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INTERACTIVE DISSEMINATION OF THE 3D MODEL OF A BAROQUE ALTARPIECE: A PIPELINE FROM DIGITAL SURVEY TO GAME ENGINES

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Abstract

The dissemination of reality-based models allows a more exhaustive knowledge of the object of study and enables a better access through real-time applications running on common devices connected to the web. In addition, difficult-to-appreciate works of art can become object of specifically designed serious educational games through the possibilities allowed by game engines. The definition of a pipeline that leads from a reliable acquisition of shape, color and BRDF features to a motivating and satisfying interactive experience is the focus of this paper. It will be analyzed, in an interdisciplinary perspective, and will undergo a series of steps aimed at preserving the features of the work of art without compromising its realistic and fluid visualization, as well as the characteristics at the base of the stylistic and artistic quality.

Keywords

Baroque altarpiece, game engine, 3D laser scanner, retopology.

1. *Introduction*

The development of specific protocols to generate accurate 3D models of Baroque artifacts and their subsequent dissemination is the main objective of this research.

The developed methodology combines complementary techniques (topography, digital photogrammetry and laser scanner) to obtain a reliable and complete documentation of works of art (Yastikli, 2007).

Previous investigations already underlined the increased possibilities enabled through the synergy of current cutting-edge acquisition technologies and traditional analysis in the field of art, history of art and archaeology (Remondino, 2011): in most cases, the achievement of accurate representations of complex shapes - altered by the action of time and man - is no longer a limitation as in the past.

In the current scenario of interdisciplinary researches on Cultural Heritage, one focus, among others, is achievement of true and long-lasting exploitation of digital models. It is worth mentioning two mainstream investigation lines, centred on 3D digital simulacra. One is centred their use as a long-standing reference for restoration and maintenance practice through an Information System (IS) (Apollonio et al., 2017), the other is focused on the pairing education/gaming: this last phaenomenon stated in 2003 with the Serious Games movement for teaching and training and then turned to Serious Educational Games (Annetta & Meng-Tzu, 2008, p. 1-12).

The purpose of this paper is the use of gaming technologies to create an interactive application in which the pivotal point is to manipulate virtual objects to develop an understanding of a complex systems: in this case a Baroque altarpiece is the virtual scenario for interacting with movable statues and objects, understand their religious symbolism, immerse in traditional folklore.

Every element inside the application starts with an accurate surveying campaign, then followed by a severe optimization process, capable to exploit, in real-time, the accuracy of active and passive sensors. As a matter of fact, geomatics and photogrammetry have been applied very little to altarpieces with specific aim of their conservation, restoration and graphic documentation (Dávila, 2014; Cantos Martínez et al., 2009).

A specific research line, dealing with the survey of altarpieces, with their morphologic

complexity and optically non-cooperative surfaces has not yet been developed in the full-range of geomatic techniques that can be specifically integrated.

To give an example, the COREMANS project, promoted by the Institute of Cultural Heritage of Spain in which its objective is the proposal and definition of criteria and recommendations, to intervene in the conservation and restoration of heritage works whose material support is made of wood, recommends graphical and metric documentation through photogrammetry (Ceballos, 2017).

However, guidelines for the achievement of reliable 3D models aimed at dissemination through the web are still far from being a matter of specific regulations and standards.

Many altarpieces, like the one shown in this paper, are not always available for a community and for tourists so, a virtual replica accessible from the web would be advisable, as well as, the establishment of standards for acquisition and final interactive models. Thus, an easy and interactive access from any computer or mobile device, to visualize the model and have access to a set of associated historical and artistic information it is close at hand and mandatory in cases like this. (Cabezos & Rossi, 2017). Being able to have an interactive manipulation (Potenziani et al., 2015) allows a disclosure of the heritage that encompasses a wide range of possibilities, from teaching to the most advanced research works, including tourism proposals, among others. It is very important, because it makes it accessible to everyone. At the same time, it allows the user to have an active role, which is more motivating and satisfying for him.

2. *The altarpiece of Nuestro Padre Jesus Nazareno*

The baroque chapel of Our Father Jesus Nazarene of Cartagena was part of the church of the old Dominican convent of San Isidoro, disentailed in the 19th century and now a military church. It is a singular work, of which in 2017 a record of the Declaration of Cultural Interest was launched (Official Gazette of the Region of Murcia, 142, 22/06/2017, 4501).

It belongs to the brotherhood of the Nazarene, popularly known as marraja, with a procession on Monday, Friday and Holy Saturday, being the processions of Holy Week in Cartagena declared of International Tourist Interest.

The "Marrajo" is a species of shark and also means an "astute person". Hence, the origin of this ecclesiastical space traditionally came to be linked to fishermen, although recent research has documented the presence of masons and other artisans among its members and in some cases among its founders (Montojo & Maestre de San Juan, 2009).

The chapel is presided by a high-level altarpiece of the eighteenth century, with an exedra that incorporates doors and niches, but without columns that articulate the structure, and an attic (upper level) that closes in arc.

It occupies the entire wall on which it supports. The powerful central tabernacle offers a novel solution, which finishes with a ribbed interior and a crowned exterior that culminates with a smaller one.

The altarpiece was made in several stages. A part was made to place the sculpture of the Nazarene with dignity at the end of 1731, when the chapel was finished.

In 1748 the *camarín* was commissioned.

A few years later, the wooden structure was extended by the sides and the upper part, as denoted by the pebbles, which proliferated in the area for just over the third quarter of the century. It has been restored in 2015-2016. Its dimensions are 8.32 x 13.06 meters (Fig. 1).

The history of the construction of the chapel is linked to the *Hermandad de Nuestro Padre Jesús Nazareno* and to the Dominicans. The sculpture of the owner that gave name to the brotherhood was very revered from its origins.

In addition to going out in procession during Holy Week, it was taken out in prayer, especially to obtain the benefits of water - and even before epidemics - in a geographical area where agriculture constitutes a source of essential wealth.

Before the seventeenth century, an association with this dedication was founded, in a context of the emergence of Passionist fraternities[1].

[1] On August 15, 1641, the brotherhood acquired the order of preachers a chapel in his church that overlooked the main street, cardinal artery in the urban layout of Cartagena. It was the first chapel of the epistle ship (Montojo, 2003, p. 21). The Dominicans saw their temple, which had expanded in that century, benefited from this construction (Montojo and Maestre de San Juan, 2009). At the same time that the convent

At the end of 1731 the chapel was finished, and the wooden altarpiece was erected and gilded, the material par excellence used in the Modern Age in Spain for this liturgical piece of furniture. It is possible that it was the central part of the current altarpiece. On December 1, the elder brother asked the town hall to attend its inauguration on January 6, 1732. He pointed out that they had managed to do "with heavy fatigue"[2]. The city council collaborated in the expenses of the inauguration

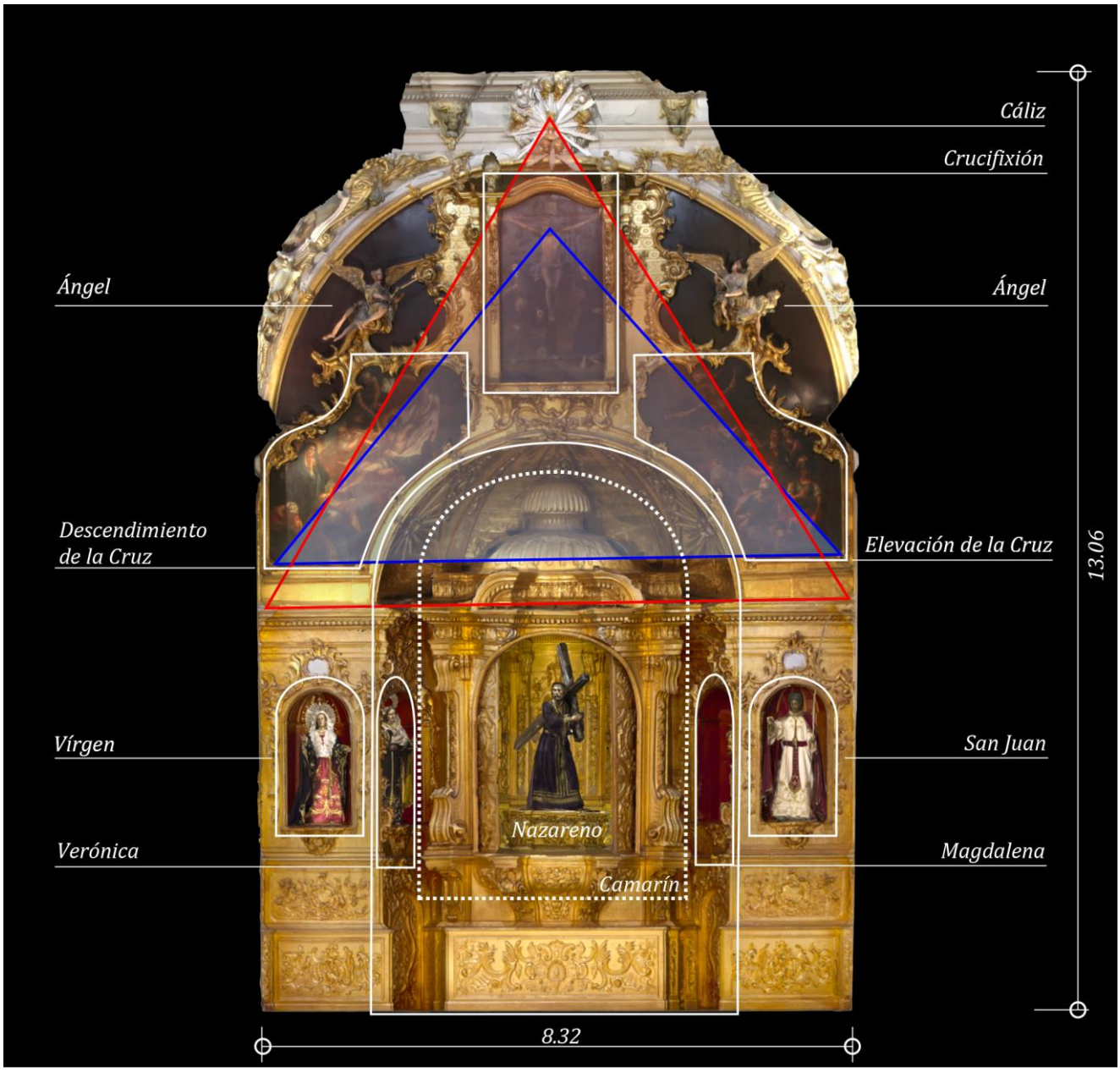

Fig. 1: Baroque altarpiece of the Church of Santo Domingo, Cartagena, Spain

building continued, the friars provided some dependence for the brotherhood to keep certain images and other goods.
To expand the chapel of the Nazarene, the brotherhood bought an adjoining house, signing notarial deed on January 7, 1695 (Montojo and Maestre de San Juan, 2009).
The difficult moments lived and the Spanish War of Succession, with the invasion of the city with English and Dutch troops, had to delay the works throughout the first decades of the following century, stage in which they obtained indulgences from the Pope.

[2] AMCt (Municipal Archives of Cartagena), AC (Actas Capitulares), 1/12/1731, f.349v-350v).

party with 560 *reales* and 30 *maravedíes*, freeing the money from the royal tax per *quintal de barilla*[3]. In the stage of Juan Martín de Iturburúa as Principal Brother, the brotherhood experienced a great apogee promoting outstanding artistic commissions. In 1748, he entrusted Nicolás Tomás, who had worked in the cathedral of Murcia, to manufacture the *camarín* according to the design elaborated by the artist[4]. He was his guarantor Pedro Marín and adjusted to 5,200 *reales*. They also gave him another 600 for the improvements he had made in the plaster work of the chapel. It must be built and placed in eight months. In 1752 it was golden, paying in part with money obtained from bullfights (Maestre, 1999, p. 8). In the following years the relations between the brotherhood and the Dominicans passed through complicated moments, trying to take away from him some prerogatives that he enjoyed[5]. Also, the marraja brotherhood would promote the increase of the altarpiece and the sculptures that it carried. It would commission it to wrap it around the sides and the upper area with niches and a frame of sinuous structure to accommodate the pictorial repertoire, with the incorporation of sculptures of angels. It has certain concomitances with solutions used in the major altarpieces of the Agustine church in Murcia and the parish of Peñas de San Pedro in Albacete, which date back to the 1750s.

It shows pebbles and attributes of passion scattered by them. Rocallas also carries the old altarpiece of the Charity of Cartagena, hired by Nicolás de Rueda in 1755. However, the movement of structures in the lower part recalls solutions used previously in Murcia (Peña, 1992, p. 287). The name of the author of the paintings is unknown. At the end of the 18th century the sailor and politician Vargas Ponce related them to Manuel Sánchez (collected by Vincent, 1889, p. 445), a priest and painter who was Francisco Salzillo's teacher. However, today it is preferred to consider them anonymous. As for the altarpiece, Vargas evaluated it negatively, according to the opposite attitude in the illustration before these baroque architectures. Ortiz, following other authors, attributes this intervention to Juan Antonio Salvatierra, while this artist, who belongs to a family of carvers, worked for brotherhoods linked to the order of preachers - the case of the Santa Bárbara altarpiece - and for other religious communities (Ortiz, 1998, pp. 65-71). As for the five sculptures that have been incorporated into the altarpiece, they have been subject to political fluctuations and changes in taste, so that the destruction and successive substitutions characterize their history. From the earliest image of the Nazarene venerated by the confraternity to the current dress made by the Valencian sculptor José Capuz in 1945, there is a long way to go. On the other hand, dated to half of the XVIII century, *San Juan Evangelista*, also of dressing and known by photography, is considered the work of the famous Francisco Salzillo, leaving in procession in 1752 for the first time. The present image is from José Capuz and dates from 1943 (López Martínez, 2017; Hernández Albaladejo, 1996). The *Dolorosa* too is attributed to Salzillo. His disciple Roque López did works for this brotherhood. A *Niño Jesús Nazareno* is verified and it is possible that this destiny had some *Soledad* that effected for this city at the end of century XVIII (Count of Roche, 1889). Other masters continued making images in the following centuries. However, who had a more lasting contact with the brotherhood was Capuz, sculptor retired in Rome and academic of San Fernando since 1927. Before the Spanish Civil War (1936-1939), he made several thrones and, after the destruction experienced, made others (Hernández Albaladejo, 1995).

On the *Verónica* is known to have joined the procession in 1773, by request one year before the officers of the Calafate Arsenal who paid for the image and the throne (Ortiz, 1998, p. 48, Montojo, 2003, p. 30).

The latter agreed to make two sculptures of the Marías or the Daughters of Jerusalem in exchange (Ortiz, 1998. P. 48). At the end of 2016, it was agreed that the Malaga sculptor José María Ruiz Montes would make a new sculpture, which he is currently making.

La *Magdalena* is the work of José Hernández Navarro in 1984. *Jesús Nazareno*, *San Juan*, the *Virgen*, the *Verónica* and two other images - "not so magnificent, not so flowered" - left, as Vargas

[3] AMCt, AC, 12/1/1732, f.366r; Ortiz, 1998, pp. 68 -71.

[4] Maestre de San Juan and Montojo, 2004: 50, AHPM Provincial Historical Archive of Murcia, prot 6192, 07/02/1748, page 138r-139v. The drawing and the conditions of execution were requested to be inserted in the notarial deed of commitment, but do not appear in it.

[5] The confrontation between fraternities and the religious orders that sheltered them was constant. Despite the problems Juan Martín de Iturburúa had to face when he was older brother with the Dominicans and with the town hall and other personalities (Arróniz, 1903, p. 5; Maestre de San Juan, 1999, pp. 8-9), he was generous with his brotherhood.

Ponce declared in the 18th century, in the Good Friday procession in the morning (Vincent, 1889, p. 451). It was also manifested a century later by Arróniz (1903, pp. 5-6).

2.1 The image arrangement and episodes of passion in the altarpiece

Every altarpiece has an order that oversees image arrangement in compliance to their pre-eminence. Although, it is not always easy to decipher the reasons that led to the incorporation of certain dedications (*advocaciones*) and to establish the iconographic program. The decision of the selection of themes and images and their distribution is rarely left to the discretion of the artist. Generally, it is up to the commissioner (not client, or purchaser) or to whom he designates to respond to his devotions and saints of his name or relatives. While choosing what is chosen should be distributed conveniently and respecting the criteria of dignity and hierarchy. The place of greater importance is in the niche or *camarín* in which the *titular* who gives his name to the chapel or the temple is located. It is located in the center of the main level of the altarpiece, wider and with greater significance. In the baroque age, they were used to clad architecture in wood with mirrors, to create reflections, making the space larger and more decorated.

The rest of the figures and represented scenes are organized to enphasize this point, an area of honor that concentrates attention and towards where everything radiates. In this case, the neuralgic point corresponds to occupy it to the Nazarene to whom the chapel is dedicated[6]. The baroque altarpieces usually have rigging systems that allow closing and opening the *camarín* through doors with decorative motifs and attributes or doorways with canvases with the function of hiding the images[7]. In this altarpiece circular sliding doors are used to store the sculpture. On the outer faces, *Jesus Nazareno* is identified by words and passionary instruments located in cartouches.

The right side of the image of the patron - not the one who contemplates - has more relevance than the left. Therefore, on the right flank of Christ is his mother. This part is called the Gospel side (evangelio) and the opposite part of the on of the Epistle. The names correspond to the places in which, during the past, one and the other texts were read during the liturgy.

The next point in dignity is the left one. In this one *San Juan*, the beloved disciple, is placed. If the altarpiece is enlarged and consequently the places in which the images are placed are increased, a reordering of these can take place, attending again to the aforementioned criteria. The reading begins with the Nazarene and continues from the right side to the left axis of symmetry and so on. However, less visible or smaller places are subordinated to those that are not. Here it happens with the concave facing that lodges two niches, relegated in front of those that are disposed frontally. So, in this case, *Verónica* and *Magdalena* would occupy such niches. The first of the women is the protagonist in a very popular episode of passion, although it is not recorded in the Gospels when wiping away the sweat of Christ, leaving his face imprinted on the cloth. As a bearer of the true portrayal of Jesus suffering, made by a hand that is not human, it has prelacy and is to the right of the Nazarene (Stoichita, 1996, p. 62-65). On the symmetrical side the *Magdalena* is placed. His devotion resurges strongly in the Counter-Reformation in evocation of repentance and penance. She accompanied the Virgin during the martyrdom of his son. Exceptionally, the image of the *titular* can be moved to the upper part of the altarpiece with definitive or temporary character. It happens with Christological and Marian images of great devotion, as well as patrons, according to the reasons that specifically concur. Sometimes in chapels that have changed their name, an image or a picture in memory of the previous name is placed in the attic of the altarpiece. In this case, the cycle of passion that is narrated in the lower part of the altarpiece ends in the upper one.

If in the first the images allude to the path of Jesus on the road to Golgotha, the other corresponds to the hill of Calvary, with the *Crucifixión* flanked by the *Elevación* and the *Descendimiento de la Cruz*.

The chronological sequence in this case would go from the side of the Epistle to that of the Gospel. The pictorial episodes are inspired by plates, especially Rubens originals. The formalization of the lateral scenes is articulated with the presence of two diagonals, whose path reinforces the

[6] But, moreover, on the cult of latria and hyperdulía - God and Mary - turns Christian piety.

[7] Similar mechanisms were used in the theater, as well as resources with light and diverse formulas that cause changing effects (Rodríguez G. Ceballos, 1992).

disposition of the body of Christ in his ascent and descent of the cross.

Considering such diagonals, we can draw a triangle with the base in the horizontal line that runs through the lower part of the painting and the other sides go through the heads of Christ and close with the top vertex in the one of the crucified one.

A larger equilateral triangle would start from the cornice line of the first body and the lateral ones would merge into the chalice, symbol of redemption, which is located at the culmination of the altarpiece (Fig. 1).

In front of the narrative staging manifested in the altarpiece, the iconic one appears outside of it through the calyx surrounded by rays and with a cloud dotted with angelic beings (Stoichita, 1996, p. 32).

Christ is risen but his blood is left spilled in the passion and contained in the consecrated glass to quench the thirst of the spirit and fill the afflictions of the Christian.

The three paintings are placed in a frame of sinuous structure and pentapartite where the sculptures of two angels with passionate attributes rest, which are also present in other points of the altarpiece in cartouches and with decorative elements in which the crown of thorns is incorporated, the three nails, the hammer and the pincers.

The angelic beings carry the spear and the branch of hyssop with the sponge in allusion to the wound on the side and to the words of Jesus "I am thirsty".

As the Gospels express, after drinking he said: "Everything has been fulfilled" and "He gave up his spirit" (Jn 19: 30).

San Lucas recounts the darkness that reigned then on earth (Lk 23: 44), as manifested by the canvases that accompany the *Crucifixión*. The death of Christ is represented here, which means the culmination of the salvific message of God to man predicted in the Old Testament. Hence, the Major Prophets are incorporated in the pendentives of the chapel, placing on the sides of the altarpiece Isaiah and Jeremiah, as prophets of birth and passion.

In the altarpieces built in the Modern Age, the *Crucifixión* is a theme that repeatedly culminates the iconographic cycle that is presented on each occasion, being the central issue of the Christian faith. However, as the eighteenth-century advances other elements and images are arranged in the attic.

On the canvas of the Marraja Chapel, the cross stands on the skull of Adam. The *Virgen María* and *San Juan* are located on the same side as the sculptures of this dedication in the lower body of the altarpiece.

The *Elevación de la Cruz* evokes the *Resurrección* as the culmination of the ascension of the body.It presents a compositional solution that allows the arrangement of numerous figures in visible places and in a variety of positions on one side and the other of the shroud.

The *Virgen* and *San Juan* to the left, two soldiers at the foot and four men at the sides and behind raising Christ nailed to the cross.

The *Descendimiento* is inspired by the work of the same subject of Rubens for the Cathedral of Antwerp, with some changes.

Engraved by Lucas Vorsterman, it reached great diffusion and its diagonal composition and arrangement of the figures in the foreground provides an arrangement that fits well with the space that the frame provides, a complex, oblique and elevated space that allows to place all the characters at first flat giving them visibility, as in the symmetrical canvas.

On several occasions and with variations, Rubens dealt with the Gospel episode of the descent of the heavy body of Christ dead on the shroud that the four evangelists mention.

Two up stairs figures help from the top of the cross. At the feet, the *Magdalena* and *María Cleofás* are kneeling. *José de Arimatea* holds the right arm with the *Virgen María* standing and with her hands in prayer and *María Salomé*, another of the pious women.

To the left of the shroud, *San Juan* stands with his arms outstretched next to another executioner on his back with his naked torso, which helps to support the dead body, as it appears, for example in an anonymous drawing by the Prado Museum of very similar composition, the disposition of the figures has the same model as in this case (Mena, 1990, p. 195).

In short, the altarpiece of the chapel of Jesús Nazareno presents, then, a complex and well-articulated iconographic passionate program, which would probably count on the advice of the order of the Dominicans to which the temple belonged.

3. Methodology

Three phases have been necessary for the achievement of the aspected result: data gathering[8], post-processing according to the general objective of metric and visual reliability, and the last but not least the development of an interactive application enabling cultural and learning activities through different platforms (local and remote).

Data processing pipeline was tailored to solve specific issues concerning efficient simulation of materials characterized by different optic behavior - corresponding to different finishings - starting from a single apparent colour texture from photogrammetric workflows. Finally, the result obtained should be appropriate for a fluid web visualization, and at the same time, supporting a full interaction with the set of all the acquired assets present in the scene (from the individual animation each statue, to movable elements of the altarpiece and so on).

The final product is aimed at fostering the awareness on symbolic features of this work of art, as well as to enhance the community's sense of belonging to the Church of Santo Domingo.

3.1 Data collection

Previous experiences concerning digital surveying of altarpieces, such as the one located in the Church of San Miguel in Murcia (Peña Velasco et al., 2017), made data acquisition consistent with highly detailed and complex shapes like those of baroque works of art. In particular, shadow-areas due to the intrinsic complexity produce several holes on the final mesh of the altarpiece: for this reason, it was designed a pipeline capable to integrate active and passive sensors. The camera network was designed in order to create a photogrammetric model characterized by a resolution in compliance with the laser scanner one. Ground sample distance (GSD) was designed in order to get a photogrammetric model with a mesh resolution that could easily fit with the one from the active sensor. The mesh-processing phases carried out inside Geomagic Design X (ICP alignment and Global remeshing) allowed an easy integration of the two models once the two meshes were merged.

In addition, it has to be underlined that logistic aspects play a fundamental role in a surveying campaign that lies almost in the middle between architecture and sculpture. The acquisition must be planned in compliance to several aspects, namely:

- Time at disposal for data gathering
- Different features of acquisition devices (resolution, accuracy, etc.)
- Allowed degree of interaction with the objects (e.g. target application)
- Presence of obstacles that generate occlusions (not measurable areas)
- A stable position of both the equipment and the surveyed object, in particular for statues[9].

These last two aspects led the surveying team to proceed to a separate the data collection and processing: architectural part of the altarpiece, on the one hand, and the four sculptures on the other (Fig. 2).

Fig. 2: Split data collection: on the one hand, the architectural part of the altarpiece and on the other, sculptures

The first day began with the architectural part data acquisition by means of a topographic base, with a quadrilateral shape (A, B, D, E). Four

[8] In the summer of 2017, 3D data collection was carried out using both laser scanner and photogrammetric campaign, completed with the taking of control points measured by classical topography.

[9] In the days before data gathering, the adaptation of the workspace in the Marraja Chapel was carried out by the Church Commission team of the Marraja Brotherhood, which consisted in the moving the images from their niches and placing on mobile bases. For the acquisition of upper areas (top of mouldings and other architectural elements), a raised platform was positioned in front of the altar as well as specific lighting equipments aimed at supplying omogeneous and controlled lighting.

stations at ground level and a fifth station (C) located at a higher level, namely on the platform, placed at 1.39 m in height.

First, the base station was oriented, establishing an XYZ local coordinate system (100; 200; 50). Then, from each one of the stations a scan was performed, using a Leica Nova MS50 multistation: the final amount of five stations were alligned by classical topography, obtaining a point cloud of with an average resolution of 5 mm for the altarpiece. The final point cloud, before running the filtering process, was formed by 15 million of samples (Fig. 3).

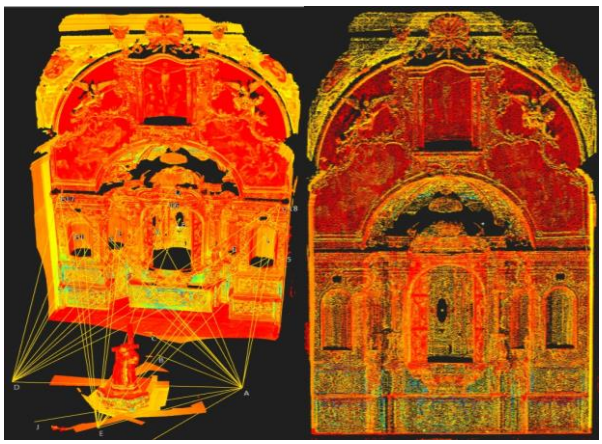

Fig. 3: Point clouds of the altarpiece and *titular* sculpture, Our Father Jesus Nazareno

In the following days the team carried out the scanning activity of the altarpiece. In addition, photographs were taken with the laser scanner integrated camera and a photogrammetric campaign conducted with a Canon EOS 1100D and a Canon EOS 700D both of them non-metric reflex cameras. Size of the image in pixels of 4272x2848 and 5184x3456 respectively. The main settings of the cameras used have been, the use of the focal lens 18 mm on a tripod, f/8, ISO 800 and shutter speed 1/13, although images were also made without a tripod with other settings in the more complicated shots. RAW format was used in order to achieve reliable and consistent colour representation for the whole set of photographed items. The pipeline is based on the use of a Xrite ColourChecker chart at the beginning of every uniform sequence of pics: a reference shot with an average illumination condition and constant parameters (focal length, shutter speed, exposute time, ISO, aperture or F number).

To complete data gathering, 15 target and 3 natural points of the altarpiece were measured. Due to intrinsically complex shape of the altarpiece, the position of the 18 control points was designed with specific care, to let them be visible from each of the stations. Their position was also planned to avoid possible damages to the golden finishing lied upon the wood of the niches (Fig. 4).

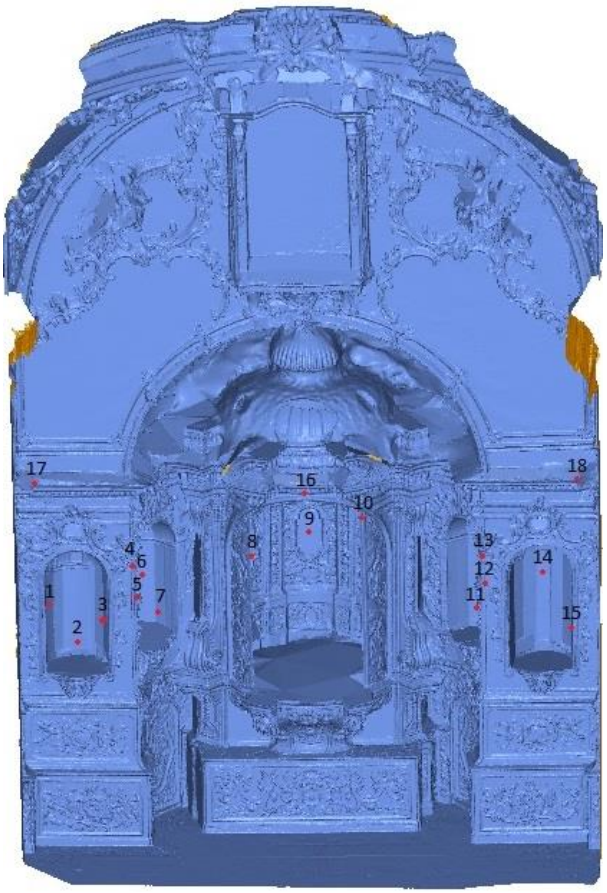

Fig. 4: Target control points from 1 to 15 and natural points from 16 to 18

Each one of the four sculptures were acquired independently, placing four stations around them: for digital adquisition of the *Virgen Dolorosa* (Fig. 5), *María Magdalena* and *San Juan* it was possible to share the same positions of the altarpiece scans. For *Jesus Nazareno*, in order to comply with the minimum distance required by the laser scanner used, two stations J and P were added. The general sampling during the scanning phase of the sculptures was 5 mm. Areas with more detail - namely faces and crowns of great complexity - were acquired at higher resolution, 1 mm, in order to integrate through an active sensor, the photogrammetric campaign that in general produces poor results in case of thin elements.

Fig. 5: Photogrammetric model of the Virgen obtained through Agisoft Photoscan

3.2 The 3D model optimization

Data processing starts with the import phase inside Leica Infinity software in which point clouds are filtered to reduce noise, eliminate unnecessary areas, and outliers. The mesh creation phase - carried out inside 3D Systems Geomagic Design X - lead to a mesh of more than 6 million triangles for the altarpiece and 100 thousand triangles for each of the sculptures approximately. The resulting architectural model presents only one significant lack of geometric information, due to occlusion phaenomenon, in the back area of the central *camarín* cupula (the scanner could not fit or be lifted to that area). For the integration of this void a specific camera network was designed to supply the general model with a "patch" characterized by homogeneous sampling. The rest of the holes were closed by the creation of flat extrusion surfaces (Fig. 6). Triangular meshes of the sculptural figures from the altarpiece were completed with similar procedures: integration of active and passive sensors, merging of meshes from NURBS surfaces obtained with reverse modelling procedures inside Geomagic Design X. The final master model of the altar can be defined, using the CGI jargon, as high-poly, or HP (7 millions of polygons). This quantity of triangular elements is far from being suitable for game engines and in general with real-time visualization. As matter of facts, these applications require low-poly models made of few thousands of elements. The standard procedure adopted in several studies provides for a robust decimation process with different resampling techniques (homogeneus edge distance, edge lenght reduced locally on the base of curvature, etc.).

The procedure proposed in this case assumes that mesh-processing applications designed for mechanical engineering and industrial design are not adequate for the obtention of low-poly models.

Fig. 6: Data integration of the laser scanner (blue): with photogrammetry (orange) and through extrusion of 2D reference (green)

To optimize the mesh, techniques from game industry were applied and customized. The procedure is summarized in the following steps, starting from the master model:

- Decimation of the HP model to an intermediate level, enabling its use inside common CGI applications[10].
- Retopology: namely, the conversion of a highly detailed triangular mesh into a low-resolution one made of quadrilateral polygons (Fig. 7).
- Quad-mesh segmentation: identification of different sub-set of polygons through braking the connectivity among sequences of edges defining specific architectural features (Fig. 8a).
- Parametrization of the segmented quad-mesh (Fig8b).
- Render to texture procedures (depending on spefic needs) to enhance the visual appearance of the low-poly model (fig. 9).

Quantitative aspects of this workflow are present in table 1, but some additional features of

[10] Geometric modelling applications characterized by a polygonal modelling kernel, supporting quad-polygons such as: Cinema 4D, 3D StudioMax, Modo, etc.

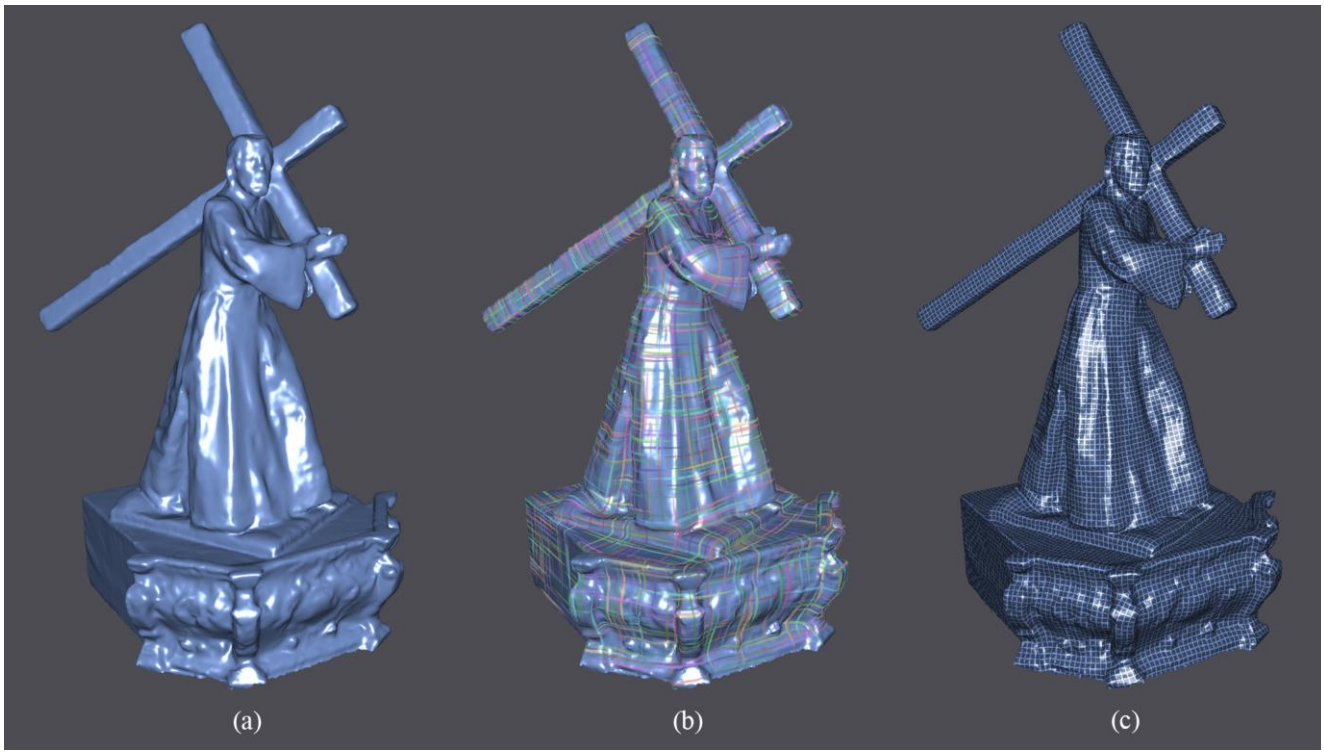

Fig. 7: Automatic quad-dominant remeshing inside Instant Meshes. (a) HP model. (b) Orientation field: a set of directions on the input surface to which the edges of the output mesh should align (Jakob et al. 2015). (c) Position field: a local per-vertex (u, v)-parameterization closely related to the coordinates of the vertices of the final mesh (the gradient is aligned with the directions of the orientation field)

the adopted protocols should be underlined: resampling methods in CGI/VFX industry, is in most cases, still manual. On the contrary, in our case, the research team tried to get rid off, or limit manual retopology (Fig. 8a, b).

The consequence of automatic retopology is than a uniform-sampling quad-mesh with far more polygons with respect to what is considered acceptable in case of commercial video-game applications.

In the case of work of arts, even if the final output is an interactive experience, it is still necessary to preserve metric reliability, and keep under control the deviation between high-poly and low-poly (Fig. 8c).

Besides, semantics, in the case of 3D models from scans and photogrammetry used in the entertainment field it is not felt as primary issue. At the contrary, in our case the architectural model is not the mere scenary or background for the action; it is a medium for the understanding of cultural, constructive, design features and symbolic features[11].

Tab. 1: Data concerning point clouds, triangular and quadrangular meshes

ITEM	Point clouds (points)	Filtered point clouds (points)	Triangular mesh (polygons)	Quads (polygons)
RETABLO	12.475.146	11.963.444	2.146.255	336.888
VIRGEN DOLOROSA	596.703	497.523	92.870	13.658
MARÍA MAGDALENA	412.536	366.511	80.105	27.168
JESÚS NAZARENO	730.781	700.419	126.908	15.763
SAN JUAN	557.919	485.821	96.562	36.985
TOTAL	**14.773.085**	**14.013.718**	**2.542.700**	**430.459**

[11] Even if it is not a priority of this case study, the optimized model could be used for other activities concerning restoration, maintenance practice, etc. Once the model has undergone to a semantic partition, it is simpler the association of its sub-sets to the records of a database.

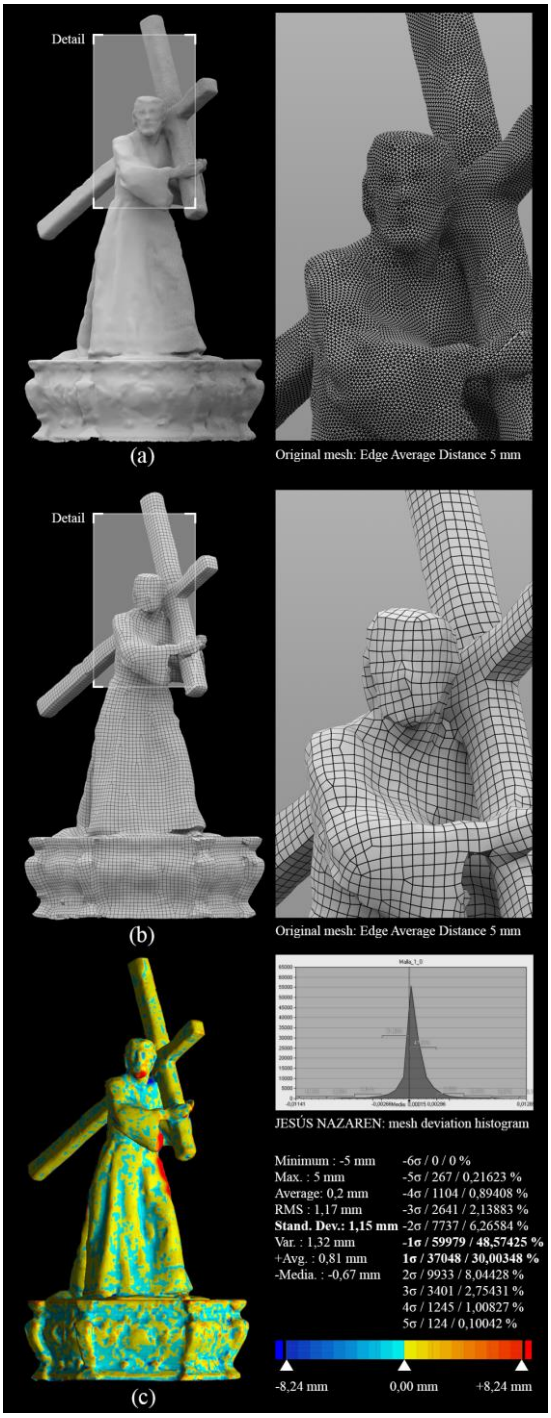

Fig. 8: (a) highly detailed mesh from active and passive sensors. (b) quad dominant mesh. (c) Mesh deviation analysis

The retopology automatic process has been significantly improved in the last years[12], testimony of the interess of several computer graphics branches towards this specific kind of structured meshes. There are many reasons, but among them, the main is the possibility of achieving connected sequences of edges aligned with the main geometric features of an architecture.

This aspect facilitates and speed manual segmentation, making polygonal representations more compact and easing mesh completion and elimination of topological and geometric defects (Cipriani & Fantini, 2015).

Quad-meshes segmentation presents some dimensional limitations due to the threshold established by means of the re-sampling; in other words, the level of granularity cannot go beyond the limit of the edge average length of the mesh.

But, to achieve some additional specification to the model, an efficient (uv) parameterization can be exploited (Fig. 9a). Quad-meshes enable a higher control on the process that converts 3D models into 2D shapes (u,v)[13] (Fig. 9a).

The general semantic of the altarpiece, with low granularity, leads to a breaking rule of the connectivity and splits the mesh into a limited number of sub-sets, then, those sub-sets will be separatly projected onto the (u,v) parameter space creating an equivalent number of islands (Fig. 9b). These 2D homologous shapes are easy to be perceive and consistent to a general formal interpretation of the surveyed object. Once chromatic and morphologic information are stored in the parameter space (occlusion, normal, and colour maps, Fig. 9c, d), additional clues will be at disposal to the user for carrying out a second segmentation of the object[14].

Render-to-texture solutions, or "baking", are standard procedures aimed at transferring information from a model to another; in particular, normals and displacement textures are commonly used in CGI for improving the visual apparence of low-resolution models by means of consistent

[12] The majority of entertainment applications aimed at character modelling through mesh sculpting, progressively implemented automatic remeshing with quads, among them: Pixologic ZBrush (Zremesher tool), Pillgrim 3D Coat (Auto-Retopo), The Foundry Modo (Automatic Retopology Tool). It is relevant to the current discussion to underline how academic projects by ETH, CNR-ISTI, and Università dell'Insubria have drawn the attention of major software houses as Foundry that decided to implement Instant Meshes algorithms starting from Modo 10.2 release.

[13] The most widespread parameterization algorithms are of three kinds: isometric (length preserving), conformal (angle preserving), and equi-areal (area preserving). For the altarpiece parameterization, due to its complexity, it was needed a mix these tools in order to achieve a proper texel density (https://www.artstation.com/artwork/qbOqP).

[14] For recent studies concerning automatic segmentation, see: Grilli et al. 2018, pp. 399-406.

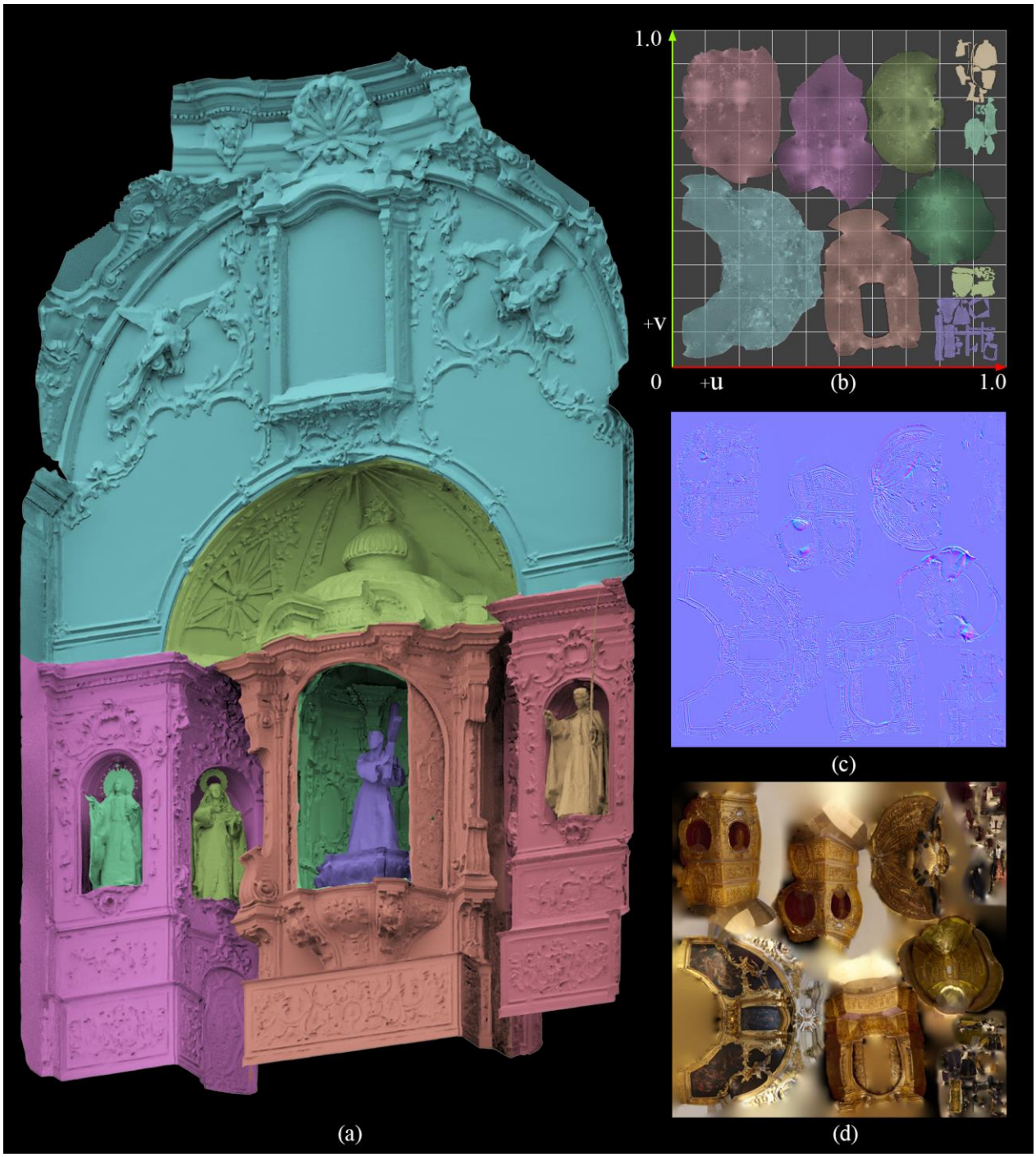

Fig. 9: (a) segmented quad-dominant mesh. (b) parameterization in accord to mesh semantics. (c) normal map. (d) apparent colour texture

procedures. Apparent colour is stored into the (u,v) space using the same parametrization of the model adopted for normal maps. Frame projection and blending is carried out inside Agisoft Photoscan activating the "keep uv" option before running texturing generation.

This last possibility can be exploited only in case the photogrammetric model and every other model (intermediate resolution, low-poly, etc.) share the same reference system established by means of the active sensor campaign.

3.3 Interaction with the model[15]

The use of 3D asset inside game engines is split into a set of steps once the optimized low-poly model and the relative set of textures are available:

- The conversion of the model from the native format of the adopted application into an interchange one.
- The creation of specific shaders/materials inside a game-developer texture creation solution[16]. In most of cases, these solutions are graph-based procedural seamless texture editors that starting from a single bitmap or a set of images create a material suitable for game engines.
- Importing of the set formed by models (included different kind of vertex maps[17], animations), materials and the corresponding textures inside the game engine.
- Designing of both interaction and interface of the application.
- Setting up the scene (lighting, materials, etc.).
- Exporting of the application.

In the case of the altarpiece, the model was geometrically optimized, parametrized and "baked" inside The Foundry Modo, then it was exported towards Allegorithmic Substance Painter[18] using the .FBX format file; colour values and all operations carried out on textures, have been performed in linear space (gamma equal to 1). Allegorithmic implements a physically-based material editor shared within its suite of applications: it means that the seven .FBX files - each one corresponding to a moving or rotating element of the altarpiece (four statues, two bended sliding doors, the architectural "frame") – have to undergo a specific PBR (Physically-Based rendering) material authoring.

In general terms, the task to carry out inside such stand-alone material editors, starts with with two textures – one applied on diffuse colour channel called baseColor, the other affecting the shading (normal, bump, displacement) –. In case of models from photogrammetric pipelines, apparent colour map is the output of a double process carried out inside Agisoft Photoscan, namely projection and blending of frames onto the (u,v) parameter space; other maps as normal can be calculated inside 3D applications by means of a "baking" process.

The only exception to this set of three assets (one model, two textures) is due to the coexistence of complex optical behavior inside a single mesh; in this case, an additional greyscale texture has to be defined in order to distinguishing different BRDF upon the same mesh.

The greyscale texture is then used to furtherly specify the properties of a mesh without having to split it along a complex sequence of edges that would be a time-consuming operation whose result could be unsatisfying.

This texture is an alpha channel obtained by means of semi-automatic segmentation of the colour bitmap to be used as a mask for materials.

Every common tool for bitmap editing implements a colour-range selection criterion that in this case was applied to the colour texture in order to roughly split golden areas from the rest of the altarpiece.

An aspect of this semi-automatic process should be underlined: the visual reliability of the (u,v) reference of the altarpiece obtained thanks to interactive parameterization tools inside the 3D geometric modelling application used. As a matter of facts, if the (u,v) layout is poor and formed by an uncontrolled number of islands (as it comes out from Agisoft Photoscan), it is almost impossible, in

[15] This paragraph shows the result of a collaboration with the LKA game development studio, authors of the award-winning 'The Town of Light' (http://www.lka.it/). Authors would like to thank Luca Dalcò and Lorenzo Conticelli for their effort for the creation of the interactive application of the altarpiece.

[16] Several applications starting from the 2003 have been specifically designed to facilitate complex tasks concerning interoperability among 3D modelling applications and game engines; among them the main commercial solutions are: Allegorithmic Substance (the suite includes: Painter, Designer, B2M, Source, Player), Pixologic Sculptris, Holger Dammertz Neo Textures. For a survey on the topic see: Retrieved 4/04/2018 from https://www.slant.co/options/12608/alternatives/~substance-painter-alternatives.

[17] Vertex maps are a comprehensive class of information stored inside the model: they include (u,v) reference systems, weight maps, normals, etc.

[18] Both applications are a standard in game industry and are constantly used in combination thanks to a set of plug-ins also capable to facilitate the "dialog" among 3D geometric modelling applications and 3D painters or shading-design software. Currently, Allegorithmic develops plug-ins for Unreal Engine 4, Unity, Autodesk Maya and 3DS Max (2018 and 2019), Maxon Cinema 4D, The Foundry Modo (series 11 and 12). Since 2007 Brad Peebler, co-Founder and President of Luxology (the former software house that developed Modo), has been in contact with the group of programmers that in 2010 launched Substance Designer.

that case, to manually edit the pixels forming the boundaries of the set of islands.

The low-resolution quad-dominant mesh has been parametrized in compliance to the formal features of the architectural elements to make them recognizable to the user of a bitmap editing application; the aim is to improve and control the boundaries across of the two areas. The set of white pixels correspond to the gold parts of the altar, the black ones to the simplier finishing of the painted wood or canvas (Fig. 10). Inside Substance Painter a gloss material (approximated to a dielectric[19]) coexists on the same mesh with gold decorations that are optically more similar to metals (or conductors): these materials absorb light at different wavelengths.

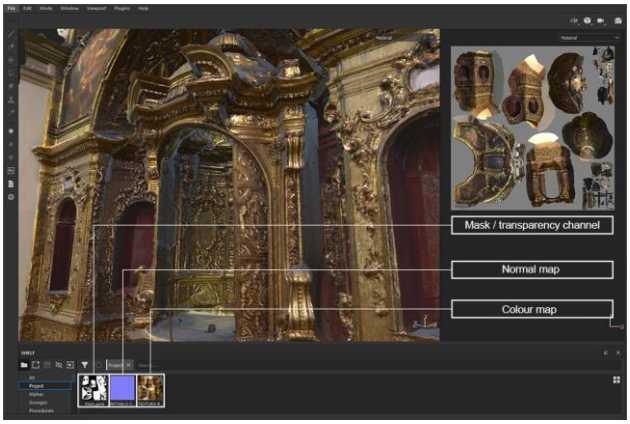

Fig. 10: Physically-based texturing via Substance Painter

In the case of gold, it absorbs blue light at the high-frequency end of the visible spectrum, so it appears yellow as a result (McDermott, 2018).

The fundamental texture for the PBR material achievement inside Substance Painter is the one called “roughness" which reproduces surface irregularities and consequently larger and dimmer looking highlights. This texture reproduces small details varying their orientation in compliance with Torrance and Sparrow model (Torrance & Sparrow, 1967).

After the setup of materials corresponding to each mesh, the whole set of assets is exported towards Unreal Engine 4: an interesting aspect concerning data compression is that in addition to the basecolor and normal, Substance exports another texture in .TGA file format that stores 3 characteristics of the PBR material: Metallic, Roughness e Ambient occlusion parameters. Each one of them is stored as a single channel of RGB bitmap (Fig. 11).

Inside Unreal Engine is now necessary to reproduce the PBR material by connecting the set of image inputs to the material outputs of each object. In order to emphasize the relation among the statues and the altarpiece a specific lighting setup was designed; to supply the scene with a general illumination and proper reflections over specular materials an HDR probe image was introduced into the scene, as well as conventional lighting sources (spotlights and point lights).

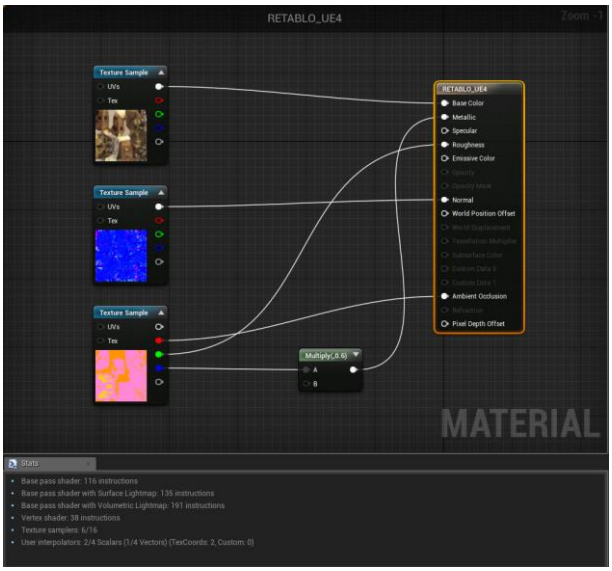

Fig. 11: The texture set from Substance Painter inside Unreal material editor

From the point of view of users’ interaction was adopted the Blueprints Visual Scripting implemented in Unreal Engine – a scripting system based on node interface.

This system allows users to get rid of common scripting languages, meanwhile providing the ability to use concepts and tools generally only available to programmers (Fig. 12).

The possibility of rotating the camera, zooming closer to the object and, in addition, the interaction between the altarpiece, the alcove doors and the virtual repositioning of statues was designed through UMG designer panel.

Each button of the graphic interface starts the animation of different elements belonging to the scene.

[19] A dielectric material has bright specular highlights of the same colour as the light source (Ciprianiet al., 2015).

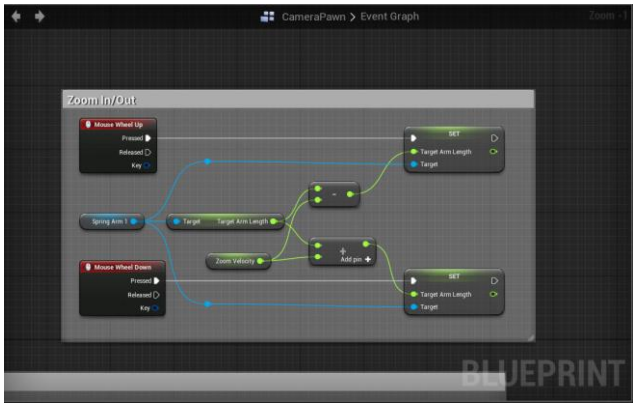

Fig. 12: Setup of the camera movement around the altarpiece

Animation paths were created by using Sequencers (Fig. 13), which allow the user to record animation keys on the properties of objects, as in this case on its transformations over time.

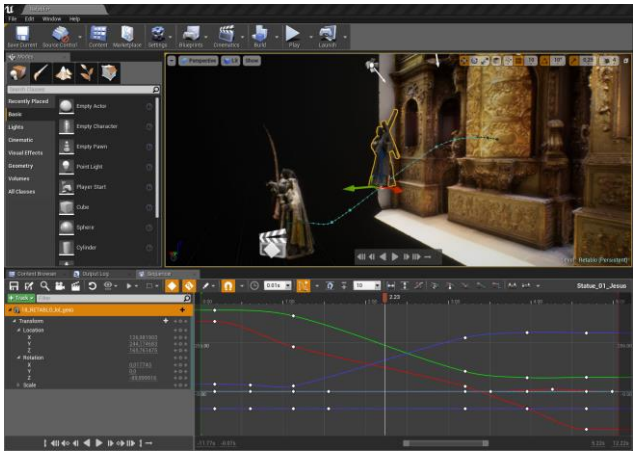

Fig. 13: Definition of animation paths inside Unreal

4. *Dissemination and interaction with the model.*

Due to the importance of this architectural piece of the eighteenth-century Spanish Levantine heritage located in the city of Cartagena, its three-dimensional documentation was carried out (Fig. 14): the purpose of this model is to be the base for possible future interventions, as well as to disseminate this BIC (*Bien de Interés Cultural*) through free-access digital platforms aimed at enhancing its knowledge and accessibility. The interactive visualization of this 3D model is possible in two ways, either on remote or on local[20]: through the website www.sketchfab.com (https://skfb.ly/6G7Ou) and through a dedicated multimedia station (or downloaded).

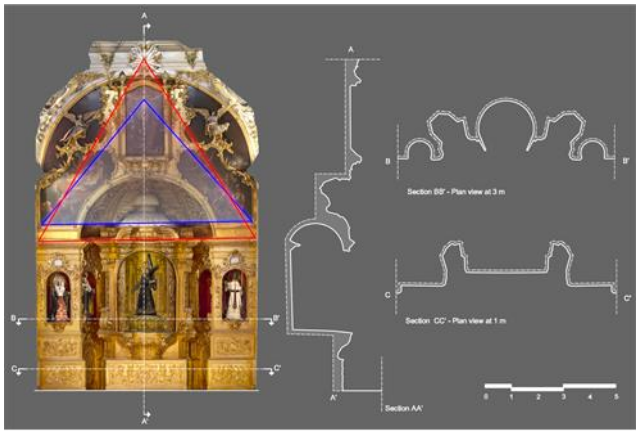

Fig. 14: Altarpiece 3D model, horizontal, and vertical sections

We must remember that this altarpiece is in a temple, which is a devotional place, subject to worship schedules and therefore not always accessible. In fact, the sculptures leave the temple several weeks every year at Easter, because they go out in procession through the streets of the city.

The virtual three-dimensional model can facilitate knowledge and can instill the interest during the on-site visit, enabling many more people reaching, through the web this valuable piece of heritage, and fostering interest and respect for it: from knowledge to interpretation, and especially by supportting the church that owns it.

These virtual models are attractive to today's society and, in addition, they make up a useful material to carry out informative spaces that promote the protection of Cultural Heritage and knowledge of society[21]. Anyone who accesses the web can move freely through the altarpiece, stopping and approaching everything they want (Fig. 15).

By means of this interdisciplinary collaboration, several achievements have been possible: metric and visual reliabilty of digital assets, their fluid interaction with the user, the scientific correctness of both artistic and symbolic contents concerning the work of art. The main limitation of the proposed operational flow regards the use of several applications - which are also belonging to different disciplinary sectors -. An extended supply chain that involves the use of multiple file formats that combine topography, photogrammetry, 3D mesh processing, baking, 3D

[20] For a survey on web-specific solution for spreading 3D models see: Minto & Remondino, 2014.

[21] On these topics, stand out, as some of the more original contributions, the recente papers: Ippoliti et al., 2019, Clini et al. 2017.

material authoring, and game engine does not facilitate the operation of managing and organizing the many files produced and their editing in case of a review.

Fig. 15: 3D model of the altarpiece (www.sketchfab.com)

At the same time, the proposed operating flow aims to fully exploit the visualization potential that distinguishes the creative entertainment industry and in particular, the game engines that, for years now, can not disregard specific programs for the physically-correct material/light setting.

As well as in video games quality and realism progressively improve the same must happen in interactive applications for the dissemination of cultural and scientific contents.

This audience is less extensive than the one that usually "consumes" multimedia contents originating from the entertainment industry; but nonetheless quite expects a similar visual quality in digital art-historical applications. However, a mere contemplation is no longer enough for today's spectator, used to new technologies and their hectic advances in the sector of interaction and photo-realistic visualization. Therefore, the possibility of interrelating with this model has been introduced, interactively grabbing and moving images, changing their locations, and then find their correct position in the altarpiece (Fig. 16). Then, the images maintain an iconographic order established in a certain way, finding the *Virgen* always to the right of *Jesús* and *San Juan* on the other side, as close as possible to Jesus.

However, in this specific case, the images are not found in the closest niches of the altarpiece, because they are placed in a more hidden position, and it is preferred, to give them greater importance, in the frontal niches.

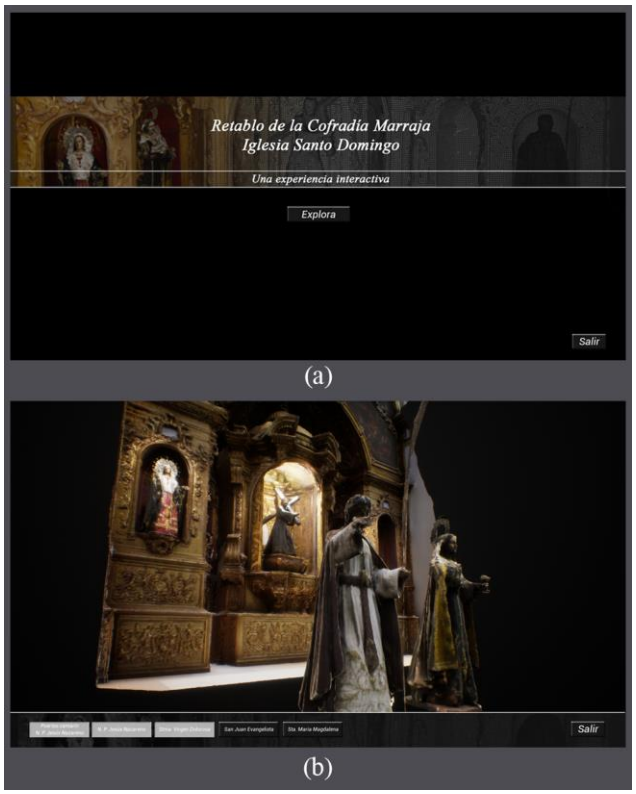

Fig. 16: Screenshots of the interactive application created in Unreal. (a) Home page. (b) A phase of interaction with the statues and the altarpiece

Thus, *María Magdalena*, is in the background, missing a *Verónica*, which currently the fraternity has commissioned to complete the gap of the other niche.

The interaction of this model is that the viewer seeks the correct position of the images in the altarpiece, appearing messages, indicating whether the chosen position is correct or not.[22]

[22] The present work has been carryed out within the projects "Aplicaciones geomáticas para el análisis, conservación y divulgación de los retablos barrocos" in the frame of the Plan I+D+i 2017-2020 of the UPCT and the project *Columnaria I. Comprender las dinámicas de los Mundos Ibéricos*, Código 19247/PI/14, de la Fundación Séneca.

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