the same resolution, with size mxn pixels, where each element of the matrix is a grey intensity value obtained by the interaction of radiation in the tissue. To maintain the ratio of the size of the reconstructed volume to the actual size of the tissue, the spacing of each voxel that makes up the volume is taken into account, which is obtained from the information included in the medical image after the segmentation.

It has been chosen using numerical methods that approximate a solution to real problems and allow obtaining anatomical models of tissues. However, this approach is affected by the complexity of the anatomical structures of hard and soft tissues, generally asymmetric, in whose analysis it is difficult to perform simplifications due to errors in the resolution of the differential equations of the problem, caused by complex geometries, inadequate imposition of boundary conditions and external loads.

Reconstructions of triangular meshes are the most commonly used and the easiest to treat in polygonal couplings.

In addition, a quad mesh can always be obtained using mesh generation techniques. This is done through software, which takes into account several factors for generation:

- The surfaces have to be consistent and topologically correct.
- Proper form of the mesh.
- Smoothing the mesh: use smoothing techniques.
- Quality

4.5. Mesh processing

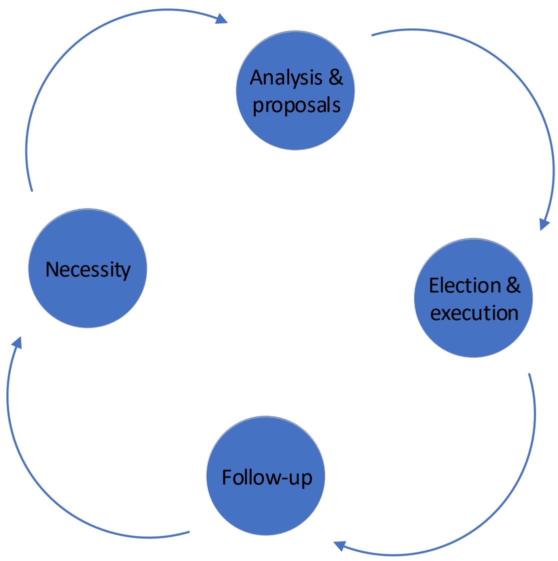
It consists of converting the geometry of the initial mesh into the mesh format that is desired according to the requirements of the problem.

A processing of the mesh, is to change the geometry of the mesh from triangular to square with transformation methods, for example. It is also considered a processing of the mesh to apply smoothing techniques or other techniques that suppose an improvement in the quality of the model according to the requirements of the project.

5. PROJECT PLANNING

5.1. Methodology

This project is done by two people, therefore besides just developing the project, there have to be a communication process, consensus and an exchange of information between the two members so that all the tasks are carried out in a fluid and efficient way.



That is why a methodology with the following steps is followed:

- Necessity: The medical necessity from which to design the right solution must be identified. In the case of this project, the need is demanded by the doctors of the Hospital Sant Joan de Déu. They are the ones who say what is need to improve.

- Analysis & proposals: Once the problem is detected, it is proceeded to study it and look for the current solutions to the problem. Both members of the team must think and raise proposals for each problem.

- Election & execution: Once all the alternatives are presented, it has to be chosen the one that seems more efficient, feasible or appropriate to the initial requirements.
  Next, it is proceeded to the development of each solution proposed according to the requirements established by the doctors.

- Follow-up: Once the task is completed, the process of verification and efficiency of the doctors begins. In case there were problems or functions that do not work in the desired way, the process to solve the problem needs to begin again.

5.2. Planning

The planning used to develop the project consisted of performing two tasks simultaneously: the 3D modelling of the hearts and the design of the application.

For the 3D modelling part, it was essential to maintain contact with the Hospital Sant Joan de Déu, being they who provided the DICOM images to segment and validated after the modelling process that was applied to them. The images of the hospital corresponded to medical images obtained from angiographies and resonances made to patients that were exported in .dcm format.

From here, the first step of the project consisted in the segmentation, cleaning and smoothing of the 3D model (through Mimics / Osirix and Blender).

At the same time that we worked in the modelling of hearts, the design of the application started. This was done using the Unity 3D software. First, a main menu and scene was created. Then, several buttons to interact with the imported heart.

The next step was to optimize the imported segmented and validated hearts in the application, through a very simple process that can be done without programming knowledge and makes planning easier for doctors.

Once the hearts were introduced, the interactions were added: scaling, rotation, the option to move around the environment and to visualize different imported hearts. Finally, the project concluded with the validation of it by the students, tutors, the people responsible of VISYON and the doctors of the hospital.

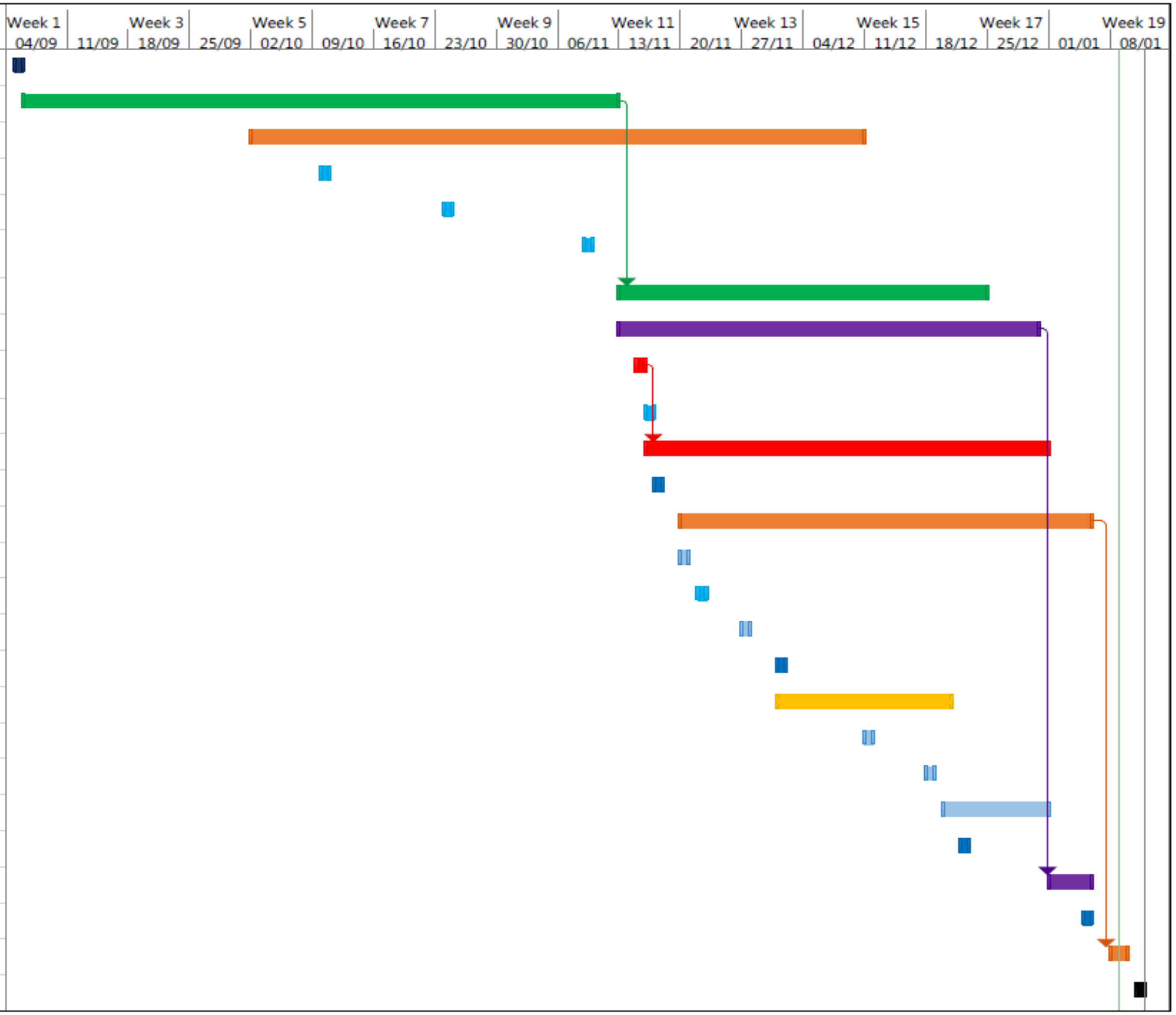
5.2.1. Gantt Chart

In order to guarantee the realization of the project in the specified time, a Gantt diagram has been performed to temporarily schedule the different tasks and documents to be drafted.

There are also meetings every two weeks between UPC - VISYON and UPC - Hospital Sant Joan de Déu.

GANNT CHART

ID	Nombre de tarea	Start	Finish
5	UPC Tutor Meeting	Tue 05/09/17	Tue 05/09/17
9	Previous research	Wed 06/09/17	Sun 12/11/17
15	Documentation	Mon 02/10/17	Sun 10/12/17
25	University Meeting	Tue 10/10/17	Tue 10/10/17
26	University Meeting	Tue 24/10/17	Tue 24/10/17
6	Sant Joan de Deu cooperators Meeting	Thu 09/11/17	Thu 09/11/17
10	Information search	Mon 13/11/17	Sun 24/12/17
13	App development	Mon 13/11/17	Sat 30/12/17
11	DICOM images obtaining	Wed 15/11/17	Wed 15/11/17
7	Sant Joan de Deu visit	Thu 16/11/17	Thu 16/11/17
12	Image segmentation	Thu 16/11/17	Sun 31/12/17
4	Vysion Meeting	Fri 17/11/17	Fri 17/11/17
16	Memory assembly	Mon 20/11/17	Fri 05/01/18
19	University Meeting	Mon 20/11/17	Mon 20/11/17
8	Sant Joan de Deu visit	Wed 22/11/17	Wed 22/11/17
20	University Meeting	Mon 27/11/17	Mon 27/11/17
1	Vysion Meeting	Fri 01/12/17	Fri 01/12/17
24	General Revision	Fri 01/12/17	Wed 20/12/17
21	University Meeting	Mon 11/12/17	Mon 11/12/17
22	University Meeting	Mon 18/12/17	Mon 18/12/17
23	Final Coordination	Wed 20/12/17	Sun 31/12/17
2	Vysion Meeting	Fri 22/12/17	Fri 22/12/17
14	App details	Mon 01/01/18	Fri 05/01/18
3	Vysion Meeting	Fri 05/01/18	Fri 05/01/18
17	Final Memory	Mon 08/01/18	Tue 09/01/18
18	Project Delivery	Thu 11/01/18	Thu 11/01/18



6. SEGMENTATION PREPARATION

The only thing left to start is to choose the program that we will use to perform the segmentation.

6.1. Analysis and Selection of the segmentation program

In order to realize the 3D modelling process of the hearts, a previous study has been done of the different 3D design software existing in the market. Having no prior knowledge on this field, we dedicated some months to reading and investigating which were the most complete and used. Thereby, some software were rejected until selecting the best two: Materialise Mimics Innovation and OsiriX, both combined with Blender.

Some characteristics were defined and a deeper study of these software was made considering the following factors of interest:

- Importation formats of the files that the program supports: The medical image file can be saved in different formats and with different characteristics each. The format explains how the information of the image is organised and saved, and how it should be interpreted by the program which will open and visualise it. The format DICOM, previously explained in section 4.2, is nowadays the most used. Neither Mimics nor OsiriX had a problem opening the files DICOM that doctors from Hospital Sant Joan de Déu provided.

- The segmentation tools that has:
    - Manual segmentation: Manual segmentation with OsiriX is a little bit basic, since it only allows drawing with a paint brush the interesting parts. On the other hand, Mimics presents a largest quantity of manual tools that allow to obtain more accurate and faster results. It is a semi-automatic segmentation, on the sense that concrete slices can be manually segmented and results can be automatically spread to the whole series. In this sense, the one that presents more resources and, therefore, seems more efficient, would be Mimics.

    - Automatic segmentation: Automatic segmentation is similar in both cases, but seems to be more accurate in OsiriX. Nevertheless, the precision in the cardiac organ is not the adequate in neither of the programs, since the segmentation is not correctly made due to not isolating the ribs and not separating the different parts.

- The operative system of the device: for OsiriX the only version available is in MacOS and for Mimics in Windows.

- The quality and efficiency of the results.

- The exportation formats of the models: The formats that the program Unity accepts to import the 3D models are .fbx and .obj; therefore, since the two selected programs do not allow to export it directly to these formats, it would be need to complement it with Blender to convert the formats and put the final touches to the models.

- Loading time of the program: since the files are pretty heavy, it interests for the loading time to be fast. Both programs require computers with a good hardware.

- Interface of the user: it is wanted to be easy to understand, simple to use and fast. Although MacOS is known for being more intuitive, in our case it seemed to us that it was much more easy to understand and use Mimics than OsiriX.

- Tutorials, documents and available aids on the Internet: being beginners, it is of great interest the amount of documents and help tutorials on the Internet. Both Mimics and OsiriX offered a wide range of documents, highlighting that Materialise Mimics Innovation, Materialise company, provides its own tutorials on the Internet.

Since the potential of these programs was seen, it was decided to do the segmentation process with both of them, and thus see and compare the obtained results.

6.2. 3D Models & Design requirements

Once chosen the software and before beginning the project's implementation, some common characteristics for the 3D models of the hearts were defined.

During the 3D modelling process, it was considered that all heart models should obey the following design characteristics:

- To obtain the most accurate model possible.
  - All elements not related with the heart should be deleted, just like bones o muscles around.
  - It is necessary to locate the congenital heart defects area before beginning deleting to not erase the pertinent part, and taking into account the length of the arteries or veins, depending on whether the congenital heart defects were located in a vein or artery far from the heart.
- To obtain a 3D model of good quality.
  - It was needed to obtain a 3D model that coincided with a real heart.
  - The faces of the 3D model needed to be the most aesthetic possible, that is why smoothing methods were applied.
- To differentiate the different parts of the heart. It was used to do so a colour palette based on those used in cardiology.
  - The oxygenated part of the heart: colours red. It contains the aorta artery, the pulmonary veins, the atrium and the left ventricle.
  - The deoxygenated part of the heart: colours blue. It contains the vena cava, the pulmonary arteries, the atrium and the right ventricle.
  - The area of the pathology: colour yellow.

7. SEGMENTATION PROCESS

The whole process of treatment of medical images explained in section 4. Medical images reconstruction, will be applied in our real case below to understand the theory and look at the results obtained in the practice.

It will be described the required post-processing part from the moment that the medical images are acquired until the 3D reconstructions in OBJ format are obtained.

The first step for the image reconstruction, already explained, is to acquire the medical images of the patient in one of the tests described in section 4.1. Medical Imaging. Each typology of the image will contribute with a different information and the doctor will be the responsible to determine which is the adequate for each diagnosis.

The files will have a DICOM format (with .dcm extension)

From now on and through the programs Mimics and OsiriX, the medical images from the files will be imported to begin with the segmentation. This process will be explained right after for each one of the programs.

7.1. OsiriX

Let's begin with Osirix:

Navigate to the folder that contains your DICOM data set. Click the Open button.

OsiriX will ask you if you want to copy the DICOM files into the OsiriX database, or only copy the links to these files. Click "Copy Files."

OsiriX will begin to copy the files into the database. A progress bar will be shown on the lower left-hand corner. When the data is imported you'll see a small orange circle with a "+" in it. This orange circle will eventually go away when OsiriX is finished analysing the study, but you can open the study and work with it while OsiriX does some clean-up postprocessing.

Once the project is opened you can set the contrast value you prefer, to see the images clearer.

Then to start the segmentation, it is used Grow Region 2D/3D Segmentation under ROI menu.

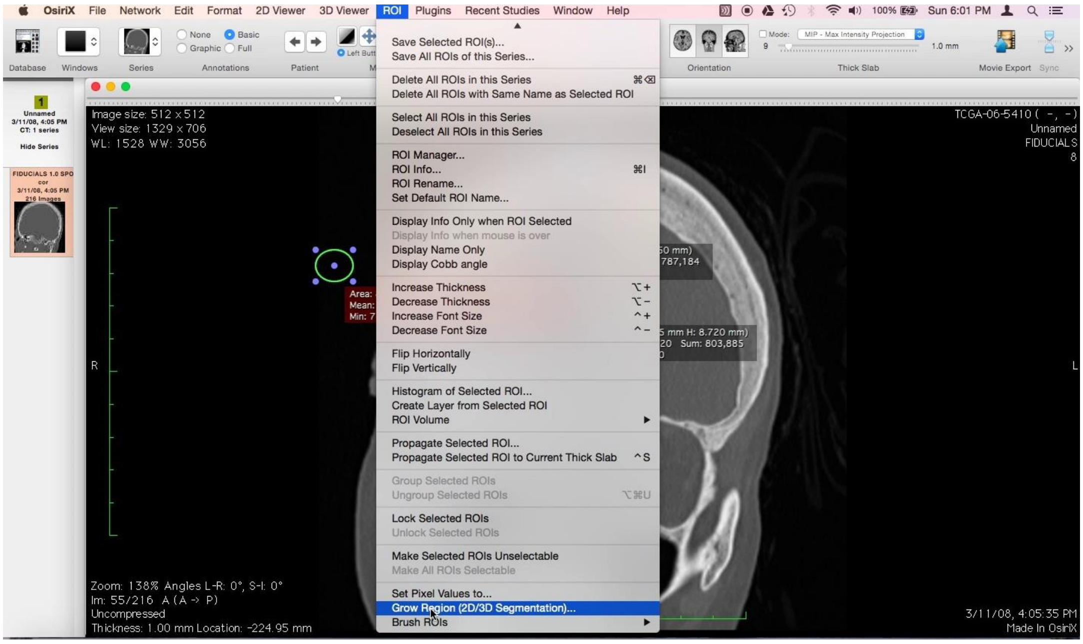


Figure 23 OsiriX Segmentation step (Source: Screenshot OsiriX)

In the Segmentation Parameters window that pops up, set the threshold value desirable and then select a starting point for the algorithm. Left click on the heart. Green crosshairs will show. All of the heart parts that are contiguous with point you clicked will now be highlighted in green.

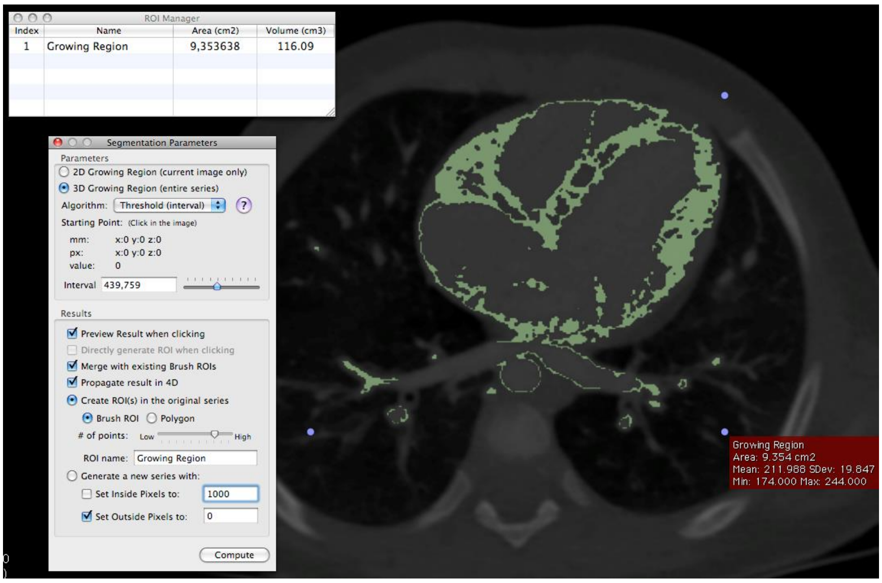


Figure 24 OsiriX Segmentation step (Source: Screenshot OsiriX)

Click the Compute button and Osirix will propagate the threshold.

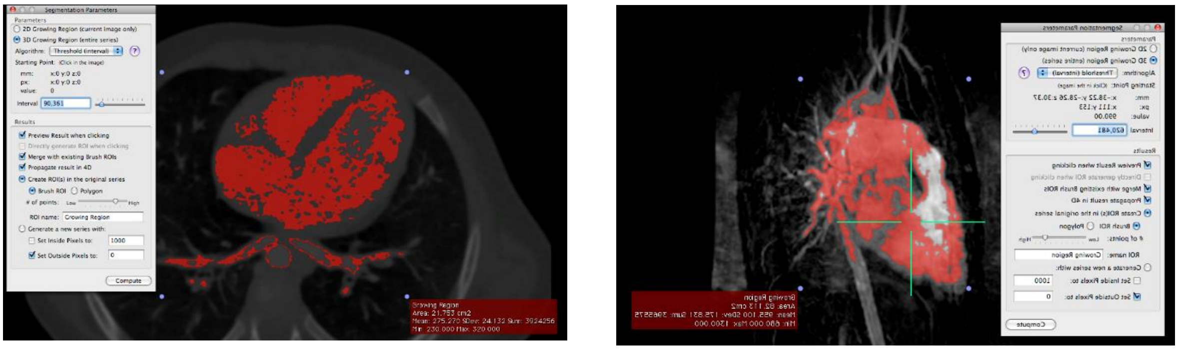


Figure 25 OsiriX Segmentation step (Source: Screenshot OsiriX)

Trying to generate a 3D surface model directly from the 3D Surface Rendering function underneath the 3D Viewer menu is tempting to use, however it will not work well for generating STL files.

Pixel values can be modified to have a better visualization of the segmentation. Inside ROIs to 3024 and Outside ROIs to -3024, obtaining this result:

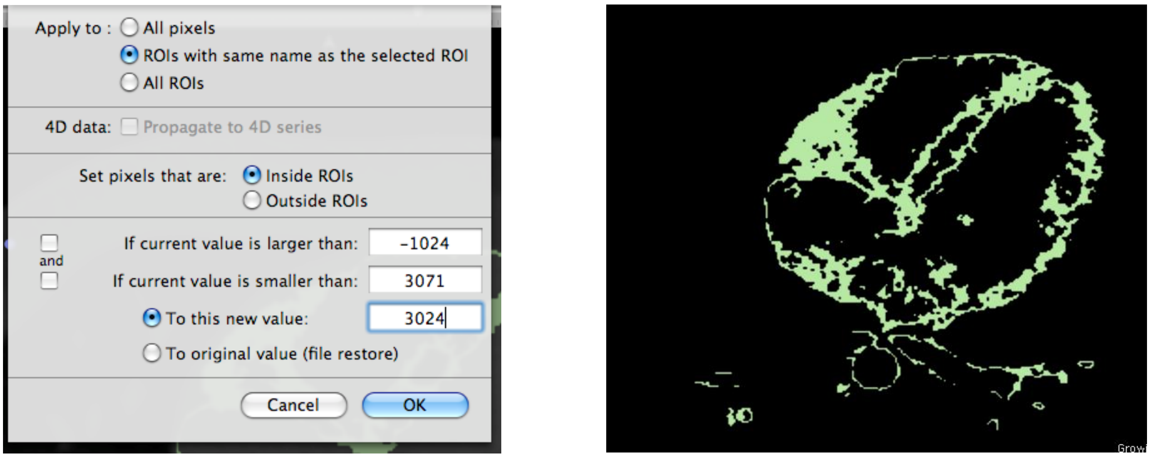


Figure 26 OsiriX Segmentation step (Source: Screenshot OsiriX)

Now everything is ready to create the 3D surface model. Click on the 3D viewer menu and select 3D Surface Rendering. Osirix will then think for a few moments as it prepares the surface.

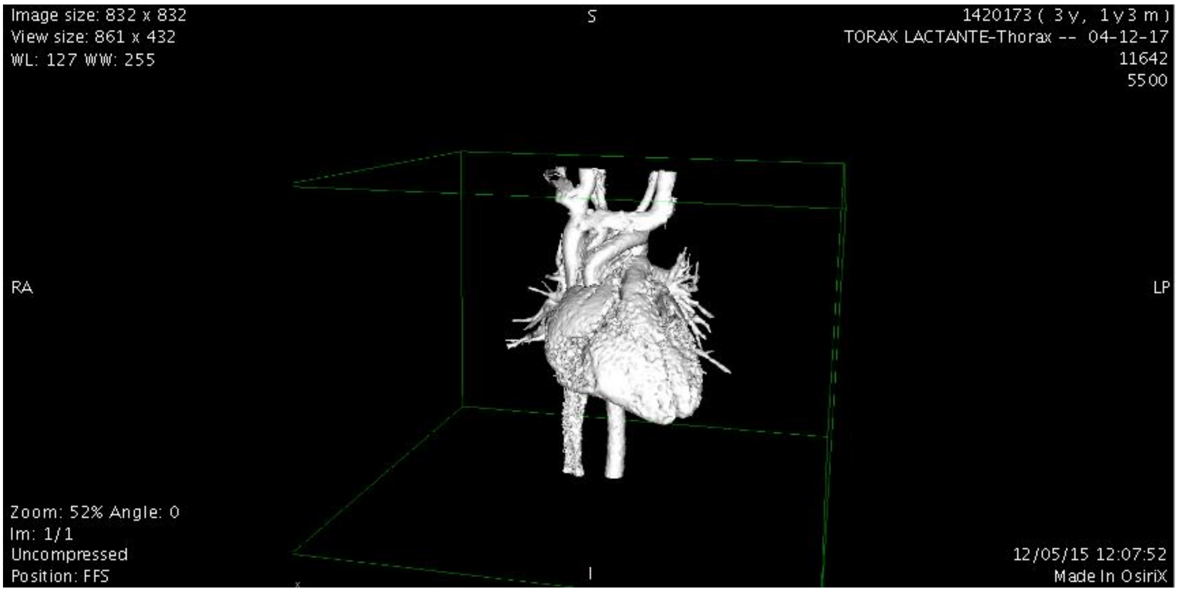


Figure 27 OsiriX Volume rendering (Source: Screenshot OsiriX)

It is also possible to erase all the parts rendered that are not part of the heart as bones. Osirix has tools to cut in an easy way what is not needed.

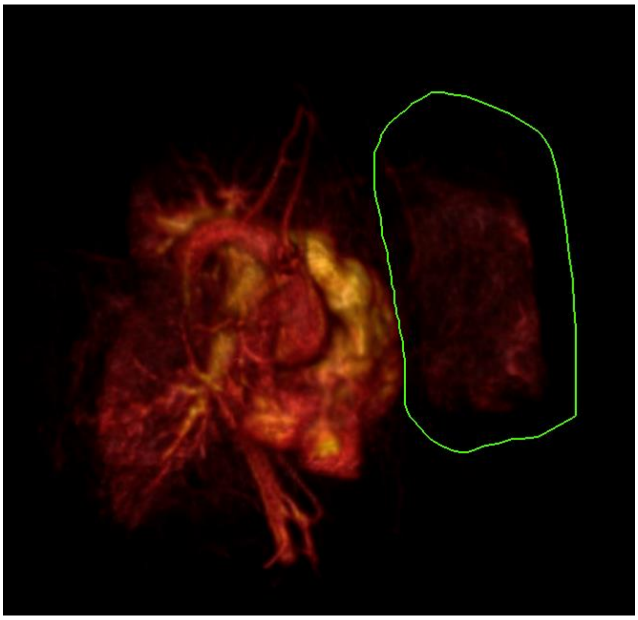


Figure 28 OsiriX Rendering tool (Source: Screenshot OsiriX)

Finally, the 3D surface model is exported to an STL file. Click Export 3D-SR and choose Export as STL. Type the file name and save.

7.2. Mimics Medical

With Mimics the steps are a bit different and the results more complete and accurate. The abundance of specialized tools in Mimics made the segmentation process as well as 3D editing and refining phases effortless.

Once the DICOM file is imported and a new project started, the first thing to adjust is the contrast and the volume rendering to the values that fits better depending the DICOM images. Volume rendering allows you to quickly visualize your 2D data as a 3D object without having to take the time to segment and create a model. It is only a visualization tool, but gives a nice impression of what your model will look like.

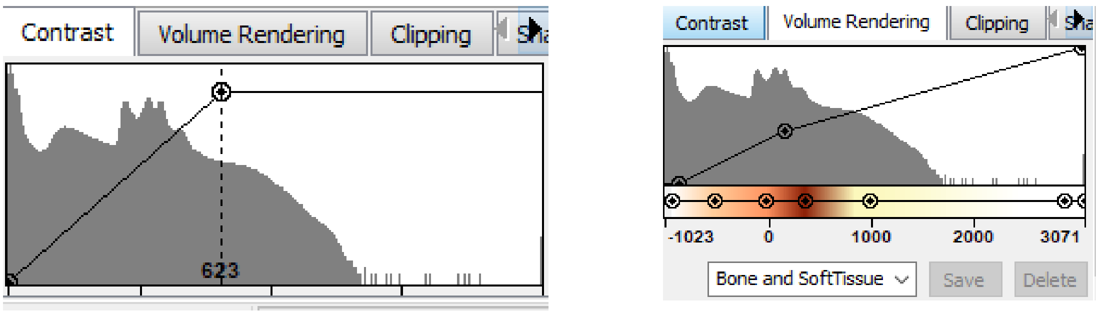


Figure 29 Mimics Segmentation step (Source: Screenshot Mimics)

Then, a specific module for Heart Segmentation can be used by clicking Segment → Cardiovascular → CT Heart, and a Threshold Range has to be chosen after restricting the Bouding Box (in red) to approximate the heart dimensions.

Thresholding classifies all pixels within a certain Hounsfield range as the same colour, or mask. There are predefined settings for certain biological materials available in the thresholding toolbar. A lower threshold allows segmentation of soft tissue, whereas a higher threshold segments bone. An equilibrium between both has to be found to get a good rendering.

The next step is to select the desired threshold by changing the sliders or entering the minimum and maximum values manually.

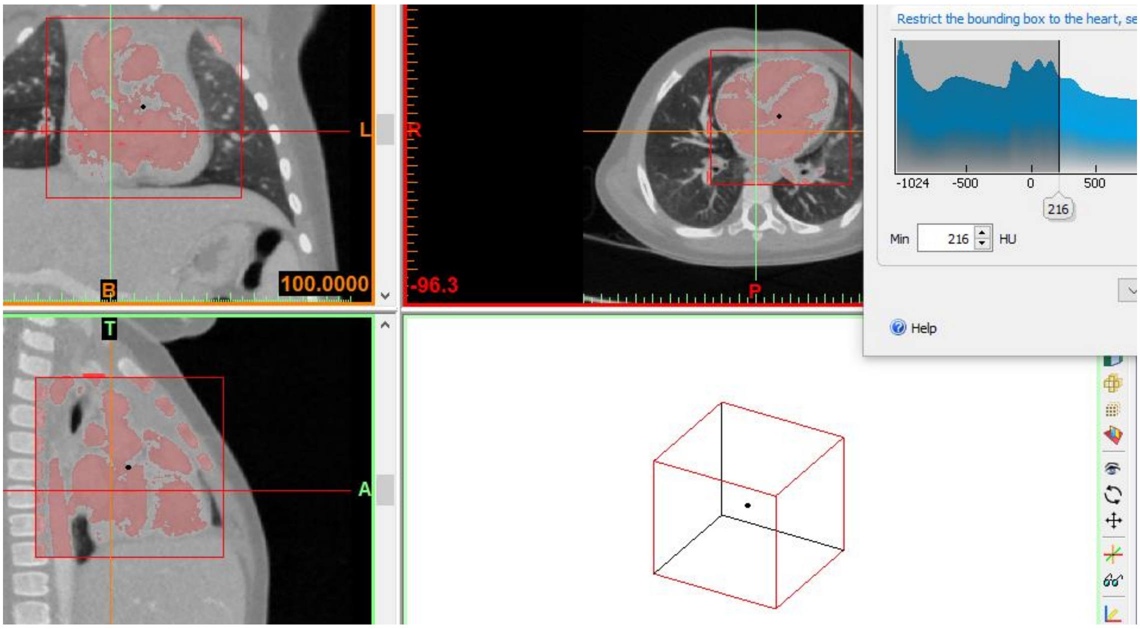


Figure 30 Mimics Segmentation step (Source: Screenshot Mimics)

Then, by clicking Advanced button, appears where the manual segmentation can be done part by part. Some seed points can be set marking the exact point where the heart part is. First the Left Atrium (LA).

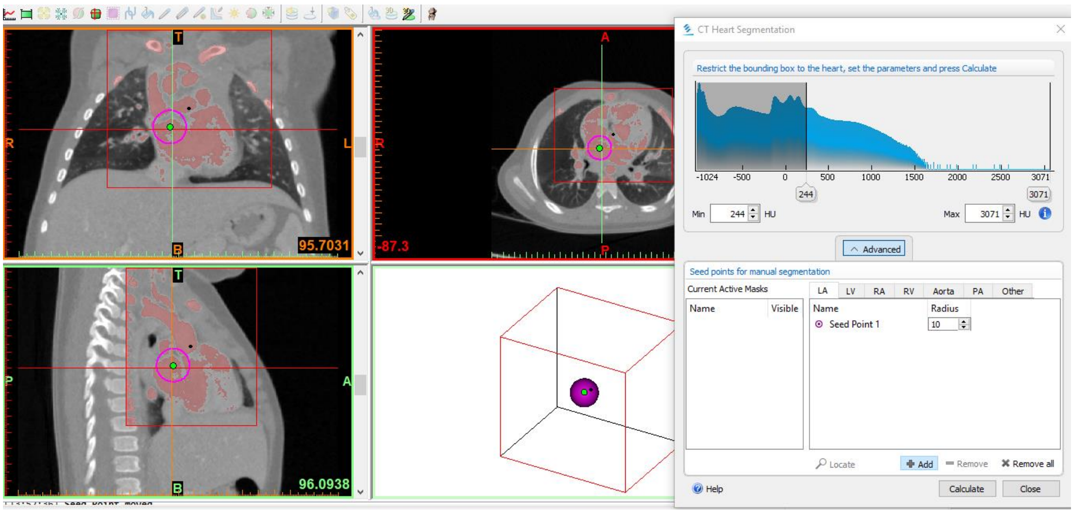


Figure 31 Mimics Segmentation step (Source: Screenshot Mimics)

Followed by Left Ventricle (LV).

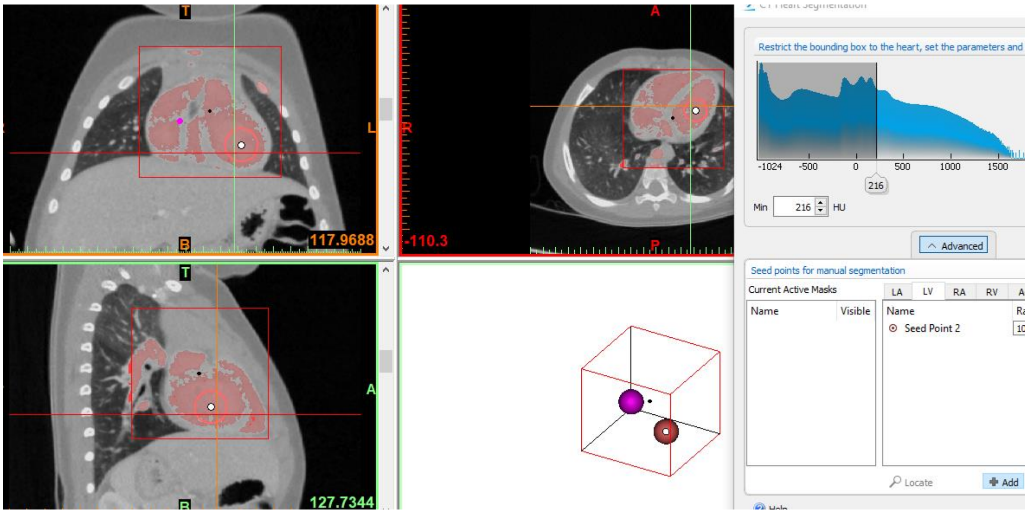


Figure 32 Mimics Segmentation step (Source: Screenshot Mimics)

The radius of the seeds can be modified for smaller parts as the Right Atrium (RA).

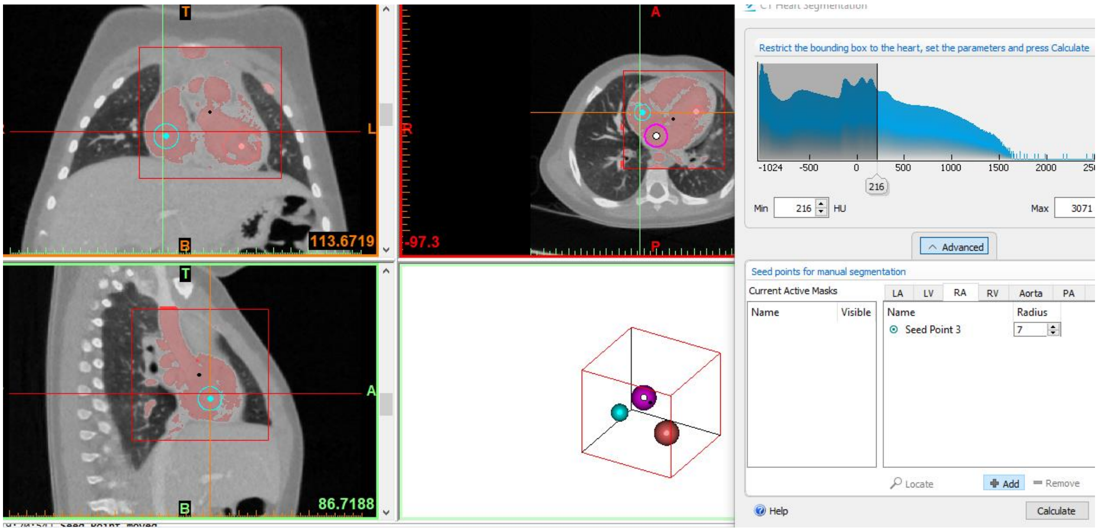


Figure 33 Mimics Segmentation step (Source: Screenshot Mimics)

And the last heart chamber, the Right Ventricle (RV).

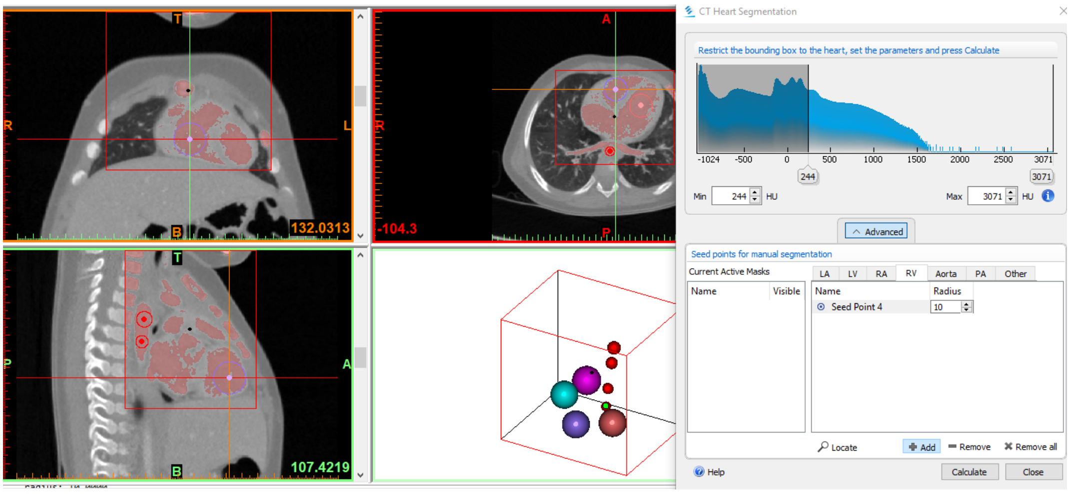


Figure 34 Mimics Segmentation step (Source: Screenshot Mimics)

For the Aorta segmentation multiple seed points were used, following the ascending and descending Aorta and the same for the Pulmonary Artery (PA).

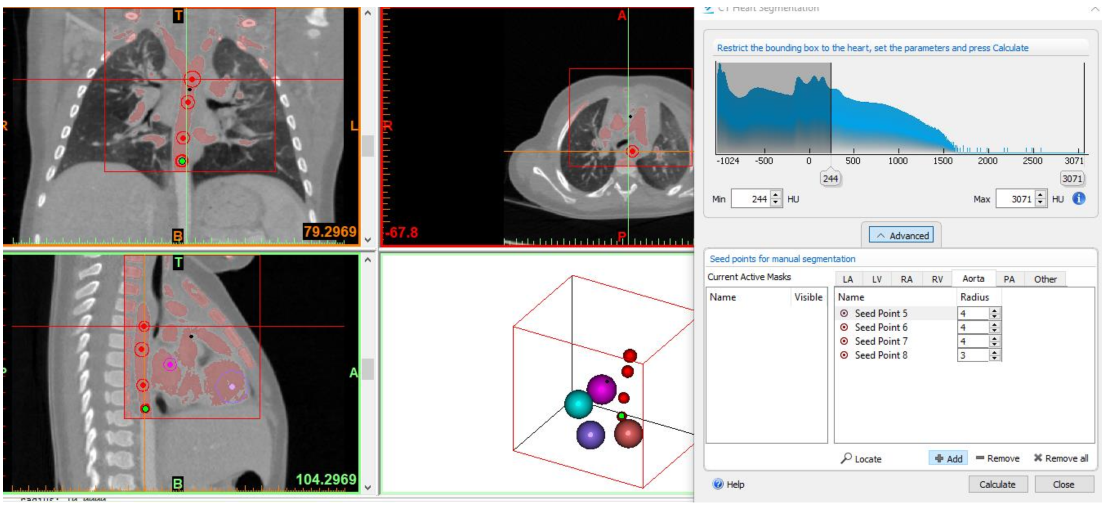


Figure 35 Mimics Segmentation step (Source: Screenshot Mimics)

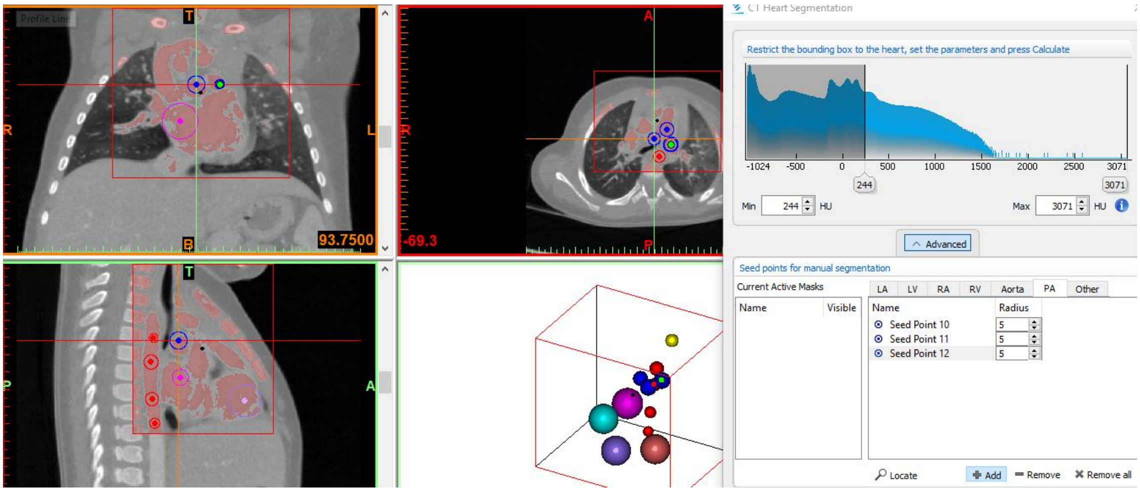


Figure 36 Mimics Segmentation step (Source: Screenshot Mimics)

Finally, in Other section, the pathology can be segmented in yellow. In this case was a Coarctation of the Aorta (CoA).

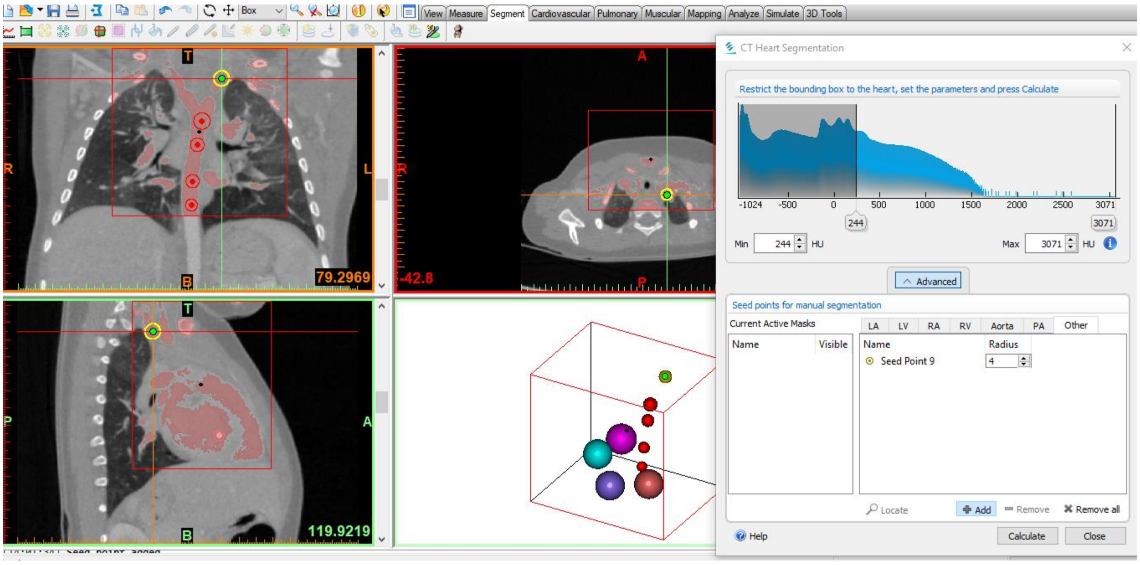


Figure 37 Mimics Segmentation step (Source: Screenshot Mimics)

By clicking Calculate, Mimics will start calculating the different masks per part.

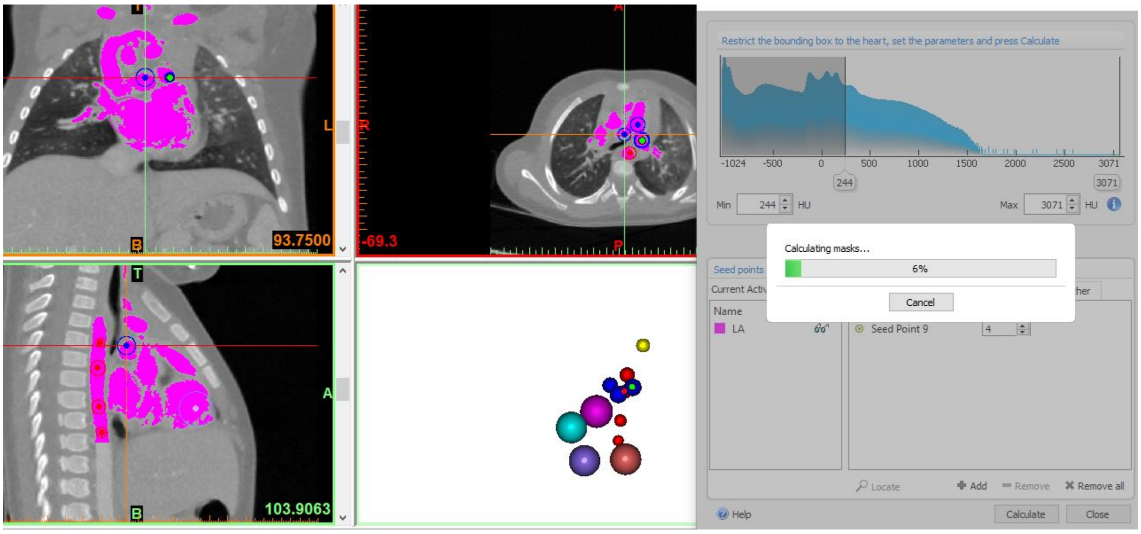


Figure 38 Mimics Segmentation step (Source: Screenshot Mimics)

The masks per each part are created and can be checked, modified and hided.

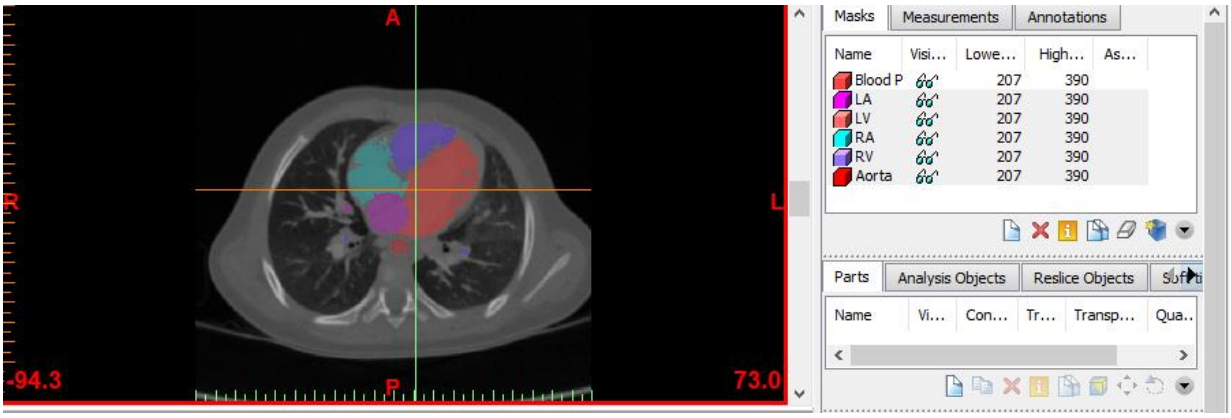


Figure 39 Mimics Segmentation (Source: Screenshot Mimics)

The results are displayed showing the 3D heart segmented.

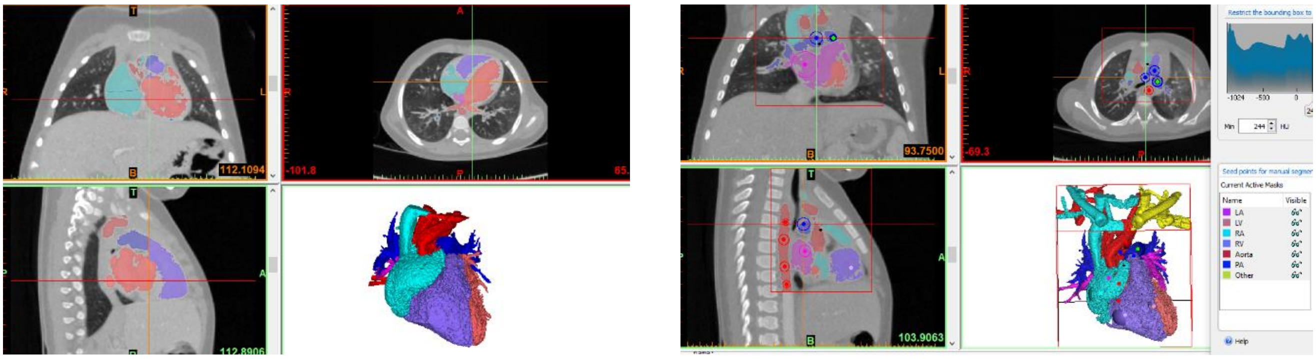


Figure 40 Mimics Segmentation result with and without pathology (Source: Screenshot Mimics)

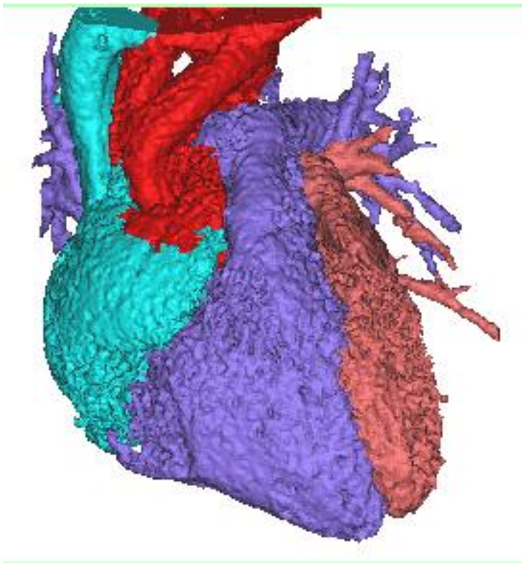


Figure 41 Mimics Segmentation Result (Source: Screenshot Mimics)

This heart model obtained can be modified with some tools before exporting it to have better quality and a more accurate 3D object.

Region Growing and Dynamic Region Growing

Region growing is used to separate masks into different parts as well as to get rid of floating pixels. Remember that thresholding must be done prior to region growing. The Green Mask contains the deleted parts and the yellow one is the new one generated. As seen it is not totally accurate.

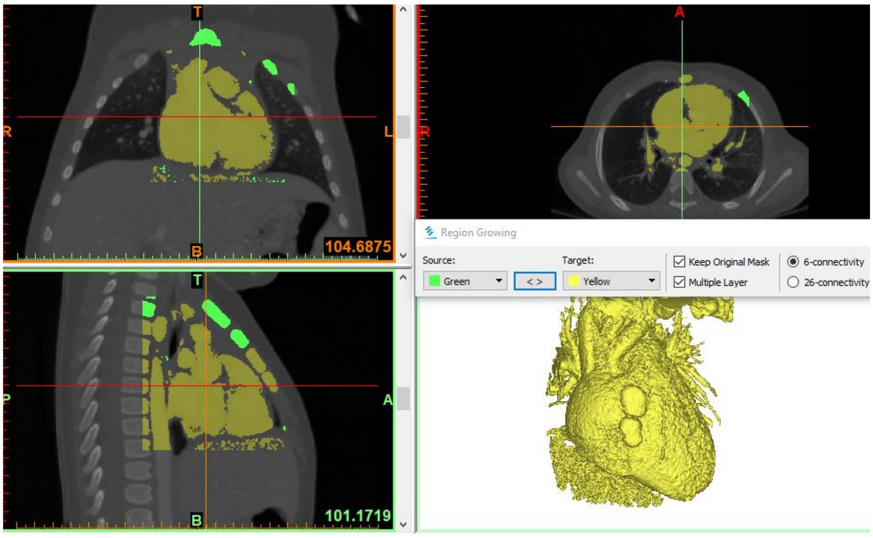


Figure 42 Mimics Segmentation Tool (Source: Screenshot Mimics)

Dynamic Region Grow allows you to grow a mask from a selected point without having to threshold first. It is extremely useful for vessels, nerves, and arteries.

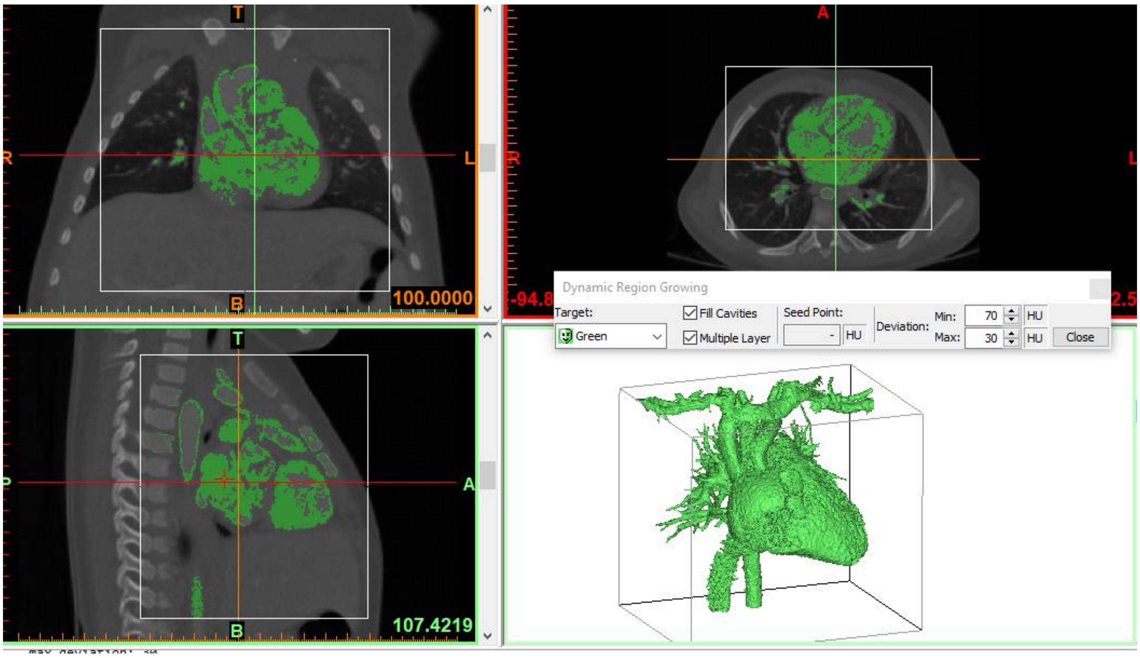
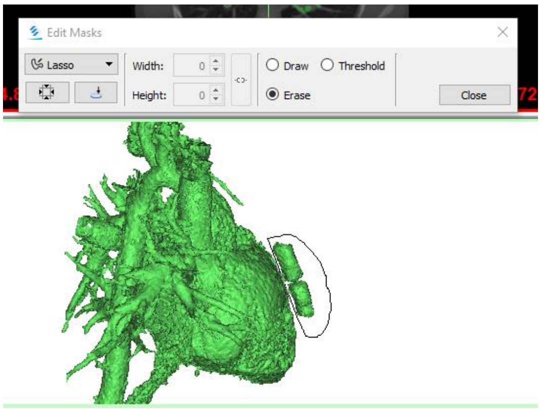


Figure 43 Mimics Segmentation Tool (Source: Screenshot Mimics)

Edit Masks

The area contained within a mask can be modified using the edit mask tools, and erase the leftover parts.



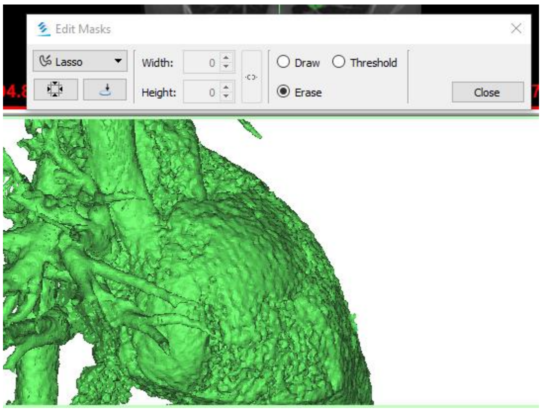


Figure 44 Mimics Segmentation Tool (Source: Screenshot Mimics)

Multiple Slice Edit

Multiple Slice Edit is a timesaving tool because it allows you to apply the manual editing done on one slice to other slices. Select adds pixels to a slice and deselect removes pixels. You can control the size and shape of your editing tool by changing type, width, or height.

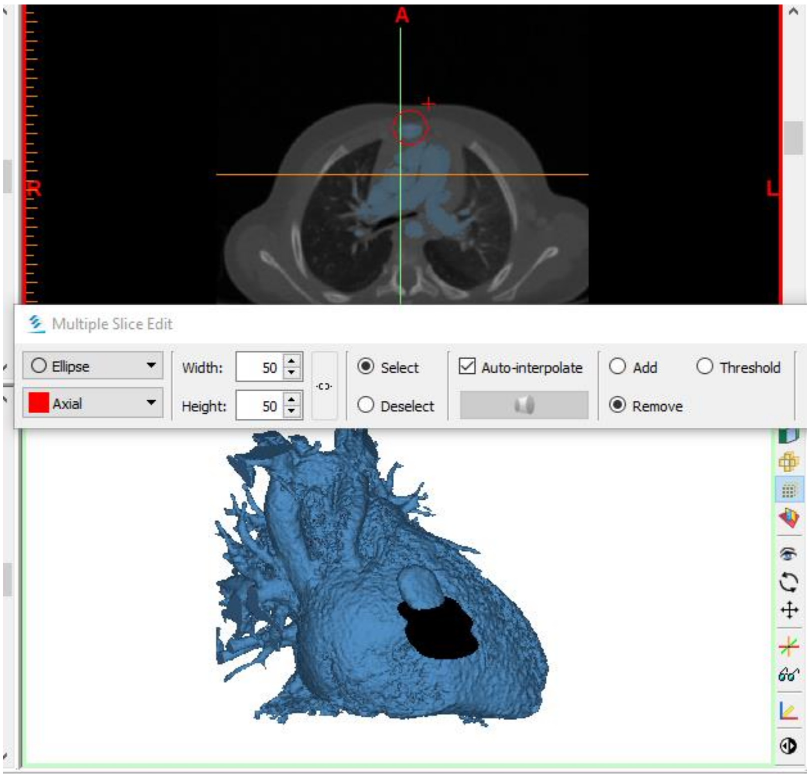


Figure 45 Mimics Segmentation Tool (Source: Screenshot Mimics)

Morphology Operations

Morphology operations take or add pixels to the source mask. You can use a morphology operation as an alternative to multiple slice edit.

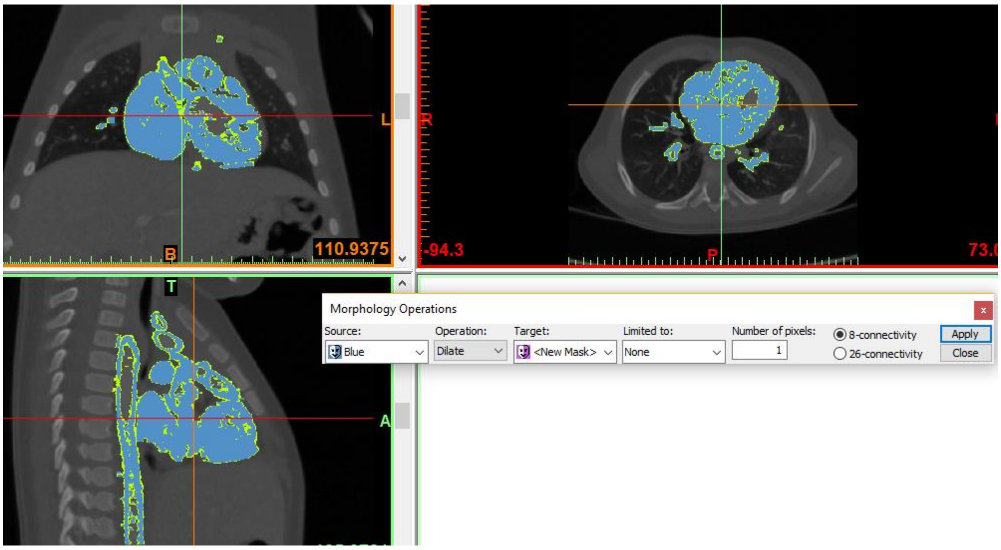


Figure 46 Mimics Segmentation Tool (Source: Screenshot Mimics)

Erode takes away the number of pixels selected and dilate adds the number of pixels to the boundary of the mask.

Figure 47 Morphology Operations (Source: Mimics Medical Guide)

Split Mask

The Split Mask tool is part of the Segment menu and allows splitting of a single mask into two separate masks. To open the tool go to Segment > Split Mask in the menu. This tool allows easy and quick separation of anatomical parts e.g. heart from the surrounding rib cage or separating talus and calcaneus in the foot.

The Split tool requires two marked regions to be used as input for splitting the selected mask. Region A is active by default and marking is possible on the axial, coronal and sagittal viewport. Start by marking Region A and then click the Region B button to mark the second region.

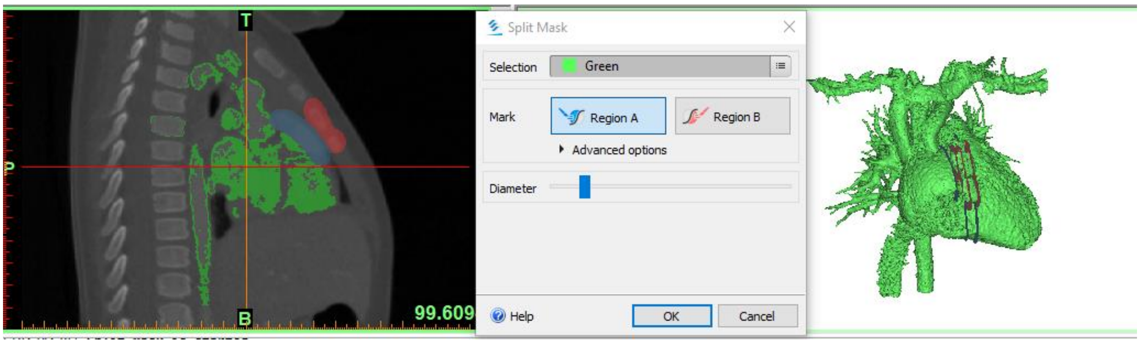


Figure 48 Mimics Segmentation Tool (Source: Screenshot Mimics)

Click on OK to start the splitting operation. After the operation is complete the dialog box will automatically close and the result will be added to the Masks tab as Region A and Region B.

In most of the cases the Split Mask tool gives good results with markings on just single slice. It is not mandatory to mark on multiple slices, but this can improve the result in case of undesired splitting.

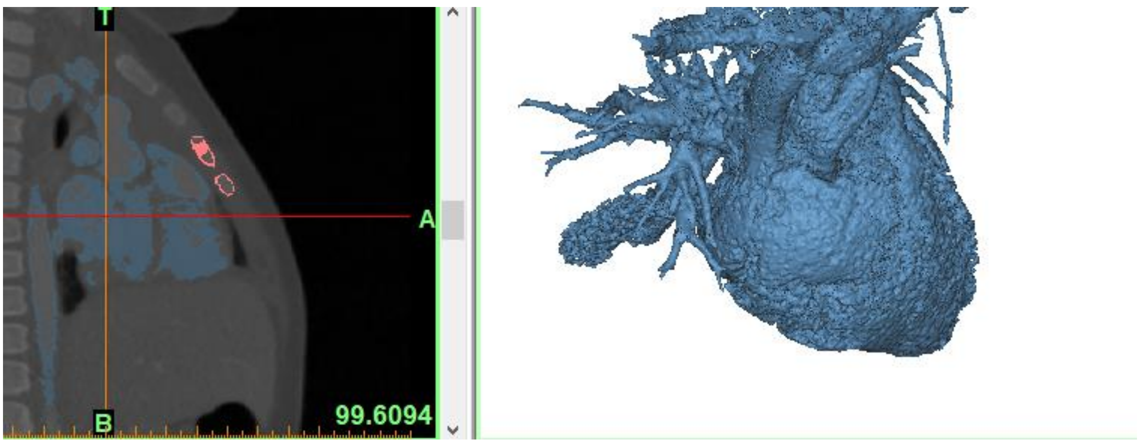


Figure 49 Mimics Segmentation Tool (Source: Screenshot Mimics)

For segmentation of the entire heart, which had an inconsistent range of Hounsfield units, the simple Thresholding tool with CT (soft tissue) preset was more useful than the Dynamic Region Growing tool, the latter being very sensitive to the starting seed point.

The most accurate method was the CT Heart tool specific module.

Doctors have all necessary knowledge to carry out efficiently the segmentation and creation of a 3D model and every informatic tool is provided to them. As doctors and surgeons comprehend at first sight what needs to be analysed in tomographies, resonances, etc., they can easily select the interested regions (ROI) which are basic to create the 3D reconstruction.

The last step is to export the .stl file. If wanted, Mimics gives the possibility to smooth and to reduce the mesh. To obtain the best quality, a Custom configuration has to be chosen.

For the smoothing: the more iterations and smooth factor, the more quality.

For the triangle reduction: the less tolerance and edge angle, the more quality.

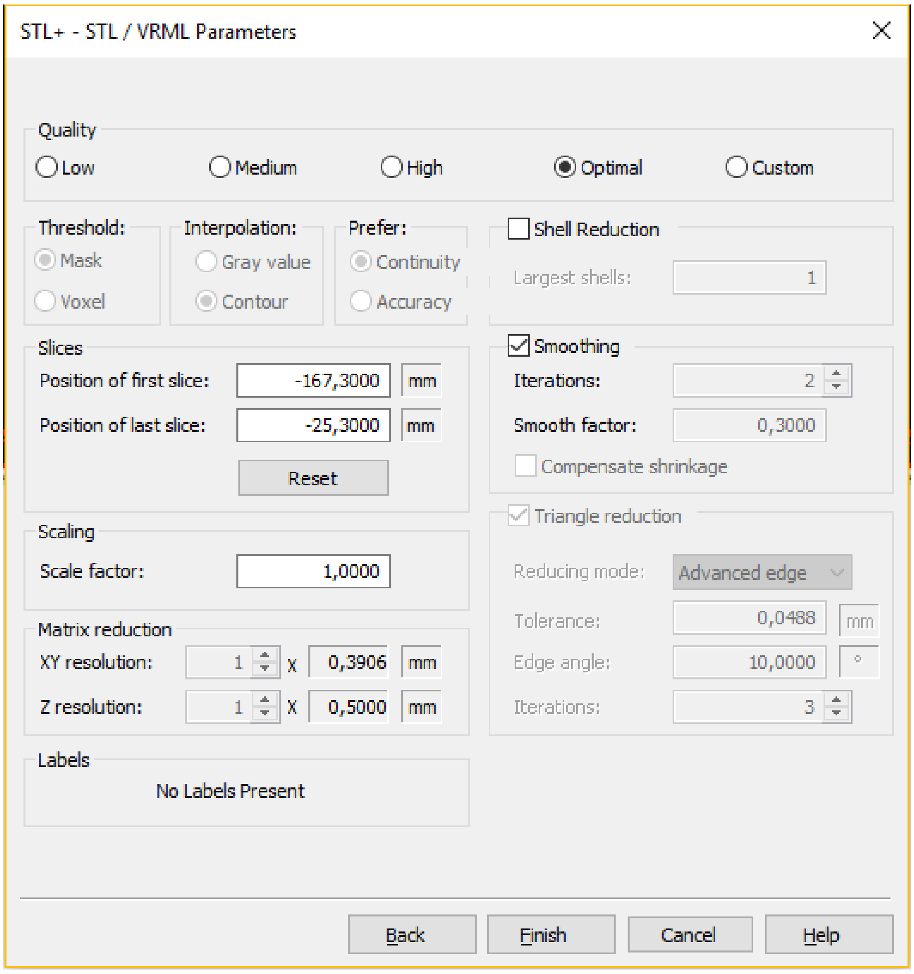


Figure 50 Mimics Export parameters (Source: Screenshot Mimics)

If not, it can be done by Blender as explained in the following section.

7.3. Blender

The last step for both ways is to use Blender to smooth and convert the 3D .stl files to .obj since is the format that Unity admits.

You can see from the 3D rendering that there are many small islands of material that have been included with the STL file. Also, the heart has a very pixelated appearance. It does not have the smooth surface that would be expected on a real heart. These problems are fixed by doing a little postprocessing.

Once Blender is opened, import the STL file. From the File menu select Import, STL, and double-click it. Blender will think for a few seconds and then return to what appears to be an empty scene. To find the heart, use the mouse scroll wheel to zoom out. When the heart is found, it seems to be gigantic. In Blender, an arbitrary unit of measurement called a "blender unit" is used. When the heart is imported, 1 mm of real size was translated into 1 blender unit. Thus, the heart appears to be hundreds of blender units large, and appears very big.

The 3D model is also offset from the origin. To fix that, select the heart, and in the lower left corner of the window click on the Object menu. Select Transform, Geometry to Origin and the heart is now centered on the middle of the scene.

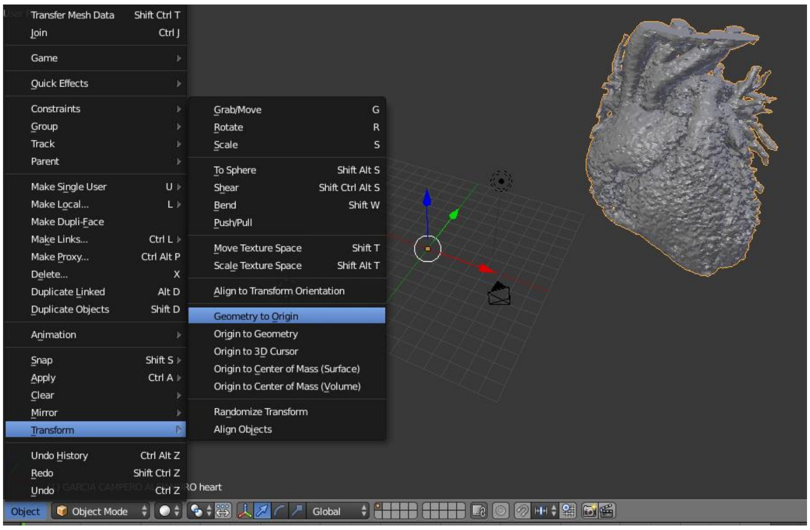


Figure 51 Blender smoothing step (Source: Screenshot Blender)

First, let's get rid of the extra mesh islands. There is a menu in the lower left-hand corner of the window that says Object Mode. Click on this and go to Edit Mode. In this mode it can be edit individual edges and vertices of the model. Right now, the entire model is selected because everything is orange. In edit mode you can select vertices, edges, or faces.

Right click on a single vertex on the model and under the Select menu, click Linked. This selects every vertex that is connected to the initial vertex selected. The selection has to be invert, by again clicking on the Select menu and choosing Inverse.

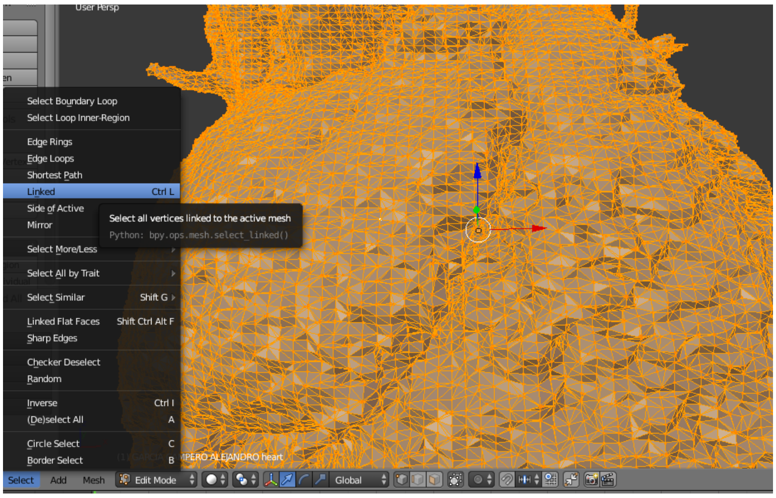


Figure 52 Blender smoothing step (Source: Screenshot Blender)

Now all of those unwanted mesh islands are selected and they only have to be deleted.

Then, to get rid of the pixelated appearance of the model surface, all the polygons have to be converted to triangles. The smoothing algorithms just work better with triangles. Once the model is all selected it has to be clicked Mesh menu, Faces, Triangulate Faces. This will convert any remaining complex polygons to triangles.

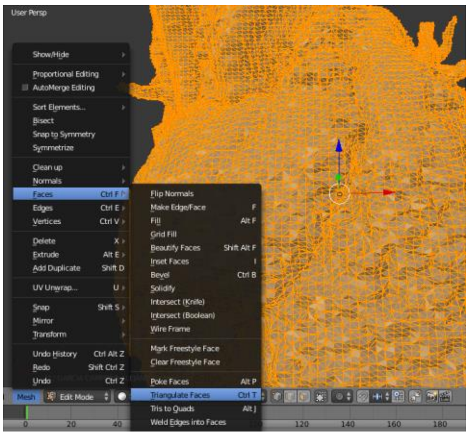


Figure 53 Blender smoothing step (Source: Screenshot Blender)

Go back to Object mode by hitting the tab button or selecting Object Mode from the bottom toolbar. A smoothing function is going to be applied, called a modifier. Along the right of the screen you'll see a series of icons, one of which is a wrench. Click on that. This brings up the modifier panel, a series of tools that Blender uses to manipulate digital objects. Click on the Add Modifier button and select the Smooth modifier. Leaving the Factor value at 0.5, the Repeat factor can be increased until the surface appearance of the model is the desirable. Click on the Apply button and the smoothing function has been applied to the model.

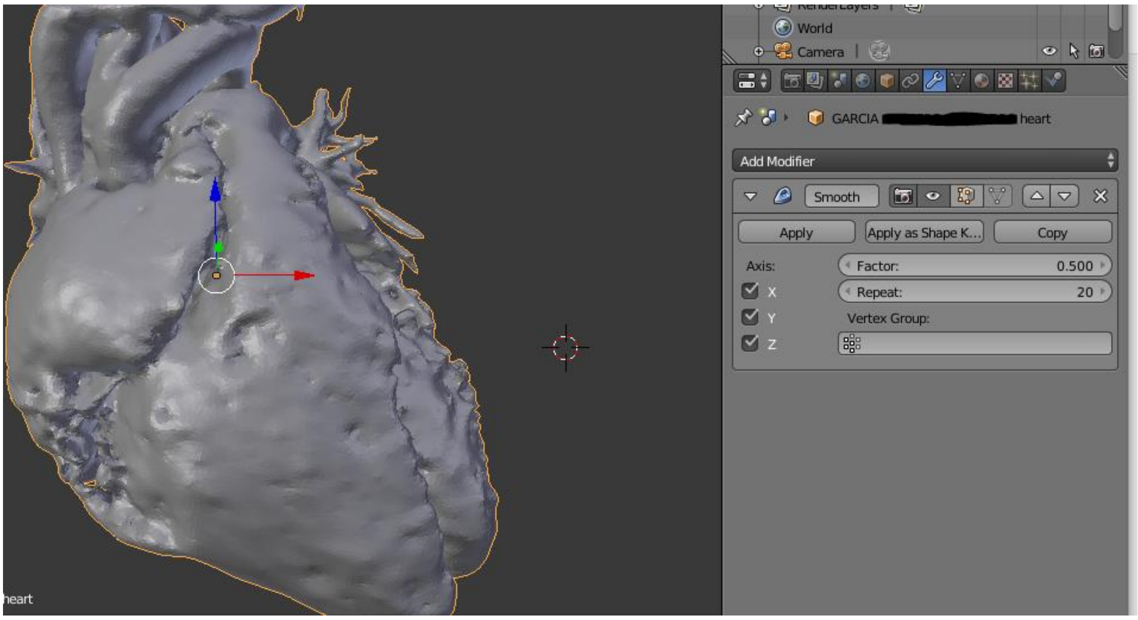


Figure 54 Blender smoothing step (Source: Screenshot Blender)

The last step is to export the model to .obj, and everything would be ready to import the 3D heart to de VR app done in Unity 3D.

Now, it can be seen that this is a task which requires a lot of dedication, concentration, experience and time.

As it has been previously explained in other points of this report, the aim of this project is to create a virtual reality app for surgical planning. Its usage will change for every new patient; therefore, it has been considered not to add any previous model and import them from the outside.

8. VIRTUAL REALITY APPLICATION

8.1. Game engine

As mentioned before, the main objective of the project was to make an optimal and easy-to-use application. When looking for engines to carry through the project, Unity has been the best one in terms of functionality and optimization. Even though It is true that there were many other possibilities, it was important to note the limitations of the project, such as the experience acquired as students in this kind of workspace and the possibility to use a paid engine or a free one.

The table of aspects from Unity gave us a free to use engine with a highly worked and intuitive interface, which made the first steps of learning way more easy and free-flowing. Although it is possible to get a pro version of the program, the planning of the project did not change much if it was considered to upgrade the license.

Since Unity is constantly changing the version to bring it up to date, it was also important to pick one and work with it within the whole project. Any changes made between versions involve a huge number of warnings or errors in the scripting part of the project, which are something to avoid when trying to bring a huge application to an end. Still there was not much change between the last version and the safest one, so we chose to use the Unity 5.6.

Speaking of scripts, using Unity there was the possibility of using two programming languages: C# and JavaScript. Both of them are highly used in most of the projects that take part in this generation, but they mainly have different aims of work. Since Java is the most used language when developing web projects or online platforms, C# is more object-oriented and has more general tools, what gave the ability to search more different ways to program actions inside the application.

Figure 55 Unity Engine Logo (Source: unity3d.com)

The objective of the project required the best possible graphic definition for the images used in the space. Obtaining a high quality and texture 3D model for the application is for sure the most important part of any project dedicated to surgery planning. The main problems that appear when trying to transfer these models to any display engine are related to the quality of these represented objects. Although it is something that still needs a lot of improvement from the start, when taking the image from the patient, the other part cannot stay behind. So, it was found that there was the opportunity to import a kind of 3D objects that were compatible with Unity and gave a really high definition when placed in scene.

Transferring this to the virtual reality world, the engine used in the project has some of the best performances offered in the actual market. It has been mainly used in smartphone applications achieving very nice outcomes, but the historical implementation of this immersive game style is now a very thankful feature between users that are getting interested in virtual reality.

There's also something to keep in mind, and it is that the Unity community has build kind of a big forum full of answered questions where people dedicates a lot of time and effort to participate. This ensures a place to resolve any problems or troubles that may appear during the project, what makes It more attainable.

The support obtained from VISYON has to be mentioned here, since although the forum has been mentioned, that was one of the main reasons to follow this path. Their experience and work are highly focused in the Unity engine and so there was the possibility to contribute with new ideas that might have seemed out of the way but with some retouches have become a true innovation and source of possibilities.

8.2. Development of the application

Before getting into the real work, it was necessary to try and decide which features had to be implemented in the project. Since there was no previous experience from the engine, all the possibilities were new and there was no influence at first to incline towards one option or another.

The main objective of this application when presented was to be something really easy to use for any user, considering that not all the players could have tried this kind of technology before, and also optimal. To achieve this, a list of features and characteristics was made and then trimmed to have only the interactions that were important and really useful for the application. There are some features that need really important improvements before they can become something useful in medical applications, so implementing those making the game harder and increasing its technical requirements was not desired.

With the first idea of the project, the application itself can be divided in some parts or categories, depending on its role in the whole work.

8.2.1. Scene

The scene of the application is the place where everything takes place. The project is made with a virtual reality engine so the idea was to immerse the user in a supposed hospital, where he/she could see the 3D heart model in a familiar space.

A surgery room has been set up with some of the elements that could be found inside, all using 3D models to make the experience more realistic and immersive. To get a clear vision from the model it needs to have a big free spot, where also it has to receive all the interactions and still give the best commodity when inside the game. The colors have been changed to get a clear contrast within the room space and the heart models and the lights are set up to show all the details in the object so no information is lost.

Figure 56 Panoramic scene view from the application

To reduce possible dizziness when in game mode, the space has been made in a small scale so the user doesn't have to move and can observe the models from any point of the room without losing sight of it.

8.2.2. Player

To be able to move around the scene and watch the space, it is required to add a player configuration inside the scene. This component incorporates the variables acquired from the headset and controllers input and transforms them into in-game actions, configurated by the interactions scripts.

The component used comes from a premade setup grabbed from the Unity asset store called SteamVR, which is made specifically for Virtual Reality devices. This is made to shorten the configuration process and is really used between most of the users. The player controller is named as "Manager" in the scene and incorporates the SteamVR plugin where all the HTC inputs are set.

When entering the game mode, the player has been placed in a corner of the room so he can watch the whole scene from the start. Since the models loaded would be in a high position it was decided that the user would be placed also in a high place. This could let the player observe the place by looking straight or down, instead of up, what could be tiring and lately evolve into neck pain after playing for a long period of time.

8.2.2.1. Controls

Even though the inputs are set in the manager, the functions in every controller have been configured by using custom scripts made for the project. There's a clear separation between one and the other: the left controller is set by the "**ControllerFunctions**" script and the right controller has the interactions made for the game.

Inside the "**ControllerFunctions"** code it is found the functions for the selection of the different options as well as the functions that each one of the *selectables* call when pressed.

To travel through the menu options, the player uses the ***left controller's touchpad**.* By pressing to one side or the other in the x axis, the menu rotates to the configured position. To select an option, the user presses the ***left controller's trigger.*** The other buttons have no function in the game itself, apart from the home button that brings the user to the Steam Home page.

This system simplifies the controls and makes the gameplay easier for any kind of user. Also, it is seen in the scene which buttons are being pressed by the player at any time, so it is easy to relocate if he/she gets lost in the controller.

The controls from the right controller are specified in each one of the interactions set for the models. The ***Rotation, Scale and Movement*** scripts only use the input from the ***right controller's touchpad***, since this makes the gameplay easier and more comfortable. There was the option to change the linear movement to a teleport system, but the scene itself is not really big so it was decided that this was the better option, although it might cause a little more dizziness.

The ***right controller's trigger*** is used to close the in-screen menus, so it works as a "back" button when using the ***Options*** and ***Guide*** functions in the menu. As in the left controller, the other buttons do not have a in-game function apart from the Steam Home one.

If there was an upgrade to the app in the future, it could be possible to add a laser function to the ***menu button***, in case the user wanted to take a picture pointing at some point of the model, for example.

The ***grip buttons*** are not really used in most the apps because they are not placed in a comfortable way and the user has to move its hand to properly press them. Despite of this they could be used, for example, as the rotation function instead of the touchpad.

8.2.3. Menu

The design of the controller menu has been made in order to obtain the most user-friendly results achievable. With an arrangement of five options, the selections have been placed in a circular form where all the options are permanently visible in each sub-menu. The idea was to have a menu that was clear and intuitive but also that would not disturb the vision space of the scene, so it was attached to the left controller. This let the player have the menu inside or outside the camera range without having to turn it on or off when needed.

Figure 57 Controller's Main Menu

There is a total of 3 different menu setups available and they all have different interactions and options specifically designed to satisfy user's needs. The main state has **5 functions.**

8.2.3.1. Import

The first option of the main menu is the import manager. The aim of the project was to make a system that lets the user easily transform a DICOM image into a visible 3D object and watch it with the virtual reality kit. So, the import system has been made to fasten as much as possible this process and let the users have a quick method to plan their incoming sessions.

To work this out, an easy naming system was made: the player has to save the *.obj* item that he wants to see in a specified folder and change its name to a number between 0 and 3, meaning this that it is possible to load 4 different objects in a single runtime mode. This function ins called "***Resources.Load"*** and is mainly for single or few object loads. For multiple imports there are other ways to import but this is the one that has the easiest procedure.

Figure 58 Import icon

This method lets non-professional users understand how to change the models they want to see without the need of and extensive tutorial that could still not ensure a proper use of the application.

In spite of these 4 possibilities, the system has been made so that only 1 of the models can be loaded at a time and each time a new object is charged, the last one disappears from the scene and is replaced by the selected one.

This function also selects the scale of the object to import as also its color and the position where it is going to be loaded.

8.2.3.2. Interactions

Rolling to the second option of the menu, there is the interactions submenu option. When selecting this option, 4 possible actions appear in the menu. As explained before, the objective was to make the application useful and easy, so the menu selections where reduced to 4 to keep it simple and efficient. Even though this was the first reason to place it this way, it is important to mention that some options were also dismissed because the quality of the models obtained could not give a real simulation of what it was representing. A particular case of this was the option of making a section out of the 3D model. Right now, the objects obtained from the transformation of the DICOM images do not give a proper model from the inside parts of the volume, so segmentation was just something that would not give useful results.

Figure 59 Interaction's icon

After discarding these options, the remaining ones that were selected as the most useful and important were: rotation, scaling, movement and screen capture. With the existing limitations, these four options could give the user a ready to use application for surgery planning or teaching methods with accurate models.

To make the user controls even more easy, the menu control was all kept within the left controller and the actions selected in the interactions menu are performed with the right controller. This separation avoids confusion and lets the player focus on each action without interacting between controllers and so making the gameplay easier.

Rotation

The main and most important interaction with the model was the ability to rotate it and see all its faces. This feature gives the user the option to incline the object in all the directions by using the ***right controller's touchpad***.

The rotation is set so the model can be turned 360º in all angles, so the player can first rotate the object in a determinate position and then use another action over it. The sensitivity of the touchpad lets the rotation to be faster or slower, depending on how far from the center the user is pressing the button.

Figure 60 Rotation icon

From the scripting part, there are many rotation methods in the Unity library. Depending on the system used, the object selected can rotate around the center scene pivot, a created alternative pivot or the local pivot of the object created when it is loaded. The last option was selected because it was the one that was more accurate and easy to use, also the one that gave the best results while performing the first tests. The name of the function used is "***transform.Rotate"*** and is one of the most used for single scene objects, when looking for an individual rotation of the model.

Scaling

Another implemented function to the game is the option to change the scale of the models loaded. Simply by pressing up or down in the ***right controller's touchpad*** the model will gradually change its scale to a bigger or smaller one.

The space in the room allows a big increase of the model if the user wanted to focus on a particular part of the model. This feature also has a position sensitivity but the speed in the tip of the touchpad has been set to a low grade to avoid undesired results or harder use of the action.

Figure 61 Scale icon

As well as the rotation function, the scaling has many options depending on how we want to change the volume of the object. It is also possible to change every axis in a different grade, but this would only deform the model and so give a bad impression of the model. Because of this the function used is "***transform.localScale"***, which gives the most common and expected results when thinking of it as a random user.

Movement

When making the list of interactions for the player, the movement was placed in a medium position. As told before, the dimensions of the room and the model are not really big so it is possible to use the application without the ability of shifting through the scene. Despite of this, after the first tries and tests of the game is was noticed that the sensation of immobility directs the user to try to move in real life. This can represent a problem since the headset is connected to the computer and, even though the cable is long, the experience could end in an accident.

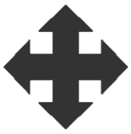


Figure 62 Movement icon

After making this hypothesis it was decided that the player needed a movement option so he/she could travel by the room and investigate or even watch the outlook from another perspective. The function also became more important when the app was tried in a different room. The position of the HTC sensors can change the place and first rotation of the player component so it is required that he/she has the ability to change its place and observe the scene from a proper spot.

Just like the two first interactions, the player movement is performed with the ***right controller's touchpad*** simply by pressing to the direction where the user wants to go. It has to be mentioned that this option does not let the user to rotate the headset position, so he/she has to turn around in reality to watch to one side or another. The function used for this action is "***transform.position".***

Screen Capture

The last added feature is the screen capture. This one is thought as a tool to keep some important information to use outside the game. If the user wants to focus on a particular part of the model and, for example, wants to share it with some of his companions or analyze it, he can take a picture of the screen he is watching at the moment.

To take a screenshot the player has to go to the camera option and then simply press de ***left controller's trigger***, just like if he/she wanted to select one of the other actions. The screen capture will then be saved in a specific folder inside the project and will be available to be watched and edited as any other picture.

Figure 63 Screen Capture icon

8.2.3.3. Language selection

To make the app a little more user-friendly it has been added the option to change the language of the game. Meaning this that the guide and options menu, as well as the indicator of the option selected can be displayed in three different languages: English, Spanish and Catalan.

When the game starts in English by default. If the user presses the language icon, it changes to Spanish. A second press turns into Catalan and another one starts again at English.

8.2.3.4. Controls

Things had to be clear at any part of the game for the player. An instructions screen has been added to the main menu so the user can check the manual at any time. When selecting this option, a screen appears in front of the camera, following it, with the instructions on how to use the controllers and what does every button.

Figure 65 Options icon

The game itself has been made to be easy to understand but for new users it is required that the player has a place to see how to play the application.

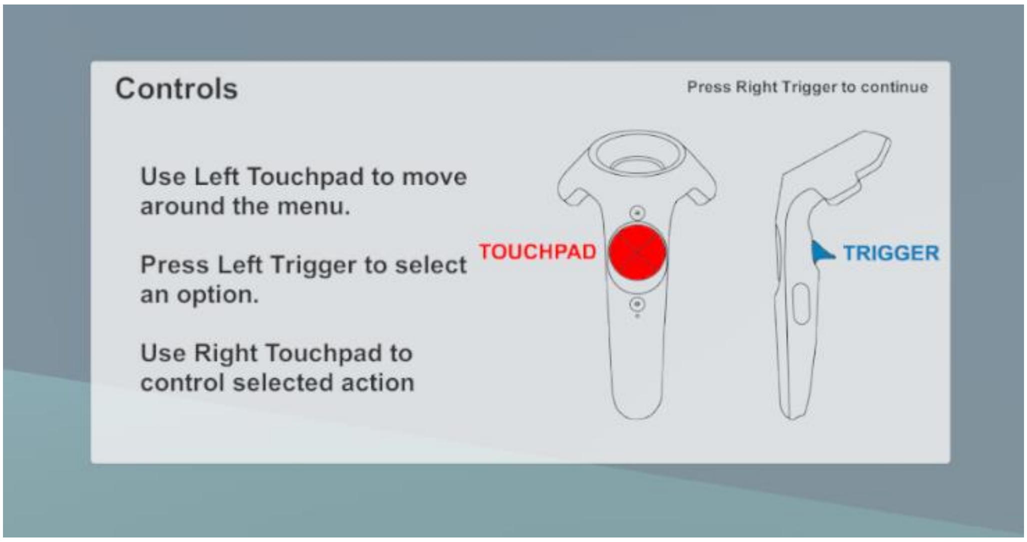


Figure 64 Controls menu

8.2.3.5. Game guide

Finally, to make sure that the player does know how to make the app work, it has been set a game guide inside the game. This *selectable* also pops out a screen in front of the headset, but now it is written the instructions on how to play the game.

The resolution obtained from the text in the corners of the headset is highly decreased as the vision moves towards the edges. This represented a problem when trying to make a big screen for the user to be easy to be seen, so finally the decision has been to make a short and precise guide, with only the necessary information to help the player get started.

Figure 66 Guide icon

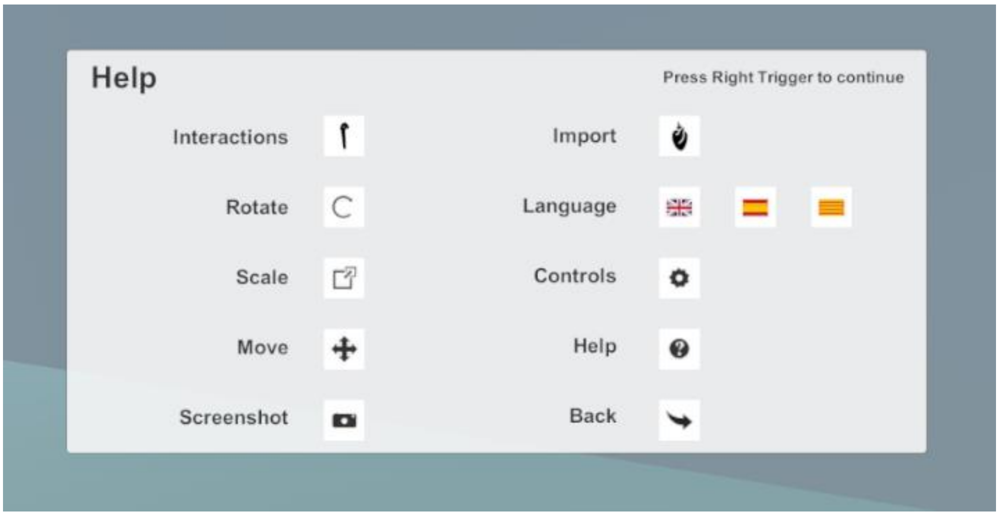


Figure 67 Guide menu

For first timers, it has been set that when the app is started, this screen automatically appears in the scene and avoids confusion when playing for the first time or after a long time.

8.2.3.6. The back button

Only inside the two submenus from import and interactions it exists a back button, which turns the user back to the main menu and lets him/her get to another option. With this feature, the other free buttons are kept open for new possible actions.

Figure 68 Back button icon

8.3. How to use

In this section there will be a quick guide on how to use the application.

8.3.1. Preparation

To start playing, first it is needed to prepare the headset and controllers, and make sure that they are working inside the sensors space.

Also before entering the program, the user has to pick the 3D models that will be able to load inside the game and put them inside the "Resources" folder inside the game project.

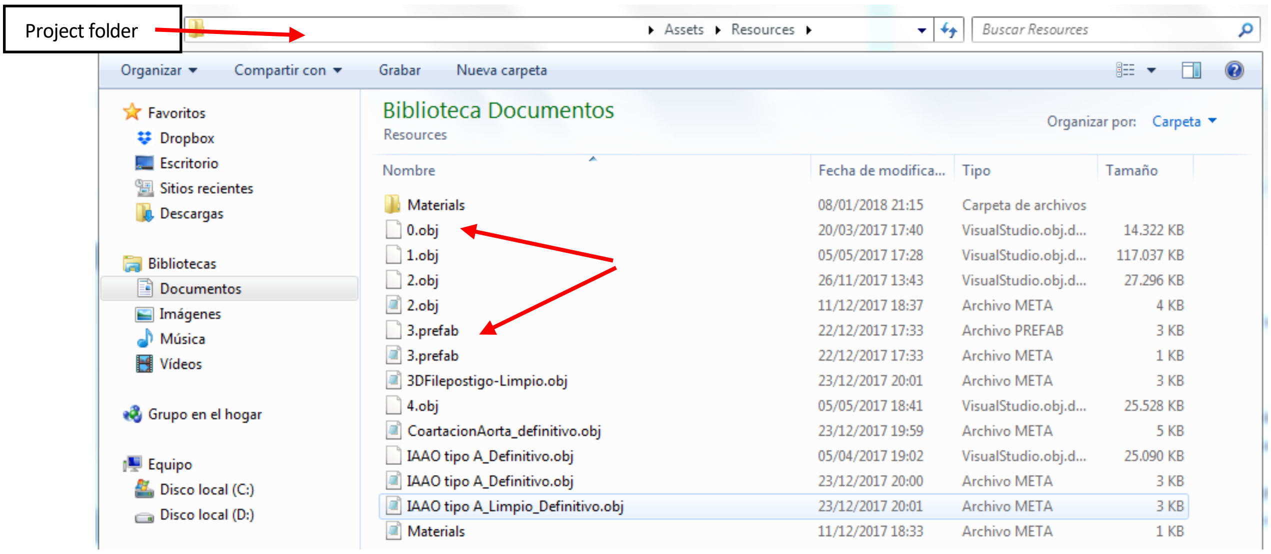


Figure 69 Representation of object saving

To load models in-game, it is required to change its names to numbers between 0 to 4, in case the user wants to charge many objects together.

8.3.2. Game Start

When the game starts, the "Controls" screen appears in front of the headset. This is a function introduced for new users. In case the player has not read or heard the instructions before starting the application, this screen will help to start using it.

To close this window, the user has to press the ***trigger*** on the ***right controller***. It is still possible to reach it at any time inside the game, by going to the controls cube and pressing the ***left controller's trigger.***

8.3.3. Model import

The idea of the application is to interact with the loaded model, so before this happens, it is not possible to interact with any object inside the room, but the ability to move around the space can be enabled at any time.

So, to start interacting, the user has to press the ***left controller's trigger*** when over the Import menu, and then select one of the available options. After doing this, a model will be loaded in the center of the room and it will be possible to interact with it.

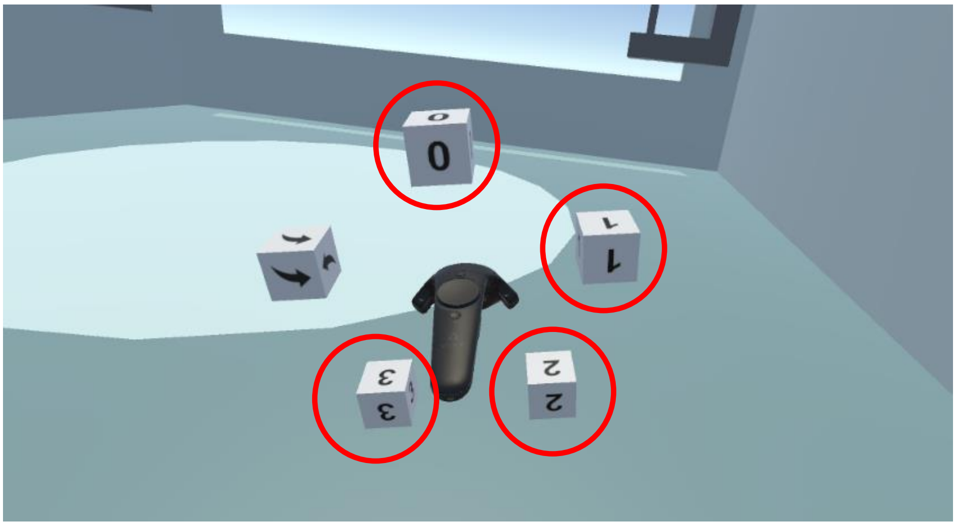


Figure 70 Import menu. Each cube matches the model named with the same number

For example, if model 2 was selected in this version:

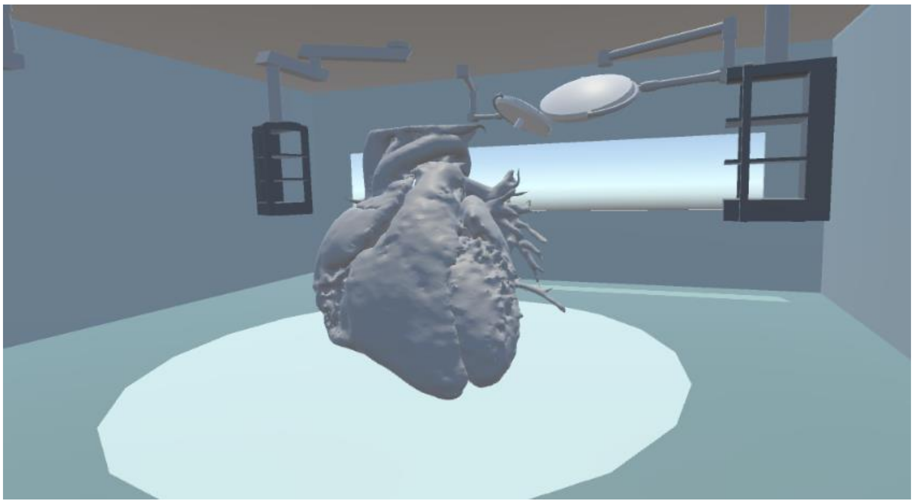


Figure 86 Loaded heart in the centre of the room

8.3.4. Use Interactions

The selected interaction by default is rotation, but it is possible to enter the interactions menu to change the option. The main ones: rotation, scale and player movement are all performed with the ***right controller's touchpad*** input.

Figure 94 Interactions menu

It is possible to rotate the objects in 360º depending on the axis touched in the controller.

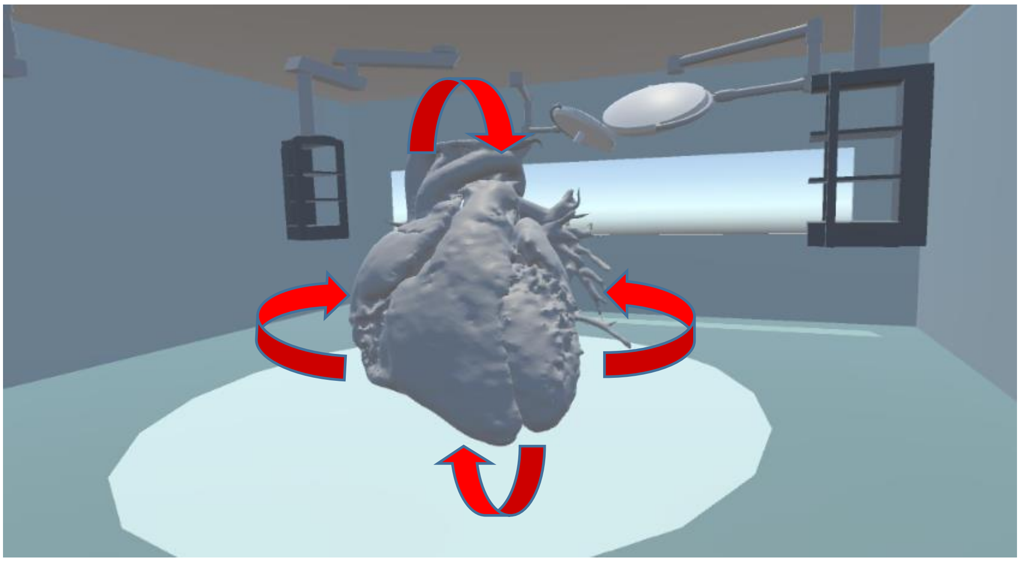


Figure 110 Available model rotation

The scale and rotation options are regulated with a sensitivity input that enables the user to perform actions faster or slower depending on its preferences.

Finally, to provide the sensation of freedom, the user can activate the movement option. This can also be useful to later take a picture from a better angle or just see the model from another perspective, just like it was in real life.

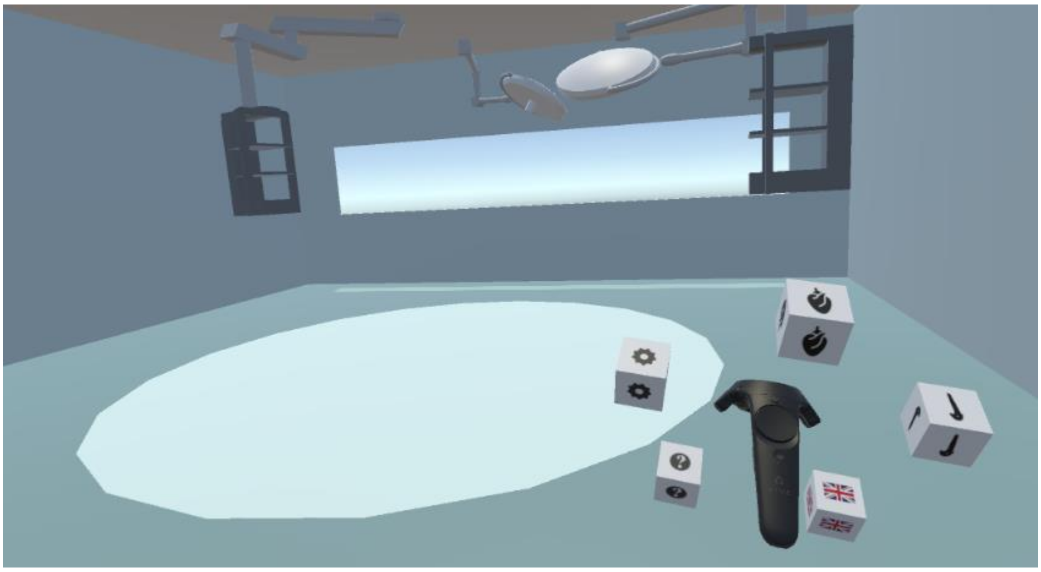


Figure 118 Player vision inside the game

CONCLUTIONS

During the development of the project and now, once finished, we can confirm that the initial proposed goals have been accomplished. Next, the conclusions which show the achievement of these goals will be exposed:

- To create an application that gives the ability to load 3D models of hearts and interact with them inside a virtual space.

  We have accomplished the creation of a virtual reality application which allows to import 3D models and interact with them in an attractive and intuitive way.

- To find an optimal way to make 3D models by using DICOM images from the hospital. Get high resolution models to make the experience inside the virtual world more realistic.

  It has been optimized with respect to the previous related projects, the hearts segmentation and its reconstruction to 3D models with a new software, and a method explained in this Bachelor Thesis which stands out for its rapidity and accuracy, the results are highly good and they bring the sensation of immersion to the user and improve comparisons with real objects. The hearts reconstructed still need to be cleaned and smoothed after their segmentation but it has been possible to find a faster way than the one proposed in the beginning.

- To find an optimal system to load images to the Virtual Reality application. Making an effective path for users to take an image and charge see and interact with it in 3D.

  One of the improvements we are most proud of is to have accomplished the importing method of the 3D models inside the application. The doctor will only need to copy the wanted object inside a folder and it will appear directly inside the virtual reality. A simple process which does not require programming knowledge as it had been necessary until now, and which optimizes to the maximum the time between the reconstruction of the 3D model and the application usage.

- To make the application intuitive and easy-to-use. It needs the required interactions to function and each element of distraction alters the functionality of the project.

The result has been the creation of a Virtual Reality app which allows an attractive and intuitive interaction, thanks to an immersive and realistic experience where a series of guides and helping tools allow to have a simple, comfortable and productive experience.

Although we have focused on congenital heart diseases, we must mention that the application could be assigned not only to the cardiac surgery planning, but also to other medical specialities. This is possible if the 3D initial model is correct and it is well segmented, obviously.

As engineers we have learned how to make a study of different technologies and software, and from some criteria choose those that best suit the needs of the project. We have managed to work in group and know how to choose the most optimal solution for each problem taking into account the contributions of both members.

Finally, to work in an organized and coordinated way among students, tutors, doctors and the people responsible of VISYON.

BUDGET

In this section, the costs associated with the development of the project are presented. To calculate the budget, it has been taken into account that the project started on 09/13/2017 and ended on 01/08/2018, which corresponds to 75 days of work.

The direct costs (personnel and equipment) and indirect costs (facilities and telecommunications) associated with the project have been calculated below:

Direct Costs

Personnel and Social Security contribution:

The calculation of the cost of personnel has been made taking into account that this project has been carried out by two people. It has also taken into account a full-time job of 8 hours a day for 75 days that include: Previous documentation and learning, Application architecture design, Development of design specifications, Programming code with C # to Unity, Writing the thesis and other documents.

Which corresponds to a total of 600 hours spent by each student.

Position	Nº of personnel	Time (h)	Cost per hour (€/h)	Cost (€)
Engineers	2	600	30	36.000
			TOTAL PERSONNEL COST	**36.000€**

For the calculation of Social Security costs, 23.6% of the contribution base was taken. According to the salary of the staff, the cost of Social Security associated with the two workers is:

36.000€ x 0.236 = **8496€**

Hardware/ Software:

In this section we have taken into account the hardware and software used during the development of the project. It has been considered that the cost associated with the computers and the HTC Vive are fully amortized in this project, since it is not expected to be reused in other applications.

Hardware/ Software	Quantity	Cost per unit (€/un.)	Cost (€)
Computer	1	1500	1500
HTC Vive	1	699	699
Unity3D	2	FREE	0
Blender	1	FREE	0
OsiriX / Mimics	1	728	728
		TOTAL HARDWARE / SOFTWARE COST	**2927€**

Indirect Costs

Facilities:

The rent of an office and the expenses associated with the rent have been taken into account.

Concept	Time (month)	Cost per month (€/month)	Cost (€)
Rent	4	300	1200
Water	4	10	40
Electricity	4	30	120
Gas	4	20	80
		TOTAL FACILITIES COST	**1440€**

Telecommunications:

In this section, the expenses of telecommunication have had to be paid, corresponding to the hiring of the internet connection.

Concept	Time (month)	Cost per month (€/month)	Cost (€)
Internet	4	50	200
		TOTAL TELECOMMUNICATIONS COST	**200€**

Total Cost

Direct Costs	
Personnel	36000 €
SS	8496 €
Hardware/ Software	2927 €
Total Direct Costs	**47.423 €**
Indirect Costs	
Facilities	1.440 €
Telecommunications	200 €
Total Indirect Costs	**1.640 €**
TOTAL PROJECT COST	**49.063€**

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ANNEX A: SCRIPTS USED

In this section there will be the scripts assembled for this project.

A1. ControllerFunctions

```
// ControllerFunctions
using DG.Tweening;
using System;
using UnityEngine;
using Valve.VR;

public class ControllerFunctions : MonoBehaviour
{
    public enum Menus {    MenuPrincipal, MenuInteracciones, MenuI
mport }
    public enum Language { English, Spanish, Catalan }

    private SteamVR_Controller.Device device1;
    private SteamVR_Controller.Device device2;
    public SteamVR_TrackedObject rightController;
    public SteamVR_TrackedObject leftController;

    public GameObject player;
    public GameObject Controls;
    public GameObject Guide;

    public Menus menu = Menus.MenuPrincipal;
    public Language lang = Language.English;

    public Transform menuTransformPrincipal;
    public Transform menuTransformInteractions;
    public Transform menuTransformImport;

    public int menuStep = 0;
```

```
    public int menuInteractionStep = 0;
    public int menuImportStep = 0;
    private int allpositions = 5;

    private float sensitivityscale = 0.00025f;
    private float sensitivitymove = 0.025f;

    private Vector2 touchpad;

    private ImportManager import;
    private Screenshot screenshot;


    //Void to start the game
    private void Start()
    {
        device1 = SteamVR_Controller.Input((int)leftController.ind
ex);
        device2 = SteamVR_Controller.Input((int)rightController.in
dex);
        import = new ImportManager();
        screenshot = new Screenshot();
    }

    //Function Update() is called every frame
    void Update()
    {

        if (device1.GetPressUp(SteamVR_Controller.ButtonMask.Trigg
er)){
            OnClick();
        }

        if (device1.GetPressDown(SteamVR_Controller.ButtonMask.Tou
chpad))
        {
```

```
            touchpad = device1.GetAxis(EVRButtonId.k_EButton_Steam
VR_Touchpad);
            if (touchpad.x > 0.3f)
            {
                SetMenuPositionUp();
            }
            else if (touchpad.x < -0.3f)
            {
                SetMenuPositionDown();
            }
        }
        if (device2.GetPress(SteamVR_Controller.ButtonMask.Touchpa
d))
        {
            Debug.Log((object)"eee");
            touchpad = device2.GetAxis(EVRButtonId.k_EButton_Steam
VR_Touchpad);
            GetRightPadTouch();
        }
    }

    //Called when player presses right controller's touchpad
    //All the interactions with the right controller and the heart
 are placed here so its easier to control each variable
    public void GetRightPadTouch()
    {
        GameObject val = GameObject.Find("Cor");
        switch (menuInteractionStep) {
            case 0:
                if (touchpad.y > 0.3f || touchpad.y < -0.3f) {
                val.transform.Rotate(touchpad.y, 0, 0);
                }
                if (touchpad.x > 0.3f || touchpad.x < -0.3f) {
                val.transform.Rotate (0, touchpad.x, 0);
                }
                break;
```

```
            case 1:
                if (touchpad.y > 0.3f || touchpad.y < -0.3f) {
                val.transform.localScale += new Vector3(touchpad.y
 * sensitivityscale, touchpad.y * sensitivityscale, touchpad.y * s
ensitivityscale);
                }
                break;
            case 2:
                if (touchpad.x > 0.3f || touchpad.x < -0.3f) {
                player.transform.position += new Vector3(touchpad.
y * sensitivitymove, 0, 0);
                }
                if (touchpad.y > 0.3f || touchpad.y < -0.3f) {
                player.transform.position -
= new Vector3(0, 0, touchpad.x * sensitivitymove);
                }
                break;

        }
    }

    //Void to count menu position when going up. Includes all thre
e menus
    public void SetMenuPositionUp()
    {

        switch (menu)
        {
        case Menus.MenuPrincipal:
            menuStep += 1;
            menuStep = ((menuStep <= 4) ? menuStep : 0);
            ShortcutExtensions.DOKill (menuTransformPrincipal, fal
se);
            ShortcutExtensions.DOLocalRotate (menuTransformPrincip
al, new Vector3 (0f, 0f, (float)menuStep * 1f / (float)allposition
s * 360f), 0.5f, 0);
```

```
                break;
            case Menus.MenuInteracciones:
                menuInteractionStep +=1 ;
                menuInteractionStep = ((menuInteractionStep <= 4) ? me
nuInteractionStep : 0);
                ShortcutExtensions.DOKill(menuTransformInteractions, f
alse);
                ShortcutExtensions.DOLocalRotate(menuTransformInteract
ions, new Vector3(0f, 0f, (float) menuInteractionStep * 1f / (floa
t) allpositions * 360f), 0.5f, 0);
                break;
            case Menus.MenuImport:
                menuImportStep +=1;
                menuImportStep = ((menuImportStep <= 4) ? menuImportSt
ep : 0);
                ShortcutExtensions.DOKill(menuTransformImport, false);
                ShortcutExtensions.DOLocalRotate(menuTransformImport,
new Vector3(0f, 0f, (float)menuImportStep * 1f / (float)allpositio
ns * 360f), 0.5f, 0);
                break;
        }
    }

    //Void to count menu position when going down. Includes all th
ree menus
    public void SetMenuPositionDown()
    {
        switch (menu)
        {
        case Menus.MenuPrincipal:
            menuStep += -1;
            menuStep = ((menuStep >= 0) ? menuStep : (allpositions
 - 1));
            ShortcutExtensions.DOKill(menuTransformPrincipal, fals
e);
            ShortcutExtensions.DOLocalRotate(menuTransformPrincipa
```

```
l, new Vector3(0f, 0f, (float)menuStep * 1f / (float)allpositions
* 360f), 0.5f, 0);
                break;
            case Menus.MenuInteracciones:
                menuInteractionStep += -1;
                menuInteractionStep = ((menuInteractionStep >= 0) ? me
nuInteractionStep : (allpositions - 1));
                ShortcutExtensions.DOKill(menuTransformInteractions, f
alse);
                ShortcutExtensions.DOLocalRotate(menuTransformInteract
ions, new Vector3(0f, 0f, (float)menuInteractionStep * 1f / (float
)allpositions * 360f), 0.5f, 0);
                break;
            case Menus.MenuImport:
                menuImportStep += -1;
                menuImportStep = ((menuImportStep >= 0) ? menuImportSt
ep : (allpositions - 1));
                ShortcutExtensions.DOKill(menuTransformImport, false);
                ShortcutExtensions.DOLocalRotate(menuTransformImport,
new Vector3(0f, 0f, (float)menuImportStep * 1f / (float)allpositio
ns * 360f), 0.5f, 0);
                break;
        }
    }


    //Void called when player presses the left controller trigger
    private void OnClick()
    {
        switch (menu)
        {

        //Switch step inside main menu. All the functions in this
one need the trigger to be called
        case Menus.MenuPrincipal:
            {
```

```
        int num2 = menuStep;
        if (num2 == 1)
        {
            GoToInteractions();
        }
        if (num2 == 0)
        {
            GoToImport();
        }
        if (num2 == 2)
        {
            LangChange ();
        }
        if (num2 == 3)
            {
                if (!Guide)
                {
                    Guide.SetActive(true);
                }else
                {
                    Guide.SetActive(false);
                }
            }
            if (num2 == 4)
            {
                if (!Controls)
                {
                    Controls.SetActive(true);
                }else
                {
                    Controls.SetActive(false);
                }
            }
        break;
    }
```

```
            //Switch step for interactions selectables. Capture sc
reen and back functions need trigger press to be called
        case Menus.MenuInteracciones:
            {
                int num = menuInteractionStep;
                if (num == 3)
                {
                    screenshot.Capture();
                }
                if (num == 4)
                {
                    GoFromInteractionToPrincipal();
                }
                break;
            }

            //Switch step for import menu. A model will be loaded
depending on the number selected
        case Menus.MenuImport:
            {
                int num3 = menuImportStep;
                    if (num3 ==0)
                    {
                        import.UnloadHeart();
                        import.Import("0");
                    }
                    if (num3 ==1)
                        {
                        import.UnloadHeart();
                        import.Import("1");
                    }
                    if (num3 == 2)
                    {
                        import.UnloadHeart();
                        import.Import("2");
                    }
```

```
                    if (num3 == 3)
                    {
                        import.UnloadHeart();
                        import.Import("3");
                    }
                    if (num3 == 4)
                {
                    GoFromImportToPrincipal();
                }
                break;
            }
        }
    }

    // Void reaction after pressing interactions selectable
    private void GoToInteractions()
    {
        menuTransformPrincipal.DOScale (Vector3.zero, 0.3f);
        menuTransformPrincipal.gameObject.SetActive (false);
        menuTransformInteractions.gameObject.SetActive (true);
        ShortcutExtensions.DOScale(menuTransformInteractions, Vect
or3.one*(0.05f), 0.3f);
        menu = Menus.MenuInteracciones;

    }

    // Void reaction after pressing import selectable
    private void GoToImport()
    {
        ShortcutExtensions.DOScale (menuTransformPrincipal, Vector
3.zero, 0.3f);
        menuTransformPrincipal.gameObject.SetActive (false);
        menuTransformImport.gameObject.SetActive (true);
        ShortcutExtensions.DOScale(menuTransformImport, Vector3.on
e*(0.05f), 0.3f);
        menu = Menus.MenuImport;
```

```
    }

    // Void reaction after pressing back button from interaction m
enu
    private void GoFromInteractionToPrincipal()
    {
        ShortcutExtensions.DOScale(menuTransformInteractions, Vect
or3.zero, 0.3f);
        menuTransformInteractions.gameObject.SetActive (false);
        menuTransformPrincipal.gameObject.SetActive (true);
        ShortcutExtensions.DOScale(menuTransformPrincipal, Vector3
.one*(0.05f), 0.3f);
        menuInteractionStep = 0;
        menu = Menus.MenuPrincipal;

    }

    // Void reaction after pressing back button from import menu
    private void GoFromImportToPrincipal()
    {
        ShortcutExtensions.DOScale(menuTransformImport, Vector3.ze
ro, 0.3f);
        menuTransformImport.gameObject.SetActive (false);
        menuTransformPrincipal.gameObject.SetActive (true);
        ShortcutExtensions.DOScale(menuTransformPrincipal, Vector3
.one*(0.05f), 0.3f);
        menuImportStep = 0;
        menu = Menus.MenuPrincipal;
    }
    // Void made to change the language enum. Called when language
 option is selected
    private void LangChange()
    {
        if (lang = Language.English){
            lang = Language.Spanish;
```

```
        }else if (lang = Language.Spanish){
            lang = Language.Catalan;
        }else{
            lang = Language.English;
        }
    }
}
```

A2. ImportManager

```
using UnityEngine;
using System.Collections;
using Valve.VR;

public class ImportManager : MonoBehaviour
{
    public Material Cor;

    //Function called to load the object
    //The string "cor" has to be a number between 0 and 4 so the m
odels can be loaded and so there can be interaction
    public void Import (string cor)
    {
            GameObject obj = Resources.Load(cor) as GameObject;
            GameObject clone = Instantiate(obj, new Vector3(4, 2,
-4), Quaternion.identity);
            clone.transform.localScale = Vector3.one * 0.025f;
            clone.name = "Cor";
            clone.GetComponent<Renderer>().material = Cor;
    }

    //Destroys the loaded heart so a new one can be charged
    public void UnloadHeart()
    {
        GameObject cor = GameObject.Find ("Cor");
        Destroy (cor);
```

```
    }
//
}
```

A3. Screenshot

```
using UnityEngine;
using System.Collections;
using System.IO;

public class Screenshot : MonoBehaviour {
    Texture2D screenCap;
    Texture2D border;
    bool shot = false;

    public SteamVR_Controller.Device device;
    public SteamVR_TrackedObject controller;

    // Use this for initialization
    void Start () {
        screenCap = new Texture2D(845, 460, TextureFormat.RGB24, f
alse); // 1
        border = new Texture2D(2, 2, TextureFormat.ARGB32, false);
 // 2
        border.Apply();

        controller = gameObject.GetComponent<SteamVR_TrackedObject
>();

    }

    // Update is called once per frame
    void Update () {

        device = SteamVR_Controller.Input((int)controller.index);
        if (device.GetPressDown(SteamVR_Controller.ButtonMask.Trig
ger)) {
            StartCoroutine("Capture");
            Capture();
        }
```

```
    }

    public void OnGUI(){
        //GUI.DrawTexture(new Rect(2, 0, 850, 2), border, ScaleMod
e.StretchToFill); // top
        //GUI.DrawTexture(new Rect(2, 470, 850, 2), border, ScaleM
ode.StretchToFill); // bottom
        //GUI.DrawTexture(new Rect(0, 0, 2, 470), border, ScaleMod
e.StretchToFill); // left
        //GUI.DrawTexture(new Rect(840, 0, 2, 470), border, ScaleM
ode.StretchToFill); // right

        //Puts a small capture of the screenshot in the top left o
f the screen for preview
        if(shot)
        {
            GUI.DrawTexture(new Rect(10, 10, 60, 40), screenCap, S
caleMode.StretchToFill);
        }
    }

    //Void to select area of the screen to be captured and where t
o be saved
    public IEnumerator Capture(){
        yield return new WaitForEndOfFrame();
        screenCap.ReadPixels(new Rect(0, 0, 845, 840), 0, 0);
        screenCap.Apply();

        // Encode texture into PNG
        byte[] bytes = screenCap.EncodeToPNG();
//        Object.Destroy(screenCap);

        // For testing purposes, also write to a file in the proje
ct folder
        File.WriteAllBytes(Application.dataPath + "/SavedScreen.pn
g", bytes);
```

```
        //If the photo has been taken, it can be shown in the top
left border
        shot = true;
    }
}
```