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TOWARD HYBRID MODELING AND AUTOMATIC PLANIMETRY FOR GRAPHIC DOCUMENTATION OF THE ARCHAEOLOGICAL HERITAGE: THE CORTINA FAMILY PANTHEON IN THE CEMETERY OF VALENCIA.

ABSTRACT

The current trend towards the hybrid methodology of combining terrestrial laser scanner (TLS) with close-range and UAV-assisted photogrammetry is becoming the most effective method for the complete capture of archaeological sites. In this work we consider three objectives in this regard: firstly, to check an integration procedure, based on different capture techniques, to obtain the best possible complete digital model in different situations related to size, lighting, and occlusions. Secondly, a "laser scanning with the help of photogrammetry" strategy for the operation with the different data sources, which allows to adapt the processes of photogrammetric orientation, cloud registration and automatic texturing, to the characteristics of each capture model. Finally, to present the digital edition of these models through automatic technical projections and realistic visualizations, to show their ability to interpret their geometry or share their knowledge, respectively.

Keywords

Hybrid Modelling, TLS, Photogrammetry, Archeological Heritage, Mesh Edition

1. Introduction

Due to their complementary, the combined use of terrestrial laser scanners (TLS) and close-range photogrammetry techniques allows us to obtain the best results. In general, "*Laser scanning can produce the dense 3D point-cloud data required to create high-resolution geometric models, while digital photogrammetry is more suited to producing high¬resolution textured 3D models, representing only the structure of the main object.*" (Guarnieri et al., 2011, p. 55). Photogrammetry has also become more versatile by the recent incorporation of Unmanned Aircraft Vehicles (UAVs), which "*has revolutionized the aerospace sector, reducing the cost and time required for spatial data acquisition*" (Fernández-Lozano & Gutiérrez-Alonso, 2016).

More and more attempts are thus being made to develop procedures that combine the best of these two capture techniques as applied to archaeological sites and artefacts. Authors such as El-Hakim et al., (2004), Lambers et al. (2007), Yastikli (2007), Al-khedera et al. (2009), Remondino et al. (2011), Alasino et al. (2012), Núñez et al. (2013), Colomina and Molina (2014), or Bilis et al. (2017), among others, report on "*the theoretical background, the methodologies and the latest advances in the documentation procedure, through digital photogrammetry and terrestrial laser scanning*" (Lezzerini et al. 2016, p. 10).

In the present work our objective is twofold; we first propose a specific TLS / SfM hybrid workflow to obtain a complete digital model applicable to different particular situations, and then show the graphic edition of the results in the form of automatic technical projections.

These two aims, as a whole, deal with an experience towards automatic planimetry for the graphic interpretation of the archeological heritage. "*At an archaeological site, both a record of the location of the objects and knowledge of the taphonomic process are necessary. (…) At this point, (traditional) 2D techniques, based on the compilation of hundreds of sections, are at a disadvantage with respect to new methodologies. (…) The 3D techniques display information on the spatial location of the objects, their textures and colours*." (Nuñez et al., 2013, p. 4421)

In this context, we here give the results obtained in our case study on the Pantheon of the Cortina family in the Municipal Cemetery of Valencia.

2. Integration of TLS and SfM Photogrammetry. Review of the technology.

For Rönnholm, P. et al. (2007) there are four integration strategies, based on the characteristics of the input data:

1. Integration at object level. In it, both TLS and photogrammetric data, are processed and interpreted separately, so that integration occurs in the final stage.
2. Photogrammetry aided by TLS. In this approach the depth information is selected from the laser data while the rest can be obtained from the images, so that registration in a common coordinate system is not essential. A typical example of this level is the creation of orthophotos using the scanner information to adjust the parameters of the transformation matrix.

3. Laser scanning with the help of photogrammetry. This approach is based in the joint registration of the data. The reference model is the most reliable scan, while the texturing is obtained from photos. This approach is useful to create very detailed final models.
4. Integrated laser scanning and photographic images at the device level, generally by mounting the two sensors rigidly on the same platform. This procedure involves taking laser scan and photos at the same time, limiting the points of view and lighting conditions.

Our work can be framed in the third strategy and involves an advanced approach in all phases: integrated capture techniques, obtaining digital models, and vector evaluation of them. A reliable alternative, that allow us to use the most appropriate methodology in each stage, compared to commercial applications of digital photogrammetry, which today represent the state of the art technology available in the market.

3. The Cortina family pantheon in the cemetery of Valencia.

The designer was the modernist architect José María Manuel Cortina Pérez (1868-1929), whose work is characterized by a marked tendency towards the fantastic, with a mixture of Gothic, Romanesque, Byzantine and Islamic elements. The pantheon in question, commissioned by the architect's father in 1899, contains an underground Crypt for the family, the entrance, and a small chapel in the upper part. In this work Cortina demonstrates his interest in formal variety and sculptural elements.

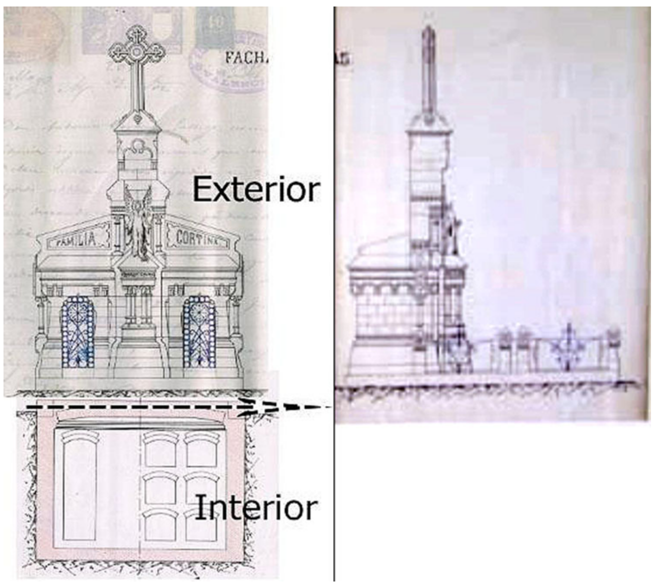

Fig.1. Original drawings by the architect. Access to the Crypt is by a staircase from the ground floor.

The access to the Crypt inside the Pantheon is through the door on the right, which can be seen in the front elevation, and then going down a narrow staircase.

4. Field acquisition

The appropiate methodology had to be developed to optimize data acquisition in order to obtain a survey of the model as complete as possible.

4.1. Data capture.

Data collection was by cameras on tripods (for the accessible outside and the Crypt), drone cameras (aerial photos), and laser scanner for the exterior and the Crypt. As in many archaeological surveys, therefore, it was necessary to use all the usual capturing procedures to adapt them to the conditions of accessibility and lighting of the model.

Tabla 1: TLS and photogrammetry parameters

TLS	Leyca ScanStation 2	
		Measurement accuracy (50 m)
		Position 6 mm
		Distance 4 mm
		Horizontal/Vertical) angles: 60 µrad/60 µrad (3,8 mgon/3,8 mgon).
		Range: 300 m @ 90 %; 134 m @18 % albedo
		Scan Rate: Up to 50.000 points/sec
		Spot Size: From 0-50 m: 4mm
Terrestrial Photogammetry	Camera Nikon 7100d on tripod	
		Sensor CMOS 24,71 megapíxel DX format 23,5 x 15,6 mm
		Objective NIKKOR 18-140 mm
		High Density AF - 51 points
		Standard ISO 100 a ISO 6400
		HDR (High Dynamic Range) images
Aerial Photogrammetry	Hexacopter DJI F550 with modifications	
		6 motors 960 kV
		Controller Naza-M + GPS
		Load capacity: 500 grs
		Battery: 3 u. 5200 mAh
		Flight autonomy: 35 min
		Modifications
		Autopilot system
		Automatic shooting system for camera (support printed in 3D)
	Xiaomi Yi Action Camera	
		Sensor CMOS Exmor R 16 megapixels (1/2,3 inch). 16:9 format
		Wide Angle lens ZEISS Tessar 155 degree. Aperture max. f/2,8
		Connectivity: WiFi, Bluetooth 4.0

Table 1. TLS and Photogrammetry parameters.

The Table 1 summarizes the main characteristics of the field acquisition equipment.

4.2. Forecast of shots and results.

In this project the goal was digitalization with a level of detail compatible with a planimetric reduction scale of 1:50, therefore with a minimum capture density of 50 * 0.2 = 10 mm on the real model[1]. This requirement is in accordance with the English Heritage Guidelines that recommend a recorded points output in the range of 9 mm in reality for a 1:50 scale. (McCarthy, 2014)

As regards the capture instruments, this involves a maximum shooting distance as follows:

- TLS Leyca Scanstation. It is easy to adjust the density of the scan process, since the stations are not going to be more than 50 m away from the model (see Table 1).

- Nikon D 7100 camera. According to its calibration data, this means shooting with the lens fully open at a distance less than d = 10 mm x 18 mm / 0.006 mm = 30.000 mm.[2]

- Xiaomi camera on the drone. In the same way, the maximum shooting distance: d = 10 mm x 6.5 mm / 0.012 mm = 5.416 mm.

5. Locations and data capture methodology.

Two very different areas were located for the data capture methodology: the Crypt and the exterior of the building.

5.1. Outside the Pantheon

The data capture by laser scanner was performed on a total of 4 locations. The first was in front of the stairs that lead to the crypt, in order to conect the exterior and interior series. The three remaining locations were placed in such a way that they completed the 3D survey of the exterior, and in accordance with the scanner specifications mentioned above.

[1] 0.2 mm is considered the graphic appreciation factor adjusted to a usual plannimetric lecture.
[2] 18 mm is the the minimum focal length, and 0,006 mm the size of the sensor photodiodes (pixel size).

The configuration of the terrestrial camera and the way in which the photographs are shot are very important. In order to obtain sharp images, the shooting protocol was as follows:

- Self-timer, necessary to avoid any movement.
- Reduced number of focal points to optimize autocalibration when processing.
- Aperture of the lens to the minimum (F / 22) to improve the level of detail.
- Low ISO sensitivity to increase the level of detail (ISO 125)
- Centre-weighted exposure metering mode, useful for matching the tonality of all the photograms.

The capture of aerial images was done shooting in wide angle photography mode for maximum aperture. The shots were made in burst mode (until 7 / sec), with the goal of discarding out-of-focus items, and with visual sighting through the native app connected via wi-fi to a smartphone.

Fig. 2. Aerial image of the pantheon with access terrace.

In the methodology used, the external and internal scans were registered separately for better precission, and then the model corresponding to the crypt was added to the exterior model, to obtain a single result.

The exterior shots from the tripod were overlapped, describing arcs around each portion of the model and combining rotations with respect to OX (pitch) in order to register all the faces with sufficient redundancy and frontality for the automatic photomodeling process (Ortiz et al. 2006).

In the aerial shots, for the same characteristics, the route of the UAV was planned using the NAZA controller autopilot system with GPS, to guarantee the safety of the mission and a stable camera platform. (ft. Autonomous Flight & Position Hold).

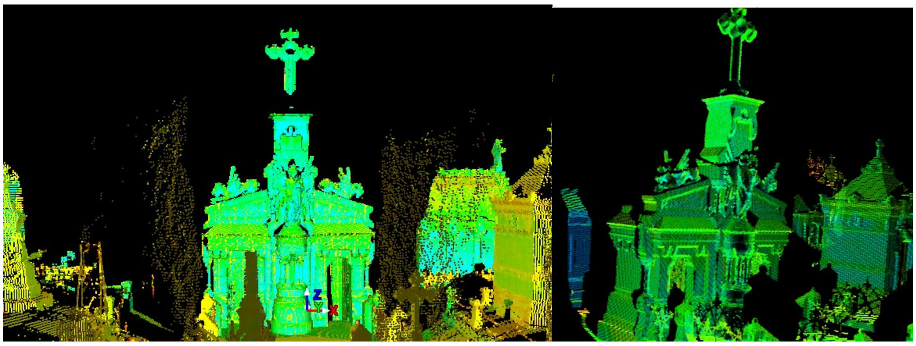

Fig. 3. Scanning of the exterior.

5.2. Inside the Pantheon. (The Crypt)

Due to its reduced dimensions, the Crypt was photographed in a circular series of closely placed shots with a flash on the camera. The texture information was registered to be used later in combination with the laser scanning.

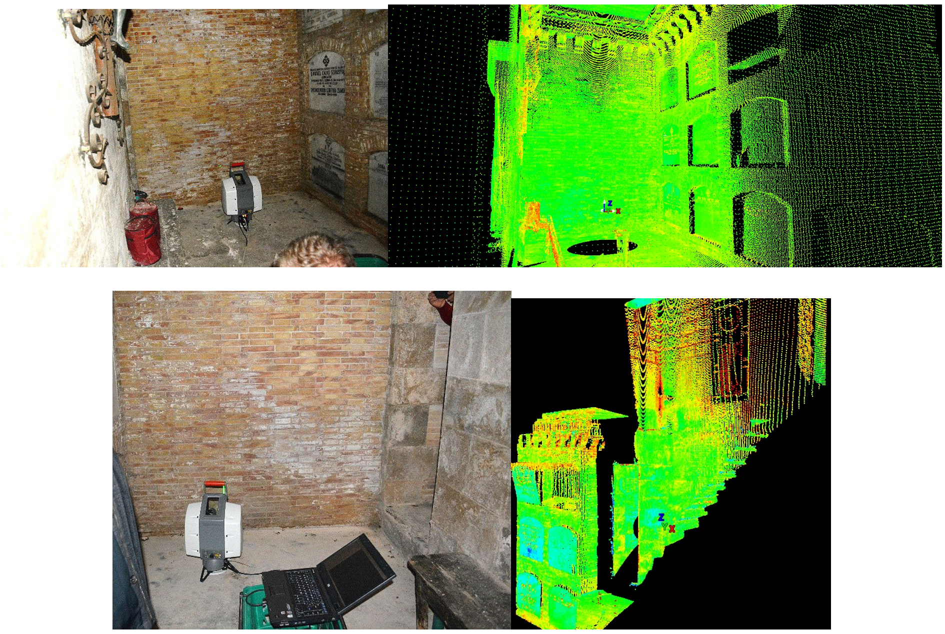

Fig. 4. Scanning of the Crypt. A total of four scans were made in the internal area of the Crypt: two in the burial chamber, one around the staircase, and another for the rest of the Pantheon with the scanner placed on the narrow staircase capturing a partial view of the exterior.

6. Hybrid workflow for the formation of the digital model.

The hybrid approach started by obtaining a reference model from the necessarily incomplete, but reliable, exterior TLS capture, since it did not include the upper section, and then register the other laser and photogrammetric models. The workflow therefore followed the third of the integration strategies described above, i.e. automatic camera orientation and the registration and mapping of textures with respect to TLS data.

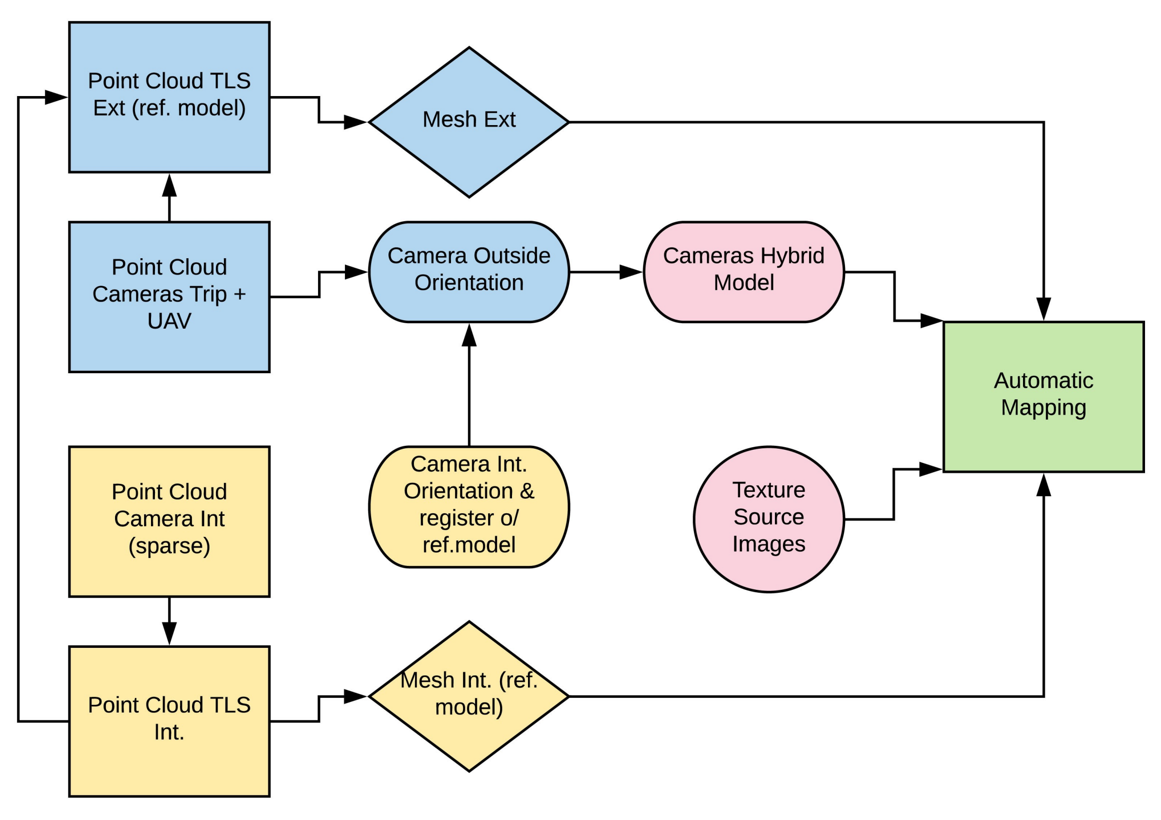

Fig. 5. General chart of the hybrid workflow.

Both the land-based and aerial photogrammetric acquisitions were used to complete the laser point cloud and obtain phototextures of the whole exterior model. The complete absence of natural light inside the Crypt required special data treatment.

Free software was used in the different phases of the process to give us the necessary versatility for the particular characteristics of the project.

6.1. Processing the reference TLS model.

Our reference model was the 3D information from the point cloud of the exterior laser scanner capture, since it had greater precision than the dense photogrammetric point cloud. This point cloud was registered in a local reference system and provided real dimensions of the building.

The four exterior scanning stations were registered in the same reference system by a point-to-point procedure (with a minimum signaling of 4 common pairs of points), including the ICP (Iterative Closest Point) optimization algorithm, to minimize the differences between each two point clouds (translations, rotations and scale).

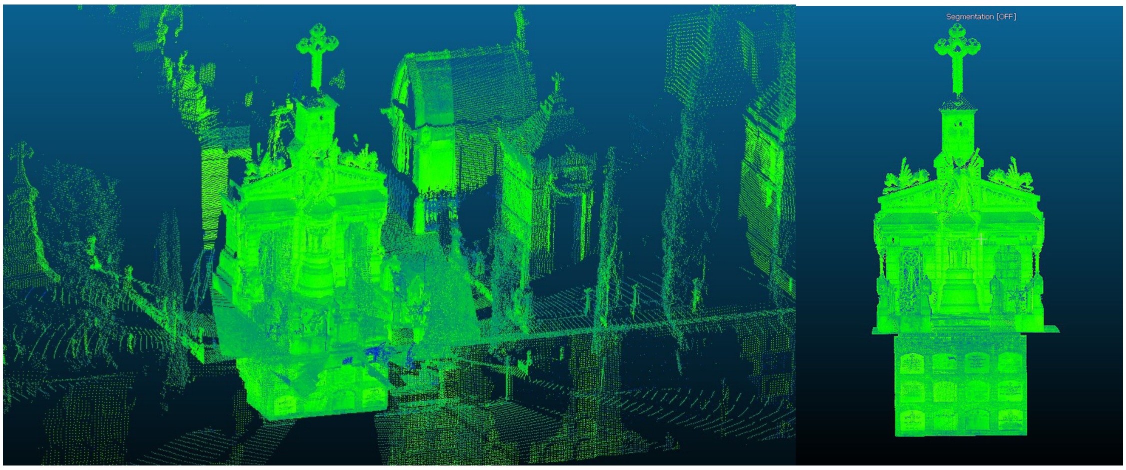

Fig. 6. TLS reference model and the Crypt scan registered.

Once the point clouds had been registered and merged (with an accuracy below 7 mm at all points) we trimmed the model, cleaned up imperfections such as redundancies, and filtered isolated point clusters below a certain threshold.

The laser capture of the Crypt, also taken from four stations, was then treated in the same way.

6.2. Photogrammetric models.

Two different situations were found in the photogrammetric planning. First, the reliable but incomplete survey of the exterior, to which we had to add the obviously less reliable aerial capture of the top of the model. The conditions inside the Crypt were very different, as there was sparse lighting and the photographs had to be taken with a flash, so that a very careful reconstruction of the scene was required.

Although our photogrammetric workflow did not differ from the basic scheme of an automatic SfM (Structure from Motion) project, we tried to solve the different phases with free software, which allowed a more precise control of the process than most commercial applications.

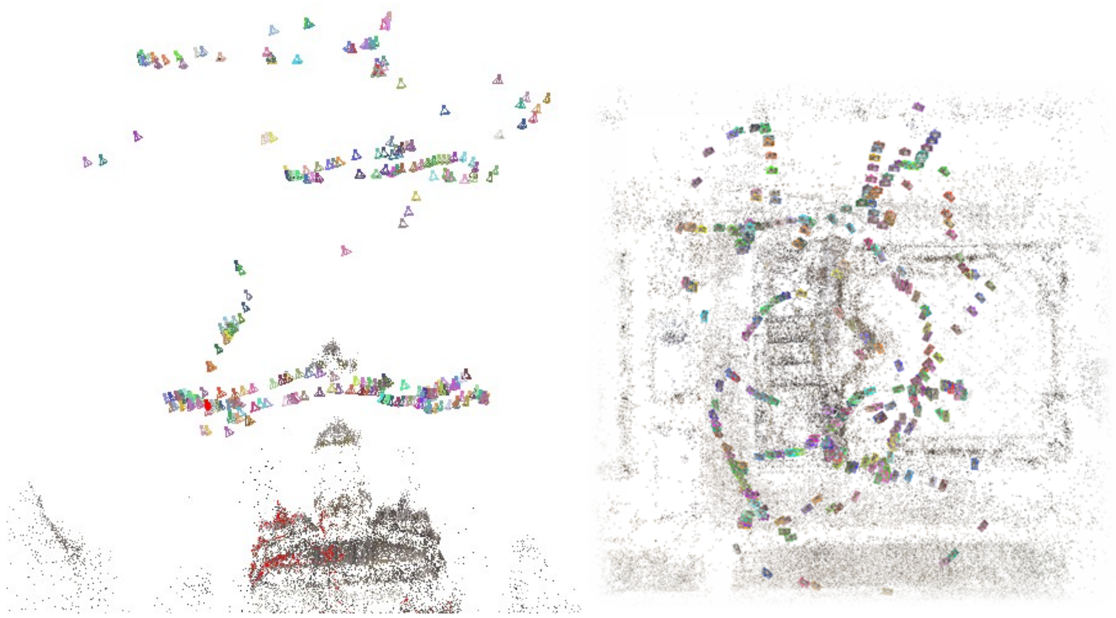

Fig. 7. Aerial capture by drone.

To improve the accuracy of the exterior model we prefixed a sequential matching analysis with a maximum of 25 images and added masks to some of them, to avoid the SIFT algorithm identifying distant points that might have considerably increased the global error.

As the accuracy of the terrestrial capture was better, it was used to form the first camera model, and we then added the aerial photograms with prefixed exterior orientation to the first. The complete exterior photogrammetric model consisted of a total of 294 photograms.

In the Crypt photogrammetric model, formed by a total of 54 images, as the camera parameters were not the best, due to the artificial lighting, we adopted the following basic adjustments to align the model these unfavourable conditions:

- Key Points: as we only had a few low quality shots, we worked with the whole frame size.
- Matching: all the photographs were used for the full matching window.

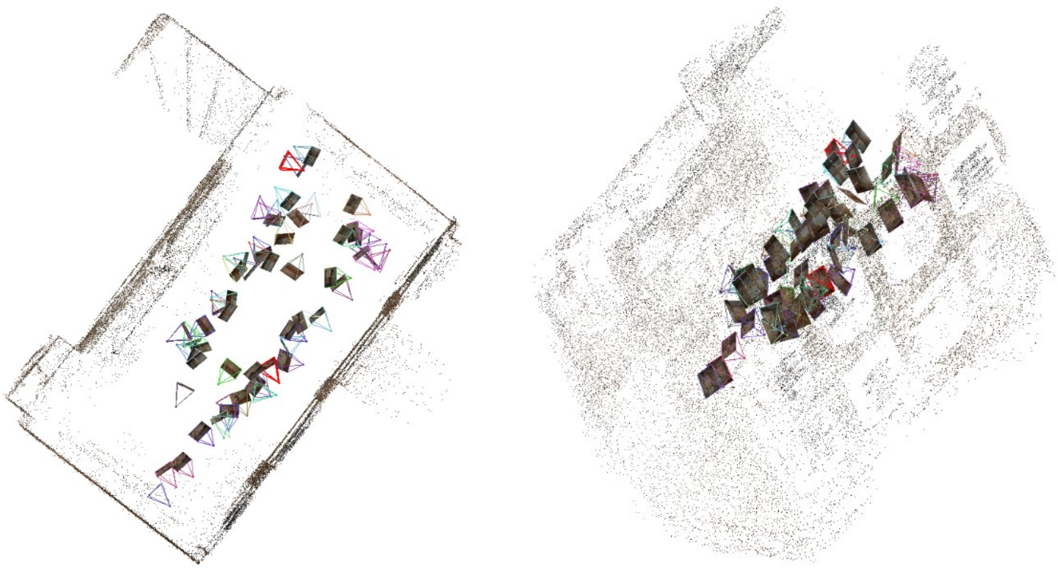

Fig. 8. TLS and photogrammetric models of the Crypt.

6.3. Registration and merging: TLS and photogrammetry.

Several registrations of the different data were necessary to prepare all of them for a staged automatic texturing process, i.e. providing the data to a stand-alone plug-in, as described below.

The complete exterior capture was obtained by registering the dense point cloud of the photogrametric model with respect to the TLS reference model, and treating this as fixed to transform its coordinates, rotations and scale factor.

To perform this operation it is advisable to use a Fine Registration procedure, based on the ICP algorithm, adjusting the number of iterations until the RMS difference between two of them is below a given threshold. For this, some previous settings are necessary: both captures must be previously roughly registered and represent the same model in the overlapping part. A noise filtering is then carried out to eliminate duplicated points.

For the registration of the two photogrammetric clusters of aligned cameras with their respective laser captures we used the signalling control points procedure to calculate a spatial transformation of the coordinates. A minimum of 6 pairs of points were selected with uniform distribution in each data base for the optimal results.

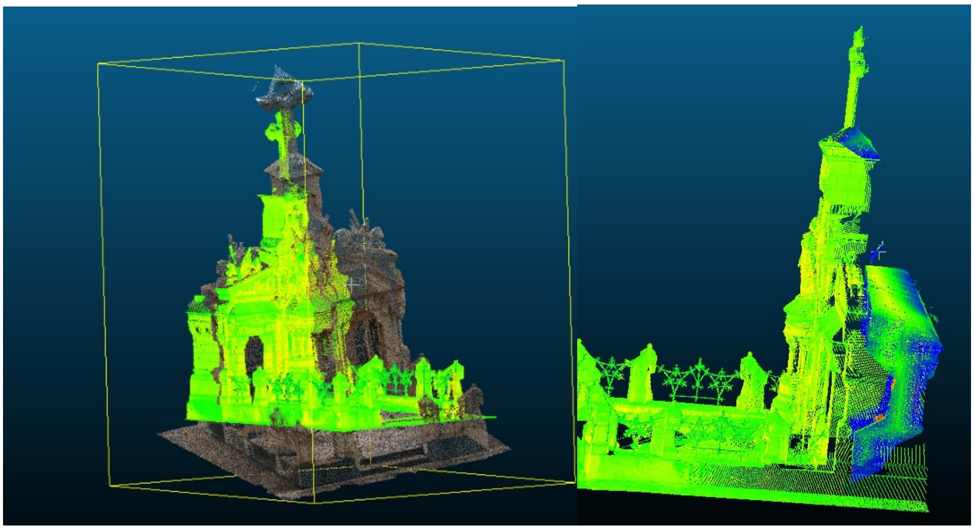

Fig. 9. The two overlapping exterior point clouds ready to implement Fine Registration.

In the Crypt model, obviously with a more sparse cloud of tied points, we also checked the accuracy of this transformation by computing the final cloud-to-cloud distance, and obtained an average error of 0.005 m. with RMS = 0.02 m., values that allow us to proceed with the mapping.

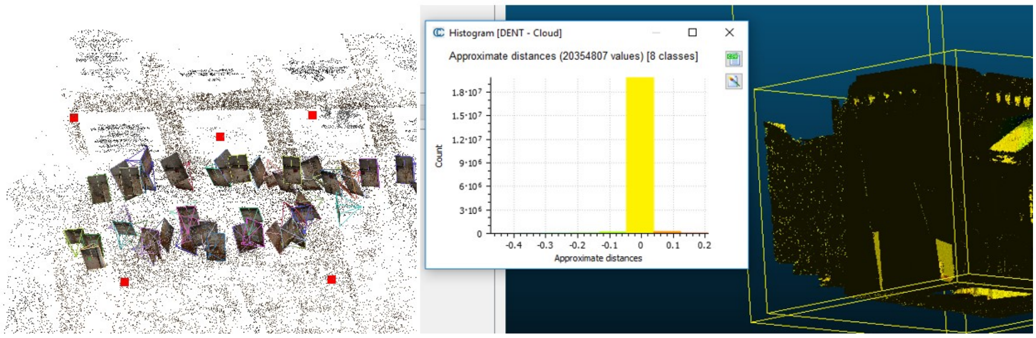

Fig 10. The Crypt model. Control points for the registration of all data, and statistical values of the transformation.

6.4. Generation of the two DSM.

The inner and outer dense surface models (DSM) were generated separately for greater precision.

We used the Poisson Surface Reconstruction algorithm, whose reliability is widely recognized, after calculating the normals of each cloud, and adjusting the "number of connected neighboring points" factor (knn), to guide the faceting process.

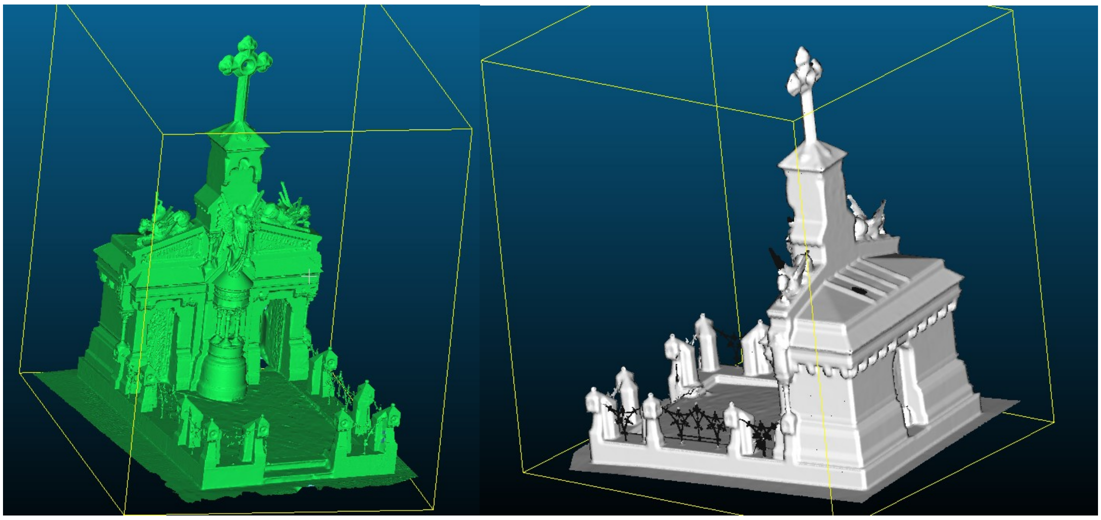

Fig. 11. Exterior mesh.

For the triangulation, the Octree depth recursive sub-sampling factor was tested until the quality of each mesh was optimal in relation to the density of its own point cloud.

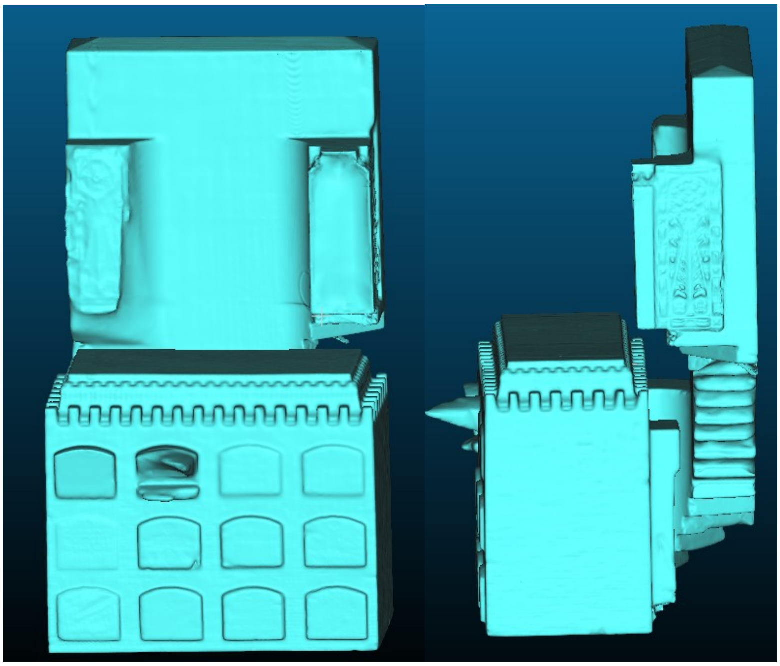

Fig. 12. Interior mesh including Crypt and staircase.

The small holes were then closed to ensure realistic final texturing.

6.5. Texturing the models.

After completing both meshes, unlike the usual photogrammetric workflow, a free software staged texturing process was implemented and adapted to the hybrid model. The question of an effective automatic approach for texture mapping onto 3D complex meshes has been described by authors such as Alshawabkeh & Haala (2005), El-Hakim et al. (2008,), or Lerma et al. (2010), among others.

In our case we achieved the automatic mapping of the cameras using the MeshLab editor plug-in "Parameterization + Texturing from Registered Rasters", and adapting it for processing many at once.

This algorithm uses the weights of the distance to the camera and to the image border in the calculations to create some "*patches that correspond to projection of portions of surfaces onto the set of registered rasters*" (MeshLab tool interface help). This ensures that the closest and most contrasted images with respect to the reference model are chosen for texturing.

Fig. 13. Staged automatic texturing of the interior mesh.

The software requires: (i) the mesh of the reference model to map on; (ii) the list of coordinates of the oriented cameras (e.g. in .out format); and (iii) the list of texture source images, registered in the same coordinate reference system. For this we programmed a little script that generates the data automatically using Python programming language.

The exterior and interior models were textured separately for the best results.

7. Automatic interpretation of the hybrid model

Finally the two textured meshes were registered from the overlapping area around the staircase. Since the meshes only partially overlapped, instead of the previous rough registration, we used some pairs of matching points as data.

The final result was a complex set formed by a combination of different processing techniques, as already mentioned. Both the Dense Cloud and the hybrid DSM offer different ways of documenting an archaeological survey.

Fig. 14. Front and rear orthophotos. The Crypt has double sided mapping of the mesh.

The orthogonal phototextured projections obtained from the mesh were in themselves a more accurate characterization than the traditional photogrammatic rectifications, since the metric quality of the planes parallel to the base projection is preserved with depth.

It is also possible to parameterize both results. The Dense Cloud yields 2D sections computed as polylines, and also 3D slices as new clouds, with a fairly sharp interpretation, unlike the meshes, which tend to round it.

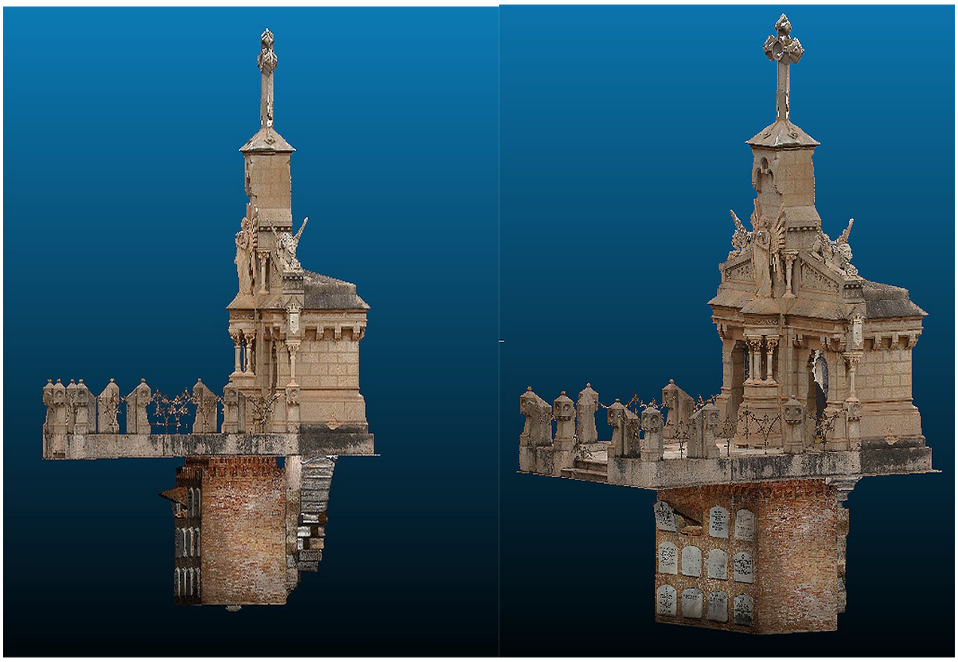

Fig. 15. DSM side views.

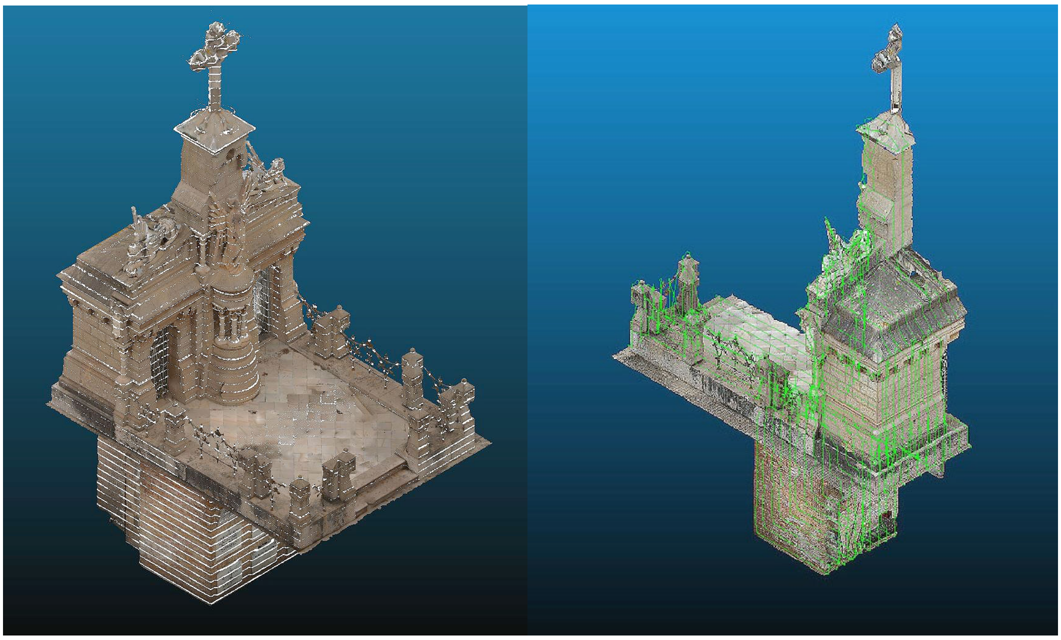

Fig. 16. Horizontal and side 2D sections of the Dense Cloud.

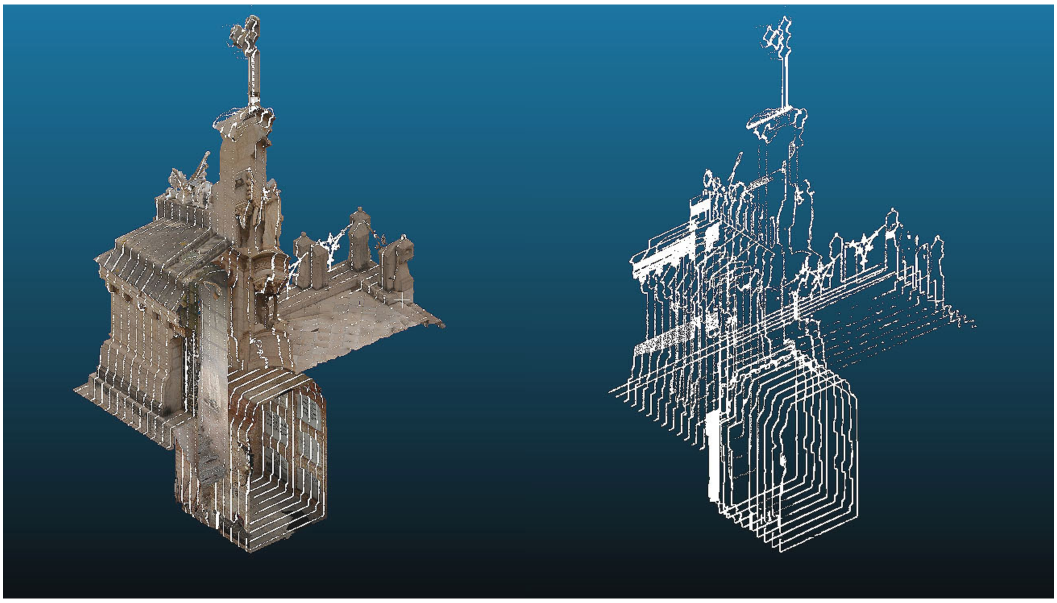

Fig. 17. Lateral 3D thin slices of the Dense Cloud.

In addition to 2D and 3D cuts, the DSM allows to obtain edges of the model by means of evaluating the abrupt change in the direction of the normal vectors of nearby triangles, giving rise to a reliable straight edge interpretation of the model. These parameterizations from point models result more reliable than from meshes, since "*point-based representations have proven to be a valuable alternative to polygonal meshes in several special applications. In particular when highly complex or dynamic models are to be processed and a proper surface topology is not necessarily required*". (Kobbelt and Botsch, 2004, p. 19)

It is also possible to evaluate some reverse engineering post-process tools at the linear editing level, such as curves or silhouettes, or 3D primitive fitting. These are obtained automatically by the appropriate operations, i.e. without significant manual geometric interpretation by the operator.

8. Conclusions

This paper describes the overall process of digitalization of an archaeological model with the common difficulties involved in this type of work, generally above-surface elements that require capturing by a drone, and interiors with poor lighting conditions.

We have developed it with a methodology apart from the commercial applications of digital photogrammetry, which has led to a specific restitution workflow adapted to the conditions of the project. For the formation of the hybrid model, the integration strategy "laser scanning with the help of photogrammetry" has been followed, although with a different methodology in the aerial part (where it was possible to work together with cameras on tripod and on drone), and in the underground part of the Crypt, with problematic conditions for data capture, and without great technical support. The processes involved have consisted essentially of: formation of the two digital models according to the characteristics of each capture (obtaining clouds of points and meshes in each case), data registration TLS - Photogrammetry, and finally, automatic mapping of each photogrammetric capture over its corresponding TLS mesh, always more reliable, processing it all at once.

All these stages have been solved by means of free software and optimizing the parameters involved, without subjecting ourselves to the restrictions required by the commercial software packages currently available in the market, so that an ad hoc methodology like this one, must guarantee, in principle, a greater reliability of the results.

On the other hand, we have successfully tested editing tools for automatic linear interpretation of the digital model, in the form of 2D and 3D sections of vector type. Along with the edition of quality phototextured meshes from the hybrid model, they show useful results for the metric and documentary recovery of an archaeological model like this.

In summary, this hybrid workflow is an advance that broadens the scope of this captation projects, insofar as *"... the methods and technologies used to survey the intrinsic characteristics of the objects (geometry, topology, texture), advance a level of analysis capable of achieving a critical recovery* " (Bianchini, 2014, p.17). Likewise, the photorealistic rendering of these models is also a promising way to bring people the knowledge and appreciation of an essential aspect of the archaeological heritage through many formats, such as those related to immersive navigation (virtual reality, augmented or mixed).

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