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The Hybridization of graphic survey techniques in funerary architecture

Funerary architecture often presents a series of specificities that makes it necessary to combine different techniques for its adequate graphic restitution. These conditioning factors are usually present both in the exterior, such as nearby trees and metalwork elements, and in the interior, due to the arrangement of small objects and furniture as well as poor lighting in the rooms.
This paper focuses on the methodology followed for the graphic restitution of the Pedreño y Deu family pantheon in the main cemetery of Cartagena (Spain). The pantheon, built in 1875, consists of a circular chapel on the ground floor and a crypt below ground level. At the start of the survey, the building, protected by municipal planning, was in a state of advanced deterioration. The techniques used for the survey of each part will be described, as well as the procedure followed to assemble them into a single model. In this work, we have been able to verify that hybridization in survey techniques is one of the best options to represent architectural heritage in case studies where there are situations of very different natures.

Keywords:
Graphic restitution; pantheon; photogrammetry; rendering; cemetery

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1. INTRODUCTION

In the late 19th century, Cartagena underwent a period of economic expansion, triggering an architectural metamorphosis. Its municipal cemetery was no stranger to this architectural fervor, prompting a repertoire of funerary architecture (Pérez Rojas, 1986). The Pedreño y Deu family pantheon, designed by the architect Carlos Mancha, is one of the most significant examples of this tendency (Fig. 1).

The pantheon, about 20 m2, has a chapel on the first floor and an underground crypt. Its formal composition consists of a cylindrical volume with a hemispherical vault topped by a lantern, with access through a portico. On the main façade, this portico comprises Doric columns and a semicircular arch crowned by a pediment and flanked by three sculptures.
The building presents a series of specificities that make it necessary to combine different techniques for its graphic restitution. These conditioning factors are present both in the exterior, because of nearby trees and an ironwork fence delimiting the plot, and in the interior, due to the arrangement of small objects and furniture and poor lighting in the crypt (Fig. 2).
This paper focuses on the methodology followed for the graphic restitution of the pantheon. We describe the techniques used to survey each of the parts into which it has been divided owing to various problems and the procedure followed for its assembly into a single model.

2. BACKGROUND

Much has been written on photogrammetric survey experiences in funerary spaces, mainly focused on the world of archaeology in periods prior to modern history. External funerary monuments, as well as tombs, clusters, burials, and catacombs, have been surveyed using these techniques. Some examples are the Roman funerary monument in Villajoyosa (Ruiz-Alcalde & Charquero Ballester, 2014) and the virtual reconstruction of several hypogea in the necropolis of Qubbet el-Hawa (Martínez Hermoso, 2019), where external architecture is combined with excavated elements. In the field of architecture and applying these techniques to funerary monuments in modern times, there are studies on the damage caused by the Lorca earthquake in 2011, which affected the historic pantheons in the cemetery of that city (González Ballesteros et al., 2012), and multiple examples of combining terrestrial and aerial photogrammetry (Martínez Guillén, 2019) in small architectural elements.

Some other papers focus on three-dimensional survey techniques to document and analyze chapels and funerary monuments. Soria-Medina et al. (2013) used terrestrial laser scanning to create a 3D model of the Romanesque church

Fig. 1 - The Pedreño y Deu pantheon. David Frutos photography, 2020

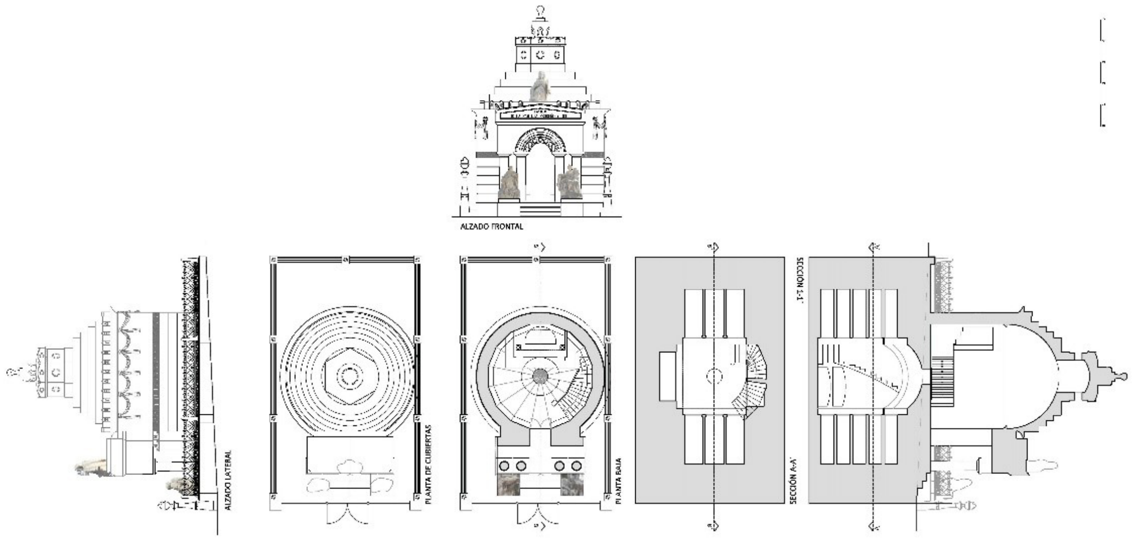

Fig. 2 - The Pedreño y Deu pantheon, 2D plans. Authors

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of Santa Maria de Castrelos in Spain. Bonora et al. (2005) used a multi-sensor, multi-resolution approach to survey Rucellai's Chapel in Florence, combining traditional measurement techniques with 3D scanning. Tucci et al. (2016) discussed the use of survey techniques to gain a better understanding of the Florence Baptistery, including a new laser scanner survey that gathered data from previously inaccessible parts of the building. Overall, these papers demonstrate the potential of three-dimensional survey techniques to provide detailed documentation and analyses of chapels and funerary monuments.
Closer to the subject of the study presented here, we find the methodology presented for the survey of the Peres i Rovira pantheon in the cemetery of Castellón (Bertacchi et al., 2020), which, although it does not include buried spaces, does address the HBIM survey. Along the same lines, we can consult the hybrid modeling process presented by Cabanes Gines and Bonafé Cervera (2020) for the Cortina family pantheon in the cemetery of Valencia, with similar proportions and characteristics to the one proposed here. This study corroborates that hybridizing survey techniques is one of the best options in these case studies.

3. WORKFLOW

The pantheon presents different lighting, color, and textural situations, depending on whether it is an exterior or an interior element. This makes it necessary to establish two strategies for its correct understanding in a single model: the realistic representation of the exterior (volume, color, light, texture) and an ideal representation (volume) of the interior (below ground level) (Fig. 3).

3.1. REALISTIC REPRESENTATION OF THE EXTERIOR (MODEL 1)

3.1.1. FIELD WORK

The exterior digital modeling of the Pedreño pantheon was carried out in the field using a 3D photogrammetric survey with topographic support from a total station laser. The choice of this methodology was based on the criteria of the functionality, consistency, precision, and performance of the workflow, where accessibility and the possibility of obtaining a final design with photorealistic texture prevailed over what other topographic procedures, like laser scanning, can offer. (García-Gómez et al., 2011) The laser scanner measures the surveyed object, obtaining the coordinates of the acquired points and so a point cloud after a postprocessing of the raw data. Also the mesh and its faces colours are generated by another postprocessing operation, but never with photorealistic texturing. Additionally this technique poses problems of access to the upper surfaces of the building, as well as some small motifs in the hidden angles of its geometry.This technique poses problems of access to the upper surfaces of the building, as well as some small motifs in the hidden angles of its geometry.
The pantheon is a small, classically-inspired modernist building about 12 meters high, with a cylindrical central plan, to which a hypostyle arch doorway is attached and on which rests a stepped dome and a prismatic lantern. Given these conditions for its external geometric definition, in addition to the ornamental and sculptural richness of human figures, acroteras, borders, inscriptions, cornices, auctions, and moldings with bas-reliefs, mainly added to the façade, the suitability of a photographic recording system that would be agile and adaptable to the polyhedral complexity of the architecture was considered. With more versatile instrumental positioning, the photogrammetric technique could provide us with complete coverage of each structural and decorative element in detail (Peinado Checa et al., 2014).

Fig. 3 - The Pedreño y Deu pantheon, exterior and interior (underground) final model. Authors

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The next question to determine was the type of cameras that should be used for the aerial and terrestrial registration, which would have to be processed to obtain a combined cloud of points with sufficient coherence and precision in the graphic resolution of the units. For the photogrammetric survey, from the lateral and upper aerial views, which also included the perimeter enclosure of the pantheon, a DJI Mavic 2 quadcopter drone was employed, equipped with a Hasselblad camera with a 20 Mpx sensor. It is an RPA (Remotely Piloted Aircraft) for professional use from the latest generation of aerial photography systems, characterized by its maneuverability, autonomy, and technological quality. The shots were taken at different flight levels following concentric trajectories around the building with circular overlaps (Fig.4), complemented by vertical passes in front of the façade from close front framings not hindered by the trees that border the cemetery promenade and also from the rear of the sculpture that crowns the main façade. In this way, 360 aerial frames of widely overlapping visual fields were taken with a wide-angle lens (26 mm focal length).

Defining the elements of the portal posed greater difficulty in the terrestrial positioning due to the variability of the visual angles and the proximity between the frontal shots and the motifs. The tetrastyle portal, built as a pronaos on a podium flanked in antis by two large seated sculptures, determined more complex situations to define both the rear spaces and the intercolumns, with surfaces rich in ornamental reliefs that made it necessary to shoot from short distances in the entire vestibular area.

The optical conditions necessary to digitally process the shots in the photogrammetric software included sharpness, homogenous focus, and equal lighting in all the image planes. Therefore, we decided to test different camera configurations to guarantee adequate depth of field and an optimal HDR (High Dynamic Range) to balance light levels.

The first test was carried out with a professional Canon EOS 5DS R camera, with a 50 Mpx full-frame sensor and a 24 mm wide-angle lens. Like the aerial shots, it was photographed in direct sunlight around noon at the end of June to reduce shadow projections. The bright sunlight reflected off the surfaces, helping illuminate the darker areas. While these bright summer conditions might work against photometric compensation, they actually worked in our favor in the ±1 EV HDR bracketing sequences (McCollough, 2009 & Nightingale, 2012) produced by the powerful Canon, improving the color tones in light and shadow and reducing the aperture to gain depth of field without forcing the sensitivity of the sensor beyond 400 ISO.

Fig. 4 - Sequence of 4 concentric aerial frames taken with the RPA to define the stepped dome and lantern of the pantheon. Authors

However, despite the high quality of the test carried out with the Canon, we encountered a serious workflow problem: the processing of the HDR bracketing by the Digic 6 of the EOS 5DS R greatly extended the shooting times, resulting in extremely long recording sessions with the consequent changes in lighting conditions from start to finish. Recording all the surface geometry of the portal, conditioned by very close framing, implied taking many hundreds of overlapping shots, producing very high-resolution images that also lengthened processing times in the photogrammetric application. Therefore, at this point, a fast and balanced photographic recording

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system was necessary, or in other words, we needed to take the photographs with a camera that provided sufficient resolution in an equalized tonal range, with focused shots, and with a rapid work dynamic. The solution was an Apple iPhone 11. With a wide-angle lens camera and 12 Mpx sensor, the A13 Bionic processor was capable of producing well-focused photos with intelligent HDR and the speed we were looking for.
Movements with the device throughout the lobby would have to be agile and stable to make the most of the same solar time zone in which we had worked during the aerial session since the terrestrial frames would have to be integrated later in the photogrammetric processing with the images taken by the RPA. By considerably reducing the weight of the camera, we could also take shots from higher altitudes using a telescopic monopod, controlling the shutter button with an Apple watch. Thus, we mounted the iPhone 11 on a small DJI Osmo 3 stabilizer or gimbal, shooting from a large number of zenithal, oblique, frontal, and nadiral angles. The final result was a block of 861 perfectly focused and equalized images, at least in the close-up and medium-length shots.
It is worth discussing here the recording of the ironwork fence that surrounds the mausoleum. Although the aerial and terrestrial shots included this element, we could not discern the detail of its geometry from the photogrammetric processing since it was too thin and complex to be defined by a cloud of points, no matter how dense. Only the masonry and foundry posts that segmented the layout could be defined in this way. Therefore, the ironwork was designed vectorially as an extruded 2D drawing for inclusion in the final model.
Finally, the eight support points were measured with a Leica TCR 407 total station laser, distributed proportionally throughout the building, and marked at well-defined vertices. The reference coordinate system (SCR) used was local, as it was a 3D architectural survey that was not intended to be included in a topographic map.

3.1.2. STUDIO WORK

Once the field photographic records were obtained and processed in .jpg without the need for further level editing, the photogrammetric processing began. The computer application chosen was Agisoft Metashape, based on the SfM (Structure from Motion) technique for geometrically analyzing pixel clusters from photographic perspectives with different parallaxes (Enríquez et al., 2020 & Martín Talaverano, 2014). The hardware used for the studio work was a high-performance Mac Pro graphic computer with a 3 GHz 8-Core Intel Xeon E5 processor.
We began constructing the photogrammetric model in the software by editing the integrated block of the cameras (air and ground), comprising 1,221 images calibrated and oriented according to the reference and support points taken with the laser station under the same local SCR. Since we had high-resolution shots and similar photometric characteristics, it was not necessary to break them down into two blocks for their subsequent fusion since the program recognized the framing between the aerial (the complete volume of the pantheon) and the terrestrial (portal detail) scopes and matched them consistently. The high-quality point clouds, both sparse and dense, were restricted and refined by their confidence level. The edges and vertices were also profiled by laboriously erasing the remaining noise points. The result was a dense cloud of 74 million points, with projection errors in the markers of less than 5 mm, which accurately matches the high-resolution photogrammetric methodology of laser scanning (León-Bonillo et al., 2022 & Marín-Buzón et al., 2021). The points of the ironwork enclosure were also removed from this cloud. They were later replaced with a CAD model.
After checking the geometry of the cloud, the textured mesh model was triangulated in a version with 2 million faces (Fig. 5), which defined all the external architecture of the pantheon together with its decorative and sculptural elements in great detail .
Finally, the textured mesh was exported in .obj

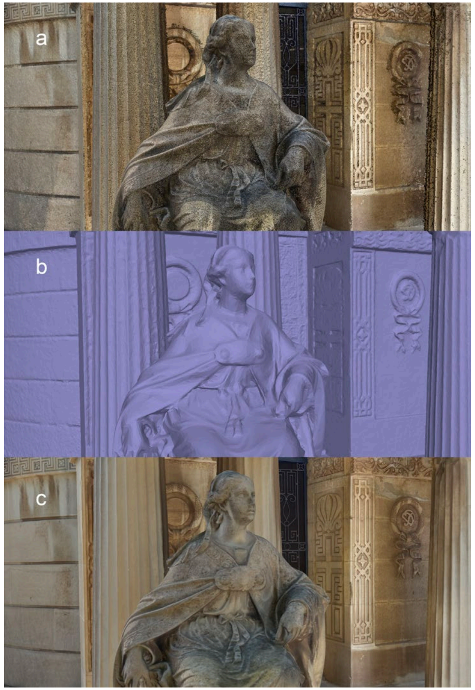

Fig. 5 - Detail of one of the sculptures in the portal in the photogrammetric model produced by Metashape: a) dense cloud of points, b) shaded mesh, and c) textured mesh. Note that the high density and quality of the point cloud present an effect very similar to the final textured model. Authors

to the Autodesk Maya 3D design software. In this program, the elements that could not be portrayed by the photogrammetric survey, mainly due to their size and details, were incorporated. This is the case with the iron fence surrounding the complex and the exterior and interior doors of the pantheon, which were modeled with CAD programs, creating a solid by extruding closed polylines.
This modeling was combined with the interior survey in another design and rendering application, thus representing the entire geometry of the building.

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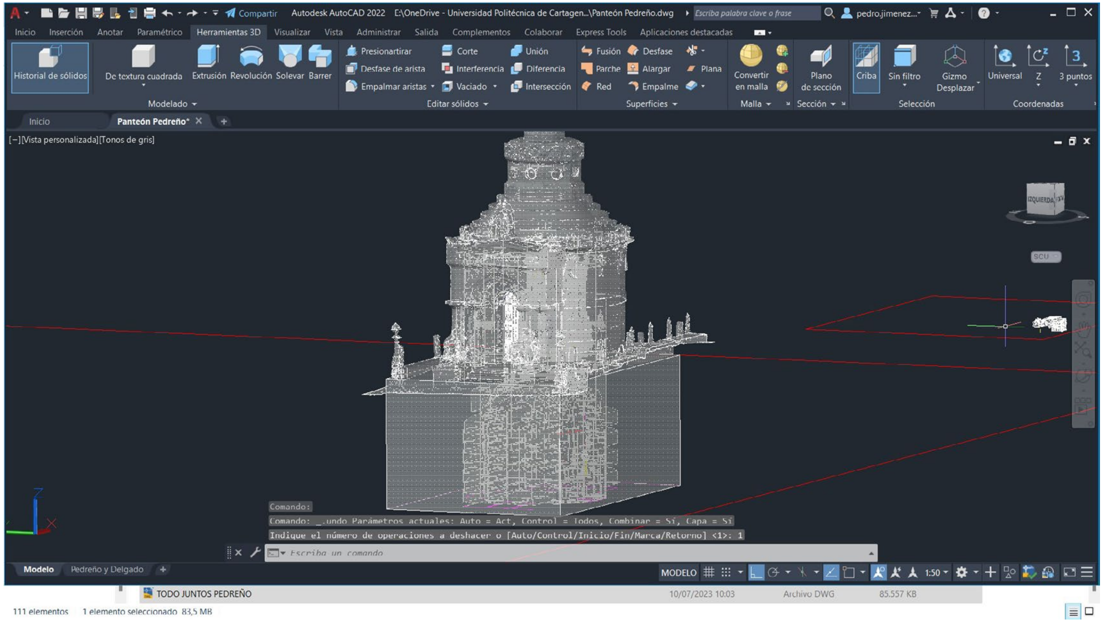

Fig. 6 - Assembling models 1 (above ground, exterior) and 2 (interior) from the same coordinate origin in the CAD workspace. Authors

3.2. IDEAL VOLUMETRIC REPRESENTATION OF THE INTERIOR (MODEL 2)

3.2.1. FIELDWORK

The exterior digital modeling of the Pedreño pantheon was carried out in the field using a 3D photogrammetric survey with topographic support from a laser total station. The choice of this methodology was based on the criteria of functionality, consistency, precision, and performance of the workflow, where accessibility and the possibility of obtaining a final design with photorealistic texture prevailed over what other topographic procedures, like laser scanning, can offer (García-Gómez et al., 2011). The laser scanner measures the surveyed object, obtaining the coordinates of the acquired points and so a point cloud after a postprocessing of the raw data. Also the mesh and its faces colours are generated by another postprocessing operation, but never with photorealistic texturing. Additionally this technique poses problems of access to the upper surfaces of the building, as well as some small motifs in the hidden angles of its geometry.

This was the first step to modeling the interior spaces, whose final result had to fit with the exterior model. However, the interior contained complex geometries that had to be approached with another methodology due to their complexity and the precision they required. This was the case of the altar, the baluster of the staircase railing leading to the crypt, a credential table, the pulpit, a bas-relief garland, and a medallion. A second system of interior measurement and survey, consisting of making digital models using photogrammetry, was employed for this purpose.

Photographs of each element were taken independently and then processed in the studio. The number of images taken depended on the size and complexity of the different models, ranging from 340 images of the altar to 36 images of the credential table. The camera, a dual 12 MP camera with 2X optical zoom and image stabilization, was that of an Apple iPhone XS.

3.2.2. STUDIO WORK

From sketching the interior spaces, we proceeded to the 3D CAD survey. The modeling was based on the plan and section drawings, with closed polylines that allowed the extrusion of solid volumes and surfaces of revolution. This facilitated formal operations of solid editing (joining, cutting, intersecting, difference, etc.) to obtain the final interior volume. During this modeling phase, the exterior model was taken into account, so both of them would coincide in the same workspace from a common origin of coordinates.

After surveying the interior spaces, we decomposed the model to break down its volumes into elements (surfaces). The main reason for taking this step was to eliminate the exterior surfaces of the walls and roof to avoid overlapping problems with the exterior digital model. The combination of the exterior and interior in the same workspace facilitated this operation by letting us visually check this aspect in the orthogonal views and perspectives. It also made it possible to assign layers to the surfaces generated for exporting to Autodesk 3ds Max, as well as assigning materials, light, and textures from that program.

Modeling the interior elements was performed with the Agisoft Photoscan photogrammetry program, which created digital polygonal models from the images taken. In creating the digital models, the color and texture information was not taken into account since the final interior rendering in 3ds

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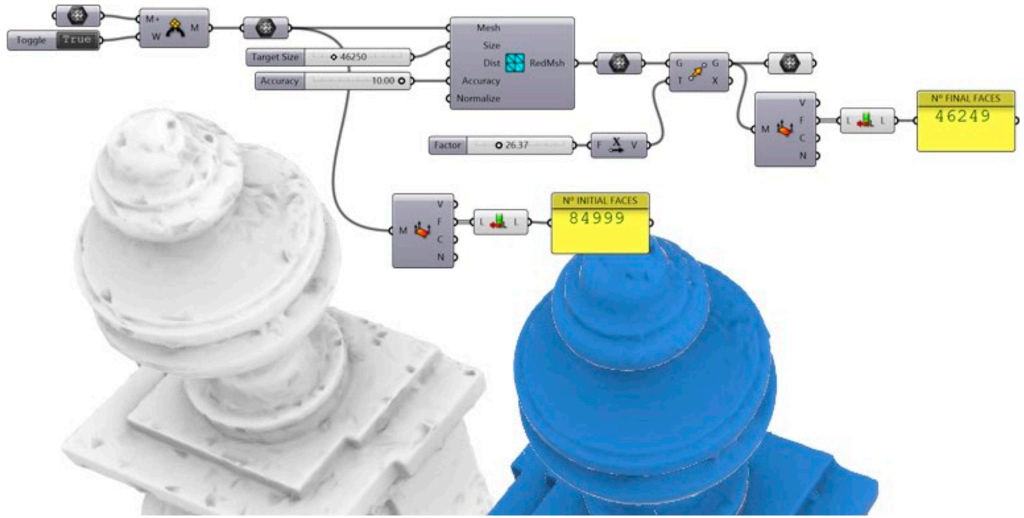

Fig. 7 - Programming in Grasshopper to decimate the mesh of the interior models of the pantheon. Authors

Max had to be ideal, in monochrome white for all the interior elements.

To correctly import the digital models into the CAD model of the interior space, it was necessary to optimize the polygon mesh of each of the models, looking for a balance between the desired final result and the performance of the equipment. The workflow for decimating the faces of the mesh consisted of exporting the mesh obtained from Agisoft Photoscan to ".obj" to import it to Rhinceros and Grasshopper. Using the image algorithm, the optimization of the mesh could be checked in real time. This same procedure could have been performed in Agisoft Photoscan, but its visualization would not have been possible in real time, resulting in increased work time.
After this operation, we imported the models from Rhinoceros to model 2 (CAD), as shown in the image.

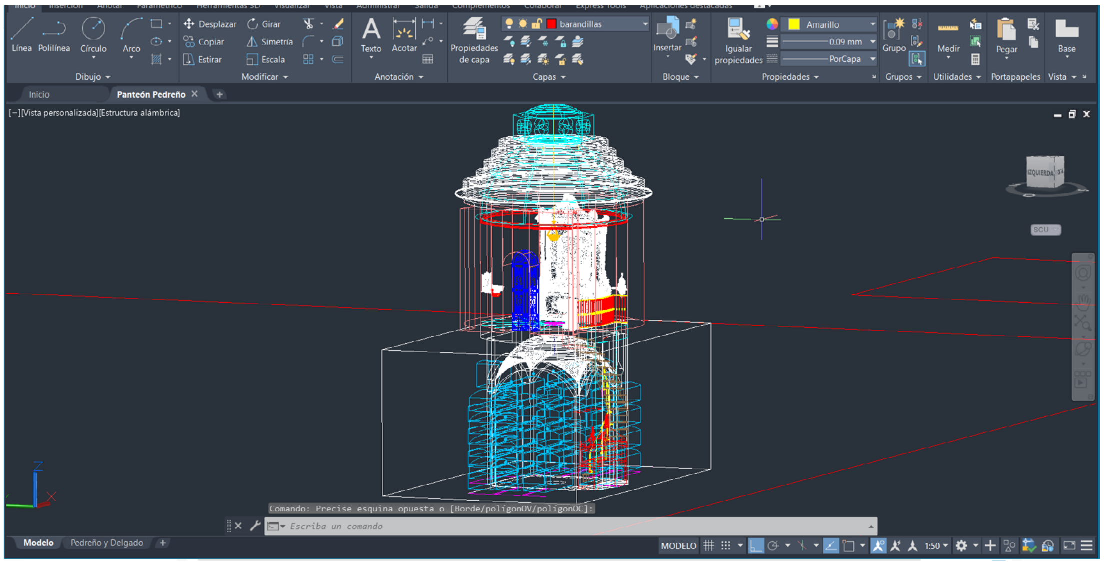

Fig. 8 - Final CAD modeling with the geometry defining the interior spaces and the interior models generated by photogrammetry and optimized using Grasshopper and Rhinoceros. Authors

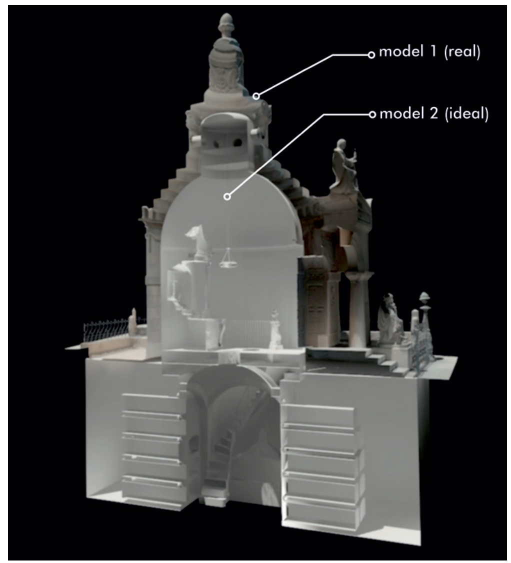

Fig. 9 - Models 1 and 2, 3ds Max integration. Authors

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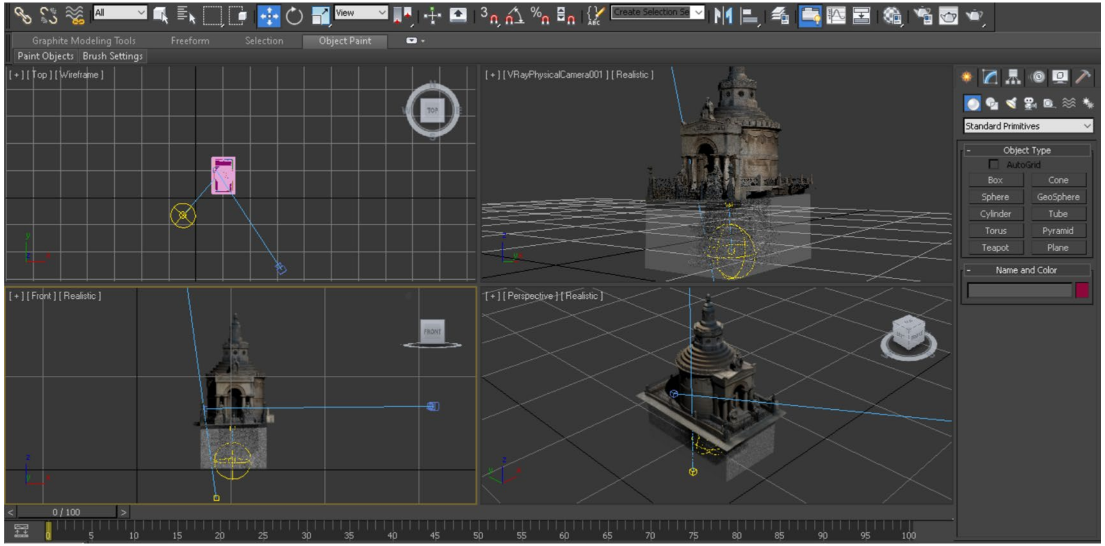

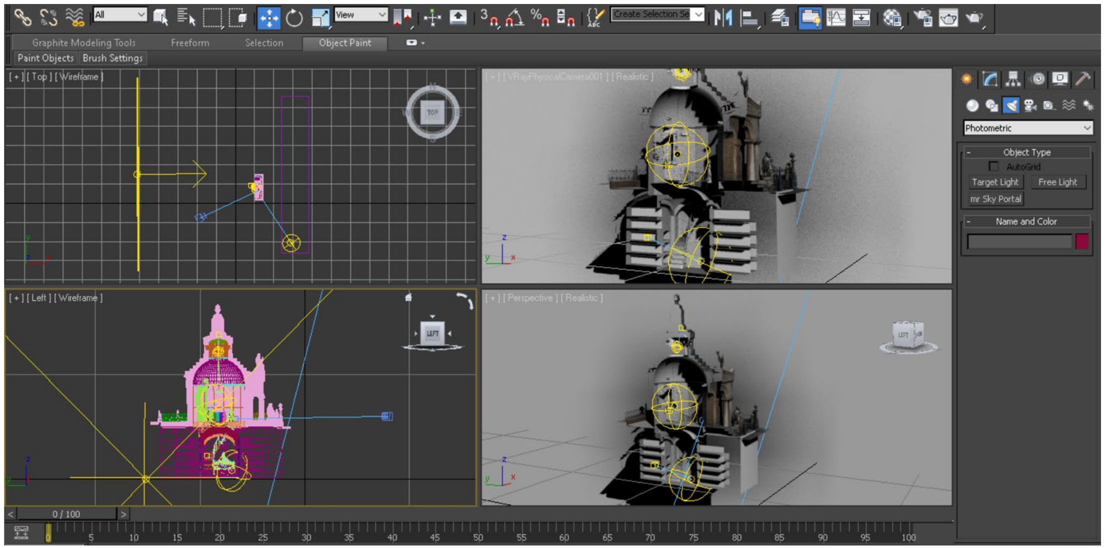

Fig. 10 - Exterior view of the above-ground part (model 1) and the below-ground crypt (part of model 2). Authors

Fig. 11 - Figure 11. Programming the rendering variables in one of the views where the sectioned pantheon, the cameras (blue), and the lighting (yellow) were shown. Authors

3.3. THE GLOBAL DIGITAL MODEL

Once models 1 (exterior) and 2 (interior) were completed, they were imported to 3ds Max, where their geometric compatibility and correct assembly were checked from a common point established as the origin of the coordinates.

To obtain the final images, exterior and interior physical Vray cameras and two types of lighting, Vray Sun for general scene lighting and Vray IES point lighting for the interiors, were used. The lighting of the real model digitized by photogrammetry was considered when positioning the lights. The interior lighting used Vray IES point lighting inside the crypt and the altar room. This interior lighting was configured to affect only the interior geometry, and it was ideal for defining the interior spaces. The material aspect of model 1 maintained the light, color, and textural information of the photogrammetric survey. The materiality of model 2 was achieved by applying flat white, with transparency or not, depending on whether it referred to the crypt (30% transparency) or the chapel (0% transparency). This semi-transparent configuration in the crypt allowed its centralized space and the volume occupied by the niches to be viewed. With this configuration, the images rendered with V-Ray Adv 2.00.03 were obtained from the different cameras arranged in the scene. The program itself made the sections by creating section boxes.

Finally, each image was post-processed with the vector graphics editor CorelDraw. The main objective of this last phase was to draw the closed contours and color fillings of the sectioned construction elements (walls, floor, floor slab, dome, etc.) for a better understanding of the spaces. We should point out that the model we worked on is not a solid but two meshes, exterior and interior, with an empty space between them.

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4. RESULTS

With the work described above, it was possible to create reliable documentation for the 3D modeling of the building, which constitutes a complete and exhaustive documentary record of the state of the building at a specific time. The methodology followed (dictated by a lack of financial resources) has made it possible to combine the faithful representation of the exterior (to which the CAD drawing of the ironwork fence was incorporated) with the modeling of the interior (Fig. 12).
This methodology included using the latest graphic techniques available: drone photography, photogrammetry, total station laser, computer-aided drawing, and 3D rendering. These techniques have made it possible to combine the representation of the exterior, made with photogrammetry (to which the CAD representation of the thinnest elements, such as the wrought ironwork, was added) with the modeling of the interior, where neither texture nor color was included. One of the main factors in deciding the techniques to be used in both models was economic. No resources were available to survey the exterior and interior of the building with the same degree of detail.

During this survey process, and due to the dissemination and interest in the work, the restoration project for the pantheon was commissioned, and at the time of writing this article, the work has been completed, restoring the building to the prestige it once had.

Fig. 12 - Pantheon. Left. Longitudinal section. Right. Longitudinal view. Authors

5. CONCLUSIONS

Graphic representation is a fundamental tool for documenting architectural heritage. Its uses are diverse. In addition to serving as a graphic record of historic buildings, it facilitates their documentation, study, and enhancement; it provides the necessary graphic support to prepare plans for an intervention project.
The techniques currently available for the graphic restitution of existing buildings are valid for the aforementioned purposes. However, all of them have nuances that make them more or less suitable depending on the particularities of each case. In view of the purpose pursued, the 3D photogrammetric survey is the most suitable technique for documenting and enhancing, as it provides a final representation with photorealistic texture. However, laser scanning, based on precisely measured and colored point clouds but without photographic texture, is a topographic procedure particularly suitable for producing technical plans.
Moreover, from this work, we have been able to confirm that hybridization in survey techniques is one of the best options to represent architectural heritage in case studies where there are situations of very different natures, as stated by Lodeiro Pérez (2010). Each of these situations has been considered independently, achieving a final graphic representation combining the two sub-models worked on independently.

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NOTE

[1] A 3D photogrammetric model of the exterior of the pantheon can be found at the following link: https://skfb.ly/6TURO

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