Virtual Restoration of a XVIII Century Sculpture

Francisco Gaitto Pereira
Jorgelina Carballo Martínez
Ana Bidarra Lourenço
CITAR: Research Centre for Science and
Technology of the Arts,
Universidade Católica Portuguesa

ABSTRACT

The dawn of computer data visualization launched a permanent challenge the representation of objects with computers. Nowadays we expect to see and experience not just a mere representation of objects but realistic objects created by computers.

This work is an ongoing experiment to demonstrate how we sought to represent artistic objects, rebuild and enhance their visual appearance, and reconstruct missing physical parts using of Computer Graphic tools. This multidisciplinary effort enables us to experience virtual artistic objects and makes them available for uncontrolled and unprepared 3d environments like classrooms, museums, or wherever we intend to easily share digital contents.

1 | Introduction

This experiment became possible since the School of Arts of the Portuguese Catholic University integrates several multidisciplinary art departments. This work is the result of a joint effort by the Departments of Sound and Image and Art Restoration, which worked together in the Research Department of the School of Arts "CITAR" (Centro de Investigação em Ciência e Tecnologia e Artes).

This multidisciplinary project started in the Restoration Department.

3rd grade students of the Restoration department carefully handled a sculpture throughout the restoration process in order to stabilize it and prevent extra degradation. . They were supervised by restoration teachers specialized in the chemistry and wood sculpture art areas.

The sculpture revealing a very high level of deterioration was stabilized. Nevertheless, it continued to present itself as a very fragile wood support.

The weakened wood support was a major drawback in the manipulation of the physical sculpture since manipulating it meant some possible damage to the sensitive parts. This important circumstance for the restoration department was taken into consideration when the first analysis to start the digital reconstruction was carried out.

By the end of the restoration process, several parts were still missing. That fact made it difficult to read the sculpture as a global art piece. One of these parts was the head. Half the face was missing.

The reconstruction of the face revealed to be one of the most important challenges for both the restoration department and the digital rebuilding project as it was impossible to ensure the true features of the destroyed face.

Since the weakened support and the full extent of the damage didn't allow a full chromatic restoration, the chromatic coating was also left unfinished. [1]

2 | Background

This work starts with an 18th century polychrome wood sculpture of a Crucified Christ.

This sculpture suffered severe termite damage. It was exhibited and used as a religious object. The preservation conditions of the building also promoted an accelerated degradation of the sculpture, so several parts were damaged and lost over time.

One of the most important missing parts is in the face since only half of it is presented. Moreover, problems associated to the weakened wood support promoted extra damage to the internal structure, especially to the joint parts of the arms, cross, white wrapping cloth...

The risk of polychromic exfoliation resulting from the weakened wood support was a severe determinant and avoided comfortable manipulation of the sculpture or even prohibited it.

This work is a step forward from the approach to the rebuilding of art objects or rooms that the depart-

1 | complete sculpture before physical conservation treatment. Original assembly on the (right), disassembled elements (left)

ment started some time ago.

In previous research projects, such as "the Rebuilding of the 16th century OPorto Cathedral", the major concern was to allow the results of the experiment over solid spread multimedia tools. Here, inside this cathedral, the user can experience time traveling through a set of panoramic pictures (taken from 3D computer models) of either sequential or multiple-choice paths. One of its main goals was making it user friendly. What also determined this experiment was the search for reliable, believable, photo realistic images. Still rendered images of the 3D model of the rebuilt cathedral were used instead of state of the art 3D real-time rendered images.

The 16th century wood sculpture of the Crucified Christ takes over the rebuilding concept of the Cathedral. By stepping from the sense of presence in space to the manipulation of the object, a change in paradigm takes place. The user is no longer the center of the image-percept. The large-scale data manipulation of 3D models is no longer a determining concern.

This project was developed so that The Virtual Sculpture could be easily manipulated. All development stages could be experienced through web multimedia tools, Java 3D for viewing real time 3D models.

3 | Related Digital Representation Work

The type of approach using photographs releases the need for high-end registration technology.

Several reconstruction projects with parallel subjects have been developed for some time. However, the process of using photographs is a common issue when producing digital surrogates.

Reference work presented relay on images for different purposes either as a guide for modeling or to be used directly to make models or even as single data storage. Therefore, it is important to understand the nature of digital representations in order to establish levels of contribution to different subject areas. This level of establishment relates either to collect or to the end results If the type of artwork conditions are of digital recording [2].

Today, defining a purpose for the digital representation will free us from the need of a single and unique digital recording process.

Next we present several projects developed to represent distinct artwork peaces in their size and complexity: In 1997, using range finder technology, a team from Stanford University developed a method to digitize accurately shapes and surfaces from physical objects [3].

Their goal of scanning Sculptures and Architecture of Michael Angelo and make them available to scholars worldwide was developed until 2004. The challenge

of scanning of large dimension sculptures resulted in complementary use of mechanical instruments of tracking for assembling the several scanned parts. Scanning of large objects or spaces usually means large amount of recorded data.

Ponte de Lima 3D

This project explored the possibility of visualization and navigation in a large-scale polygonal model of the historic area of Ponte de Lima and the destroyed 14th century Wall. For this purpose an efficient render engine was produced which was capable of easily handling over a million polygons on a common pc. Additionally, highly optimized and large-scale polygonal models of the village and of the Wall were also produced.

The result is the possibility to explore the historic space of the existent village, the evaluation of floods and navigation in the destroyed 14th century Wall, its towers and defensive entries on the complex.

The type of rebuilding work was based on artistic interpretation of collected elements and the modeling was mainly a skill task to produce an optimized geometry suited to the powerful render engine [4].

16th Cent. Cathedral

This project produced a model of the Cathedral as it was originally in the 16th century.

One of the main goals of this type of navigation, which freed modeling from optimization constrains, was photorealistic image. Nevertheless, man skilled tasks led to the production of the project, from data interpretation to modeling the building and the surrounding spaces.

Despite the speculative project for recreating hypothetical spaces, the type of images produced was always meant to be as realistic as possible and to be used on intuitive largely spread multimedia tools such as panoramic images [5].

CHI in Foz Côa

Cultural Heritage Imaging is a foundation dedicated to register digital data of the world cultural resources on sharing technology. Their current approach is widely based on digital photographs as a way to register permanent data with scientific purposes. .

The processed results allow a clear viewing and identification of the engraved images. [6]

The digital photographs of pre-historic images existent on Foz Côa resulted in a project which allowed not only a clear viewing of those images but also the existence of a permanent digital data (where those same photos are stored) whose scientific worth is considerably high. If we use Polynomial Texture Maps [7], the resulting images can show the engravings under different lighting conditions. The manipulation of the virtual light source produces a strong feeling of reality of an object over a static digital image.

Polynomial Texture Maps

 The use of Polynomial Texture Maps [8] makes photographs go beyond conventional image data. PTM can register more than the common color values. It can also register functions of two independent parameters that define R, G, B per pixel.

The result of this process can be of great importance since the possibility of real time image manipulation increases the degree of perception from a static image. PTM have been used as a scientific approach to registering data from objects and light source in known experiments.

Reflection Infromation Imaging (RTI)

Reflection Information Imaging is a process of storing surface reflection information for each pixel of an image. This process makes it possible to produce an image with the reflectance information that builds the perception of the shape of the objects.

To produce an RTI image several photographs with different known light sources of a scene or object are needed [9]. These images are then synthesized in an RTI image.

This type of data allows manipulating the lighting on a photograph of an object.

Since it is a process based on common photographs, the easiness of creation and the realistic results make RTI a solid approach to register and display several kinds of artistic and archeological objects.

4 | Development

The overall purpose was to evaluate the possibilities of registration, reconstruction and representation of relevant geometrical data.

This work was developed as an experiment and several goals were achieved as small projects: Data Collection and Image Visualization, Geometry Reconstruction and Art Object Representation.

The 3D Virtual reconstruction of the sculpture focuses on the visualization and manipulation of the virtual object as the center of experimental projects. A geometric platform was produced for this purpose.

Since our choice for visualization was using a 3D model of the sculpture and real-time render on the web browser, we required a low polygon model of the sculpture.

The intention of using this media support was to have a more flexible way of experimenting and viewing the work in progress until its completion and most of all to make it available for discussion to the multidisciplinary team.

While at the physical reconstruction stage, the digital
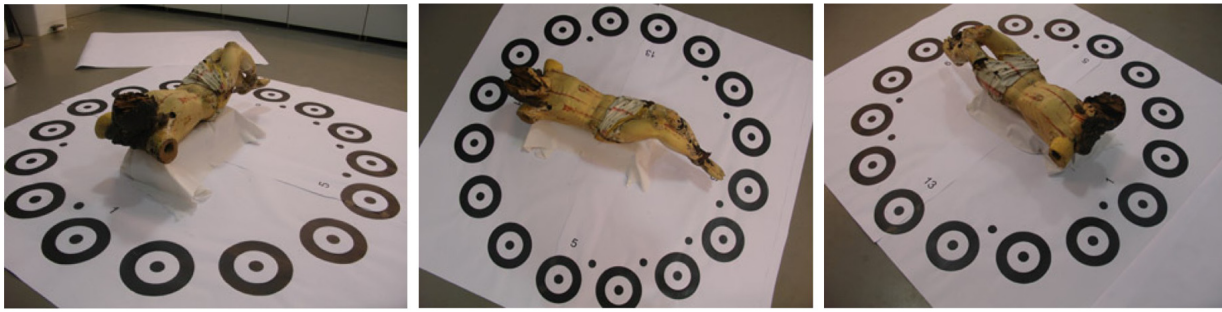
2 | sculpture over target background

project tried to identify the needs of the Restoration department and several different small projects were defined.

First of all, collecting data for different experiences determined the beginning of the digital project.

4.1 | Image Data
4.1.1 | Digitalization

Instead of modeling the sculpture it was considered the use of a scanner. Although modeling revealed itself to be a more controllable process for geometric optimization, it would be difficult for future models of the same sculpture to get the same level of detail and scale, making them less compatible.

The choice of a scanning method was then made. Only non-intrusive possibilities were considered: no probe contract or laser could be used. Structured light scanning by soft light image patterns would also be complex to use since the sculpture had a considerable dimension, about 1 meter high. Therefore, several small models were needed to make the entire sculpture model.

The option of a profile scanning method using multiple photographs revealed itself to be simple, accurate and affordable enough for our needs.

What made this scanning process time efficient was not the modelling process but the possibility of making more models to add the same level of detail and image tone to the main model keeping the scale. [10].

The scan was done using 42 images of the sculpture. A previously executed target base pattern was created to fit the complete sculpture to avoid the need for multiple models and stitching.

The target also allowed establishing a scanning scale for the main body and other parts of the sculpture, like arms, cross, etc.

After some experiments it was possible to make the final target since it was used as a chromatic background to easily extract the profile of the sculpture.

The target base pattern also made possible to identify the camera position and camera target so that the making of the scanned model can be later performed. The camera used was a SLR Sony DSC-W50.

All images were registered with ISO 200, F2,8 , 24 bit color set and 2816x2112 pixel.

The lighting was carefully controlled to get an artificial diffuse illumination and get as much light as possible (and free of shadows). The laboratory lighting was set with powerful projectors on a tripod pointing the ceiling. The position and type of projectors were registered for posterior scanning of other parts.

The D Sculptor 2.0 professional version, a profile scanning software, was also used to make the model. The final model resulted in carefully executed low polygon geometry with a 20877-triangle mesh, which allowed a comfortable resolution for our model. Image 4.

To view the resulting virtual sculpture, Java revealed itself to be very efficient at viewing real time 3D models and delivering believable images of the sculpture model onto the explorer's web browser.

4.1.2 | Texture Setup

The software used to assemble the geometry is able to deliver a full textured model. However, the created texture map is an abstract triangle patch image made from the original photographs, which were used to make the profiles for the model. This resulting texture map relates to a coordinate index to correctly map the geometry according to the triangle mesh.
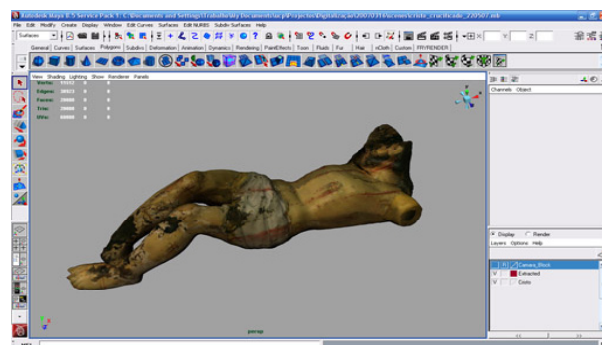
3 | scanned sculpture on the modeling software
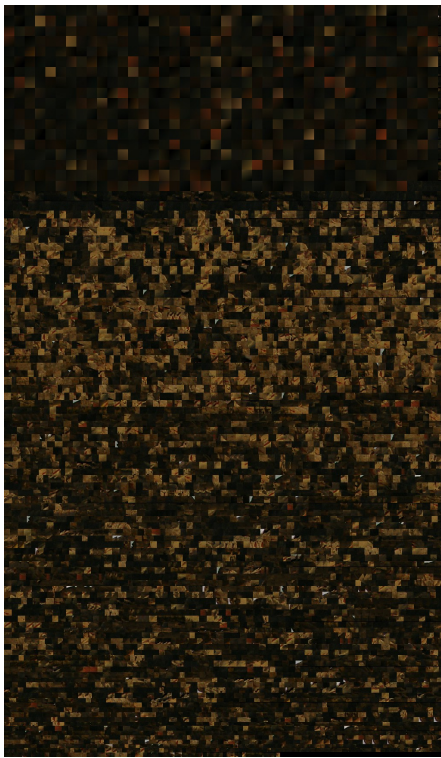
4 | original coating texture map

Since it was planned to work on the texture in order to rebuild it, the patch image and geometry needed to be rebuilt in order to get a workable coating texture map. This implicated a new projection of the texture map over the geometry (cylindrical or spherical). Although the texture image rebuilt by this process can be easily recognized, the kind of projection deforms the image to an impracticable working base.

The choice of making the texture-coating image and remapping it to the geometry base revealed a more efficient and precise image base.

The images were carefully chosen according to several references on the original photographs and monitored with a texture editor of the modeling software Maya.

The coating texture map was now a set of undistorted images, which were set on the related geometric areas with a planar projection.

Several images were selected and relevant body parts were identified.

The relevant parts on the body of the sculpture were the head, the torso, the wrap cloth and the legs.

The head was divided into three sides, front, left and right according to the gap on the face. This enabled us to get a clear definition of the remaining face and its expression. The torso was mainly relevant in the front (in the flatter and larger area of the chest); the side parts were selected to better define the painted damage.

The wrap cloth could also be divided into three

parts according to the painted blood and damaged wood.

Finally the legs could also be divided into several sections according mostly to the damaged paint and its position.

The result was precise and the selected areas of the undistorted texture image could now be worked on.

The image was assembled with the image editor software Photoshop, resulting on a base 2048x2048 jpg texture map with 1.395KB.

On the image editor, a mask was defined to clearly identify the parts and areas being used on the multiple planar projections in each photograph.

4.1.3 | Texture Rebuilding

The final geometric model had applied the new texture map on the modeling software. Since the mapping relates to UV coordinates in the geometry, replacing a texture map avoids re-projecting the new texture because the geometry coordinates keep the same information over on any replacement map, even on a scale change situation.

By using this process, it was possible to remake the texture and test it in real time in the geometry.

The first rebuilding experiment was to repair the photographed damages on the texture map. Since the photographs taken were as neutral as possible due to diffuse lighting   no shadows or uniform chromatic coating , the virtual restoration process was partly similar to a real one by digitally painting the areas with similar colors to the surroundings. The digital imaging process allowed to have several solu-
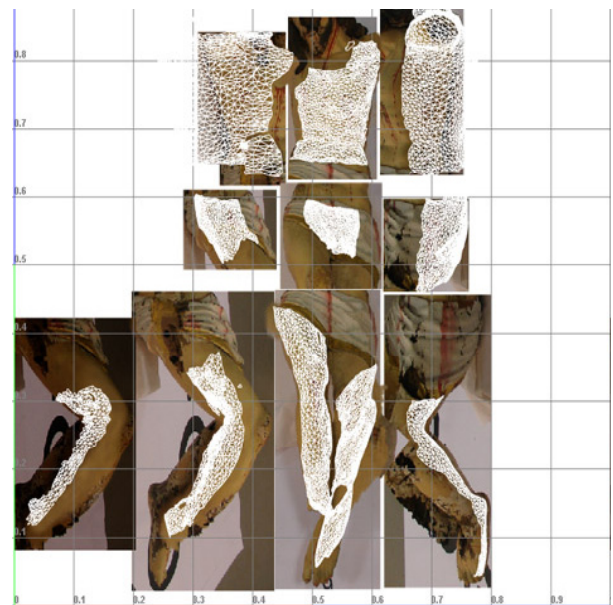
5 | coating texture map with related geometry

6 | restored coating texture map

tions and choose the one which best suited the area being virtually restored.

While testing the images, the geometric model was also used by simply replacing the base texture map with the new restored one. The illumination on the virtual sculpture helped to verify and choose the final restored solutions for the map.

The result was a set of possible maps for coating the geometry model and the possibility of identifying the areas changed by digital painting, allowing to visually assessing the extent of the damage on the sculpture. This information can be useful for real restoration since the results can be predicted in advance with comfortable reliability.

This process is also useful as a registration process of the assessment of the sculpture. It allows registering previous interventions, identifying and registering areas by different restorers, or proposed techniques. It can also be used in another context to register and assess degradation over time.

In future experiments we will explore the use of x-ray in the sculpture to register not only the sketching under the paint but also objects on the inside of the sculpture. Overlapping this kind of information in the virtual sculpture will allow to understand the construction process, wood sculpting and its painting.

5 | Geometry Rebuilding

The main goal of this stage was to assess the possibilities for both registration of virtual reconstruction and scanned geometry.

The solution to virtually rebuild the missing face of the sculpture allowed us to start a discussion on solutions that did not compromised the sculpture.

The purpose of this reconstruction was to carry out a complete replica of the sculpture. Therefore a plan was developed to make a wood replica from elements of the virtual model.

5.1 | Face Rebuilding

This work was developed with the aim of experimenting techniques in order to produce the missing part and integrate it on the base model.

The sculpture revealed serious damage on the face. The extension of the missing part was so severe that it left very few clues to complete the head of the sculpture.

The first experiment made consisted of using the elements on the face to get proportions and adopt an approach to the head.

On the modeling software some measurements were taken and several possibilities were experimented. From this first trial on the existent half head, the right side, we could conclude that we were dealing with an unsymmetrical face. Thus, it was now more difficult to understand how the missing half, the left side, might have been and reconstruct it.

5.2 | Studies and collecting references

Some signs of expression still found on the damaged face, along with the development of our work, gave us the subtlest clues although not enough to complete the head.

Since it was impossible to rebuild the missing part of the face according to the original head because there were no images available from the complete sculpture, it became essential to collect references from other sculptures from the same epoch.

The main problem was to get a sample sculpture with the same character on the level of the expression.

This sculpture is a particular case since the sculptures from the 16th century that got to our time were somehow different, either because of the carving or type of paintings or expression. Several others sculpted in stone got further away from our delicate wood sculpture, especially the ones in harder stones. However, one soft stone sculpture became of a relevant importance because of its similarity in size, its morphology and most of all its expression.

This sculpture found in the 11000 Virgins Chapel in the Saint Anthony's Monastery in Alcacer do Sal was the most relevant reference because of its dating (also from 16th century). It was accepted as a creation of an important artist named Francisco de Holanda.

Images collected from Holanda's sculpture gave us significant information about morphological face elements, the kind of nose and scale, the shape and placement of the eyebrows and the overall expres-

sion of pain and suffering on the face.

5.3| Redrawing the sculptures face

Since we realized that the missing part was different from the other side, we tried to draw what were the possible solutions for the face.

From the beginning it became very clear that the missing part conveyed most of the expression on the face. Small and delicate changes on the drawing made an enormous variation on the expression of the sculpture. The use of the existent elements together with the information from Holanda's sculpture made it possible to start assembling the mouth, eyebrow, nose and overall face.

To develop this stage, a frontier of the damage face was established using the virtual model. A render image was prepared with a 3Dcamera, created and set strategically at the normal angle of the missing area.

The resulting render image was edited and the missing area was removed and replaced with a white shape. In the end the image was printed; hand drawings were made on the white shape to complete the face surrounded with the photograph of the existent face and head.

The result was an image with lines for relevant expression elements and soft stains for volume information.

5.4 | Modeling the missing part

To start modeling the missing part we needed a reference that was produced with the hand drawing.

The drawing on the printed image was scanned and projected by the 3D camera at the normal angle of the missing area.

The virtual sculpture has now the drawing reference on the head and over the scanned geometry of the damage area. According to the new face, the frontier was trimmed and replaced by a new polygonal shape, which would be modelled and would complete the head's reconstruction.

Since the new flat polygon shape was a clear from any image, once again the scanned drawing was projected on the new frontier shape and the reference lines were then visible and modeling started.

Some few simple cuts were made on the flat polygon over the drawing lines. These few cuts allowed firstly the placing of elementary segments equivalent to the eye, mouth, nose and moustache. Then, more cuts were made to gradually increase the definition and to keep control of the model.

The modeling process was performed according to the direction of the projection, given the drawings projection along the normal of the damage geometry, therefore points on the flat polygon were pushed and pulled along the normal direction of

the projection.

Soft stains registered on the drawing, that helped to establish how high and deep the face elements modeling should go, controlled the amount of the deformation.

The result was a virtual sculpture with the rebuilt face according to the hand drawings. For a clear identification of the reconstructed area, a neutral grey coating was applied to the modeled geometry.

7 | drawing of the face of the sculpture

6 | Viewing the results

From the beginning the viewing of the results was determined by the use of widespread multimedia tools. However, the conclusion of the reconstruction emphasized the need for testing and verifying the work produced.

This verification experiment was developed using augmented reality concepts. Merging the virtual rebuilt geometry with the real-time captured video gave us the possibility of a better perception of our work on site.

There are several tools and platforms available for virtual and augmented reality. In our experiment we used the AR Tool kit [11].

There are several steps to consider to function with it: tracking of camera orientation and position. The identification of the camera position produces a virtual camera to render the virtual model. The rendered image of the model is overlapped with the streaming video image.

To try to visualize our model over the real sculpture, our geometry had some adjustments according to
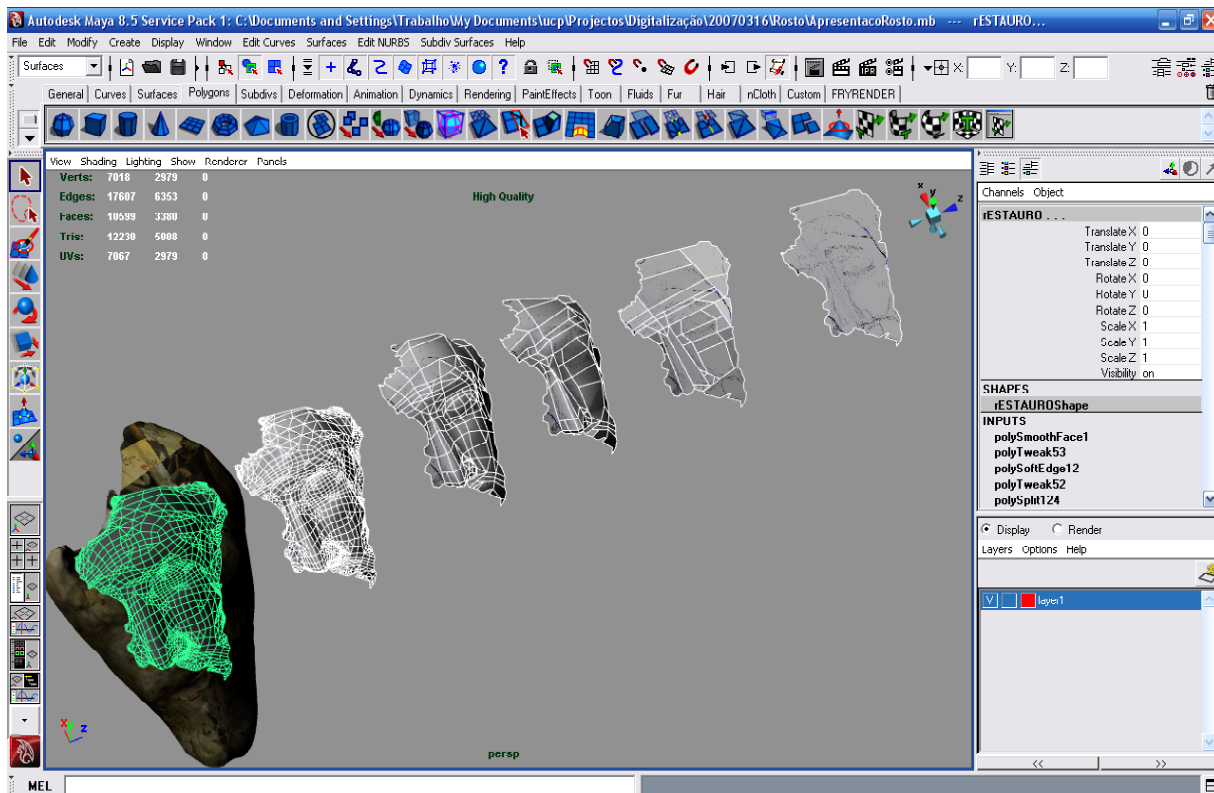
**8** | modeling stages with wire frame of the geometry
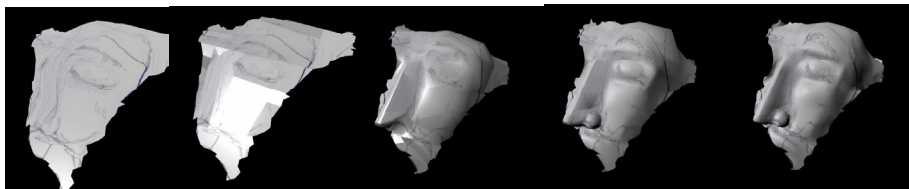
9 | modeling stages, (right to left) drawing on the flat polygon, element placing, smoothed geometry, increased detail and expression, final model.

the working needs of the AR Tool kit. For this augmented experience to succeed it was needed to set up the camera target marker. The marker was firstly placed in the missing area. However, some parts of the face caused occlusions on the target marker preventing a correct tracking of the camera.

Several experiments for placing the marker were carried out and the best visible place was found over the upper chest of the sculptures.

The model had to have the correct placing according to the location of the marker. Therefore our first attempt was made from the virtual model to test and place the rebuilt face linking to the marker.

The VRML model type needed for the AR Tool kit was converted from the rebuilt geometry and finely tuned on a VRML editor for better results in normals and material shading.
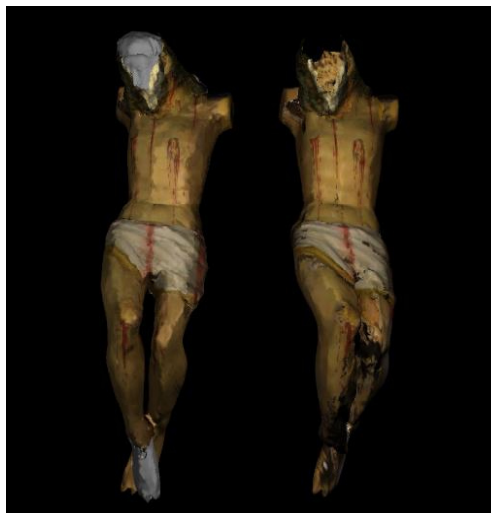
10 | Virtual sculptures, restored and rebuilt (on the left), original (on the right)

7 | Conclusion

This project was developed from a conservative handling of the incomplete wood sculpture to a digital restoration of a sculpture of considerable physical size. With the results from the digital process it was possible, making use photographs and current affordable software. It was possible to produce a virtual model with a highly controlled polygon count and a believable polygon mesh.

The duality of purposes for this work were achieved either from the 3D model, its processed texture map setup, allowing a photorealistic restored virtual model and also the possibility of reverting the process and viewing the missing parts over the correct place on the real sculpture.

Finally, the modeling of the missing parts was used as a valuable reference for a wood replica to be made. It's now possible to test solutions for rebuilding the wood sculpture with virtual models and real time render on the web. Also, anticipating the expression and morphology, helps the long hand carving work to achieve an expected image.

The overall process revealed efficient for its simplicity and accuracy on the production of solutions suited for computer screen size user.

REFERENCES

[1] Bidarra, Ana, Carbalo, Georgelina, Pereira, Francisco Gaitto, "Prevención, Estudio, Planificación Y Seguimiento: Un Caso Prático" III Congress of Spanish group of IIC, Oviedo, 2008

[2] G. Pavlidis, A. Koutsoudis, F. Arnautoglou, V. Tsioukas, Methods for 3D Digitalization of Cultural Heritage, Journal of Cultural Heritage 8 (2007) 93-98

[3] Gregory G. Slabaugh and Thomas Malzbender and W. Bruce Culbertson and Ronald W. Schafer, Digital Michael Ângelo, Proceedings in Siggraph 2004

[4] DI, UMinho, Fernandes, António Ramires, www.di.uminho.pt/pl3d

[5] Pereira, Francisco Gaitto, "Reconstruction of Oporto's XVI century Cathedral" in Symposium proceedings ARCHITECTURE THAT ISN'T THERE: Virtual Recreations of the Destroyed, the Altered and the Never Built, Cincinnatti, 2005

[6] CHI, Cultural Heritage Imaging, www.c-h-i.org

[7] Barbosa J. e Sobral J. e Proença A. Detecção Automática da Localização dos Focos de Luz na Modelação

11 | testing patterns with ARToolKit

de Baixos Relevos em Texturas PTM. Departamento de Informática, Universidade do Minho, 2007

[8] Malzbender, T., Gelb D., Wolters H., "Polynomial Texture Maps", HP Laboratories, Siggraph 2001.

[9] Mudge M., Malzbender T., Schroer C., Lum M. Hewlett Packard Labs, VAST/CIPA 2006, Nicosia Cyprus November 4, 2006

[10] Yee K. Wong K. Cipolla R., Reconstruction of Sculpture From Its Profiles With Unknown Camera Positions; IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 13, NO. 3, MARCH 2004 381

[11] H. Kato, M. Billinghurst, B. Blanding, and R. May. AR-ToolKit, Technical report, Hiroshima City University, December 1999