Proceedings of the joint international event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES, Valencia (Spain). 26–28 April 2021

Received: 30/11/2020
Accepted: 17/03/2021
DOI: https://doi.org/10.4995/Arqueologica9.2021.12153

COMPARATIVE INVESTIGATION OF THE 3D REPRESENTATIONS OF THE HOLY AEDICULE OF THE TOMB OF CHRIST

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Abstract:

The significance of preservation of cultural heritage is undeniable, which is why both their geometric documentation and the creation of their digital “twins”, i.e., reconstructions and replicas at any scale, are essential procedures. A special category of cultural heritage is sacred sites which combine historical, spiritual and religious values. The most sacred monument of Christianity is the Holy Aedicule covering the Tomb of Christ in the Church of the Holy Sepulchre in Jerusalem. This paper aims to investigate and compare the various three-dimensional representations of the Holy Aedicule of the Tomb of Christ, which exist both in physical and in digital form. Initially, the main structural phases of the Aedicule are presented, including its destructions and restorations. Moreover, the different categories of the three-dimensional representations of the monument are defined. With reference to the replicas, both the reasons of their construction and their list in the form of a dataset table are presented. More specifically, in the context of this research, the three-dimensional representations of the Aedicule are divided into two major categories: the replicas constructed worldwide and the geometric documentations of the monument's condition through the years. Regarding the replicas, a list of the discovered representations is created, and this database is visualized and depicted in an online web map along with essential information with the use of an open-source Geographic Information System (GIS). Based on this visualization an online web map has been created. Furthermore, the previous geometric documentations and surveys of the Holy Aedicule of the Tomb of Christ are presented. A comparison is conducted between the 3D models of the Aedicule, which were created by the University of Florence in 2007-8 and the National Technical University of Athens in 2015-17. The impact of the Holy Aedicule across the world is examined through statistics based on the type, date of construction and location of the replicas. The possible deformations of the monument's structure are detected from the assessment of the results from both the processing and the comparison of the 3D models. In conclusion, future works are suggested focusing on the discovery of the total number of replicas worldwide and the monitoring of the condition of the Aedicule.

Keywords: cultural heritage, geometric documentation, three-dimensional representations, online webmap, digital photogrammetry, 3D reconstruction

1. Introduction

Sacred sites are considered to have a major impact on the various religious communities across the world. The vast number of the existing shrines, which can be detected globally, is strong evidence of both the devotion and the veneration of the faithful. Moreover, they constitute a symbol of the spiritual beliefs and values that are inherited from previous generations (Alexopoulos, 2014). Consequently, sacred sites differ from other forms of cultural heritage and represent a unique category, which demands a particular approach as far as their conservation and preservation are concerned.

Among all the sacred sites of Christianity, there is one which is acknowledged as the most important monument, because it proves the authenticity of the Christian belief. This is the Tomb of Christ located in the Church of the Holy Sepulchre in Jerusalem, which verifies the entombment and the resurrection of Christ in the eyes of the Christians. The Holy Aedicule, a small edifice surrounding the tomb, was erected in order to protect this valuable shrine. As a result, the documentation of the Aedicule's condition and its preservation is vital and should be a priority.

Focusing on the practices for the documentation of religious cultural heritage, such as the Aedicule of the Tomb of Christ, the most appropriate methods will accurately represent the monument without causing any damage to the original. Special treatment and sensitivity are required (Alexopoulos, 2014). 3D modelling with the implementation of laser scanning and digital

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photogrammetry are non-destructive techniques that offer new perspectives for three-dimensional cultural heritage recording, with precise and representative outcomes.

The main purpose of this paper is the research on the three-dimensional representations of the Aedicule of the Tomb of Christ, which consist of the replicas and the geometric documentations. The main structural phases of the Holy Aedicule, from the day of its erection until the present day, are presented to better perceive the evolution of the form of the monument.

Regarding the three-dimensional representations of the Aedicule and more specifically the replicas, their locations around the world are detected and archived, with the aim of creating a list with their name, type, date of construction and image. Afterwards, this database is visualized and digitized with the use of an open-source Geographic Information System (GIS). The final goal is the creation of an online interactive web map, which depicts all the spatial and attribute data related to the replicas.

Furthermore, the various geometric documentations of this significant edifice are highlighted and some of their data are further processed. From the analogue data which were acquired by the National Technical University of Athens during a metric survey on the monument in 1995, an attempt is made in order to construct a new 3D model through digital photogrammetry. Additionally, a comparison is carried out between the two 3D models of the Aedicule created by the University of Florence in 2007 and the National Technical University of Athens in 2015. In this way, both the alterations and the deformations of the shape of the edifice through time are detected, with the creation of 2D drawings and the application of the multiscale Model to Model Cloud Comparison (M3C2) algorithm, which computes the local distances between two point clouds.

2. Structural Phases of the Holy Aedicule

Many cities in the world are characterized by great religious significance because they are places where either an incident of a saint's life had been recorded or many sacred sites are located. Jerusalem is a historic city that attracts numerous pilgrims not only from different parts of the globe but also from different religions. Its uniqueness derives from the multiculturality and the fact that it is identified as the Holy Land for three major religions: Christianity, Judaism and Islam.

Jerusalem is one of the most famous pilgrimage sites, especially for the Christian community, since it is the Holy City where the scenes of Christ's crucifixion, burial and resurrection took place. The Holy Rock of Golgotha (Calvary), the Tomb of Christ and the spot that parts of the Holy Cross were discovered are enclosed within the Church of the Anastasis (Resurrection) or the Church of the Holy Sepulchre, which is located inside the walls of the Old City of Jerusalem (Fig.1).

Many Christian Communities coexist within the Church of the Holy Sepulchre. The Greek Orthodox, the Roman Catholic Franciscans, the Armenian Apostolics, the Copts, the Ethiopians and the Syrians represent the Christian Communities that are all active and each one "owns" different sections of the monument. The respectful sharing of common areas for religious ceremonies is achievable due to the Status Quo of the Holy Sepulchre, which defines the ownership, the rights and the privileges of each community (Georgopoulos et al., 2017). The most vital religious shrine that all Christian Communities are devoted to and attract thousands of pilgrims from around the world is the Tomb of Christ.

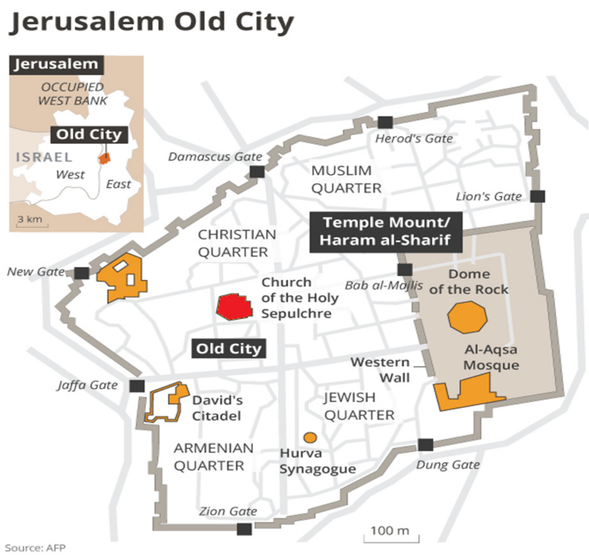

Figure 1: The Church of the Holy Sepulchre in the Old City of Jerusalem © Middle East Eye 2020.

The Tomb of Christ reflects the belief in the miracle of the Resurrection and reinforces the Christian faith because it is evidence of the events described in the Gospels. The rock-cut tomb, where it is believed that Christ was temporarily entombed after his crucifixion, is enclosed within a small edifice called the Holy Aedicule or Kouvouklion (Κουβούκλιον) in Greek. This structure, which is protecting the holiest monument of Christianity, is located at the western side of the Church of the Holy Sepulchre, underneath a tall cylindrical building called the Rotunda. The Aedicule has undergone multiple structural alterations through the years due to successive destructions, damages, earthquakes, fires and attempts of reconstructions.

The first Aedicule was erected by the Roman Emperor Constantine the Great in 326 AD, whose mother, Empress Helena, discovered Christ's Tomb. The main characteristics of its structure were a porch which consisted of four columns and a gable roof leading to the Tomb chamber at the western side. The burial chamber was surrounded by five decorative columns and had a conical roof (Fig. 2) (Biddle, 1999).

The first destruction of the monument occurred during the Persian invasion, led by emperor Chosroes II in 614 AD. Both the Church of the Holy Sepulchre and the Holy Aedicule were damaged to a great extent (Jeffery, 1919). An attempt for their reconstruction was carried out in 629 AD by Abbot Modestos. Although in 1009 AD Khalif Al-Hakim Bi-Amr-Allah ordered the complete demolition of the Church of the Resurrection, the Tomb of Christ was possibly injured but eventually it was not destroyed (Macpherson, 1892). The following years the Byzantines undertook a restoration to the whole complex. Concerning the Aedicule, its form was preserved and was similar to the initial edifice built by Emperor Constantine.

In 1009 AD Jerusalem was again under the control of Christians until 1187. During this period, slow progress of reconstruction had begun. The form of the Holy Aedicule was modified with the adjustment of four additional elements which were never significantly altered until the present day. More specifically, these features are an eastern room fully integrated with the rounded western structure (now the Chapel of the Angel), a cupola over the burial chamber, a chapel attached to the west end of the Aedicule (now the Coptic Chapel) and two benches, which were placed at the entrance on the sides of the door of the Aedicule (Fig. 2) (Biddle, 1999).

The state of the Aedicule as time passed was deteriorated and decayed and the rehabilitation of the edifice was crucial. In 1555, restoration was carried out by the Franciscan custodian, Bonifacio of Ragusa (Fig. 2). Even though Bonifacio had claimed that the reconstruction was from the foundation, there is a possibility that only the cupola was restored, and some parts of the structure were repositioned (Moropoulou et al., 2019).

The Church of the Holy Sepulchre was once again extensively damaged by a fire that broke out in 1808. The roof of the Rotunda collapsed on to the Aedicule and as a result, the outer parts and the cupola of the edifice were mainly damaged. The structural condition of the Aedicule was in urgent need of restoration. In 1810 this goal was accomplished by Kalfa Komnenos, who rebuilt the edifice in a new style (Fig. 2), apart from the marble slabs of the Tomb Chamber, the base of the structure's exterior and the Coptic chapel. The Chapel of the Angel, the dome over the Tomb Chamber, the exterior walls and the cupola were entirely altered (Biddle, 1999).

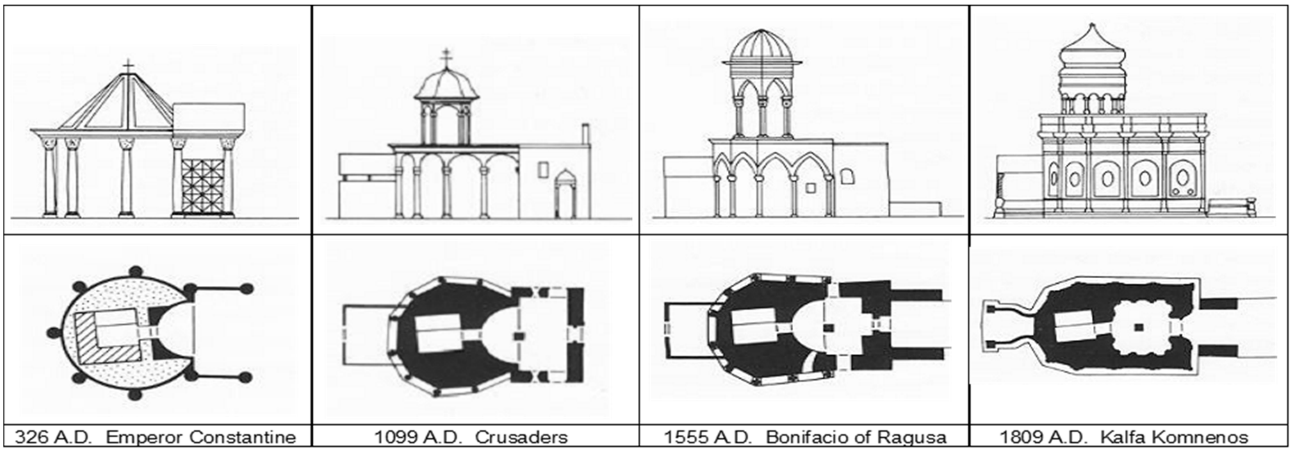

Figure 2: South view of the Aedicule through time (Up), and plan of the Aedicule through time © Martin Biddle 1999 (Down).

The Aedicule was damaged once more by an earthquake in 1927. An external iron frame was installed by the Public Works Department of the British Mandatory Government of Palestine in March 1947, as a temporary solution, in order to prevent the collapse of the Aedicule. After many years of decay, a rehabilitation project was carried out by the National Technical University of Athens, which would intend to restore the monument. The project was successfully completed in March 2017 and the main goal of the specific restoration, which was the assurance of the sustainability of the Aedicule, was finally achieved (Moropoulou et al., 2019).

3. Development of Web Database

3.1. List of the Replicas

An alternative way of 3D representation and therefore of documentation of the Aedicule is by its replicas which exist in physical form. The majority of these reconstructions were created by pilgrims who took measurements of the dimensions of the original monument when they visited Jerusalem. The significance of this sacred site is highlighted through these structures which exist worldwide. Each replica corresponds also to a structural phase of the Aedicule, thus the study of these representations result in a better understanding of its form through the years.

The Church of the Holy Sepulchre, as a building complex, had also an impact on the architecture of both churches and monasteries globally. The Rotunda in particular, the tall circular structure surrounding the Holy Aedicule, influenced the construction of round medieval churches which is an unusual architectural phenomenon for the specific period.

Churches, tombs, burial sites, calvaries, monasteries, relics and religious items comprise the main examples of the replicas. This paper is aiming to give prominence to the sphere of influence of the Aedicule and the Holy Sepulchre through the detection of their three-dimensional physical representations. Eventually, the amount of the discovered replicas was 109 in total and they consist of different types, which were divided into various categories:

- True-to-scale replicas of the Aedicule (23 of them), which have the dimensions of the monument and most of them have similar or even identical form
- Edifices of the Aedicule (9 of them), which are composed of structures that represent the shrine, but they are not identical replicas of the original.
- Miniature Models of the Aedicule (15 of them), which exist on a smaller scale and were usually used as reliquaries.

- Calvaries (45 of them), which consist of many chapels recreating the Stations of the Cross, including the burial chapel.
- Buildings inspired by the Holy Sepulchre (17 of them), which represent some architectural features of the Church of the Holy Sepulchre.

In this way, a database was created with the total amount of the detected replicas worldwide, along with additional information for each one such as name, type, location, date of construction and an image if possible.

3.2. Creation of Interactive Web Map

The subsequent step was the development of an online database that would be accessible by all the users of the internet. This could be accomplished with the production of a web map of the replicas and the implementation of a Geographic Information System (GIS). The characteristic advantage of GIS software is the combination of spatial data that are geographically corresponding to the real world and of attribute data that provide additional information about each of the spatial features. In this way, the user is available to both have access to a wide range of information and display them in any such away in order to create a desired visual outcome (Research Guides, 2019). The QGIS (Quantum GIS) (QGIS, 2020) software was eventually selected for the depiction and the visualization of the places where replicas of the Aedicule and the Holy Sepulchre are located.

Based on the list presented previously and taking advantage of the tools provided by QGIS, a map was produced for the digitization and visualization of the replicas' locations. The structures were classified into five different categories (layers) depending on their type (true-to-scale, edifices, miniature models, calvaries and buildings inspired by the Holy Sepulchre) and new fields were added to the attribute table of each category according to the information from the dataset (name, type, location, date of construction and image). The Open Street Map was used as a basemap and the vector data, which describe geographic data in terms of points for this project, were placed at the location of each copy. Finally, a new 'action' was created in QGIS. Actions happen when the user clicks on a feature, allowing the retrieval of additional information (Esri, 2020). It was called "Show Image" and it would enable the appearance of an image by picking the replica that it represented.

When the visualization and the map of the Replicas of the Aedicule and the Holy Sepulchre were completed, it was possible to create a web map. A web map is the presentation of a map online, which was initially created with a Geographic Information System (GIS), and the user is able to interact through different tools, such as pop-up windows with additional information for the visualized data, continuous pan and zoom and measurements of distances on the map (Esri, 2020). The map should be converted to a form which is compatible with a browser and for this reason the Qgis2web plugin was installed. The specific plugin generates a web map from the current QGIS project, either as OpenLayers or Leaflet form. Qgis2web creates the final web map by replicating as many aspects of the project as possible, including layers and styles, and converting them into HTML, Javascript, and CSS files, that can be viewed from the browser (QGIS plugins, 2020).

With the aim of creating a web map for the project of the replicas of the Aedicule and the Holy Sepulchre, the parameters of the web map were defined, which consist of the data layers, the overall appearance and the way that the web map will be exported. First of all, the Leaflet form was thought to be the best choice, due to its simplicity and the user-friendly environment. Moreover, all the layers of the project and their fields would be depicted on the web map. Regarding the appearance, the different layers would be presented at the upper right corner of the web map, pop-up windows with the additional information of the attribute table of each layer were enabled and the highlighting of every aspect that will be picked by the user was also selected. Some tools were added, such as the geolocation of the user, the metric measure tool for distances and areas (units: meters) and the research tool. The web map would be depicted in full-screen, with an extent which would fit to the layers and with maximum zoom level 28 and minimum zoom. The title of the web map was not available through the Qgis2web plugin, but it was added through the tab 'Project' > 'Properties' > 'Project Title'.

In order to upload the specific web map to the internet, a web hosting account was required. For the presentation of the web map the web server of the National Technical University of Athens was used, which provides to the members of the university the ability to create a personal website. When the personal website has been activated, access to the personal website for modifications is available through the link: ftp://username@users.ntua.gr/ and the use of FTP software, such as FileZilla (FileZilla, 2020). The user must enter the link of the web directory and the passwords in order to log in through the FileZilla software. When access is permitted, there are two separate windows depicting the files of the desktop computer and the files in the web directory. The user decides which files will be transferred to the web directory. Thus, the 'index.html' file and the folders with associated Javascript and CSS files which were exported from the Qgis2web plugin were uploaded to the web directory.

The web map of the replicas of the Aedicule and the Holy Sepulchre was finally online and accessible through the internet (Fig. 3), through the website: http://aedicule-replicas.rf.gd/?i=3#3/25.02/-16.16

4. Methodology for Point Cloud Evaluation

4.1. Geometric documentations of the Aedicule

Through the years several scientific researches have been conducted in order to geometrically document the state of the Aedicule. The first metric survey of the monument was carried out by a Franciscan monk named Father Virgilio Corbo (1960-1973), who documented the holy shrine and created accurate drawings of its condition (Custodia Terrae Sanctae, 2020). The first documentation of the monument was performed by Martin Biddle (1989-1992) in cooperation with a team of British experts, with the implementation of photogrammetry and 3D modelling (Biddle, 1999). In the years 1993-1999, the National Technical University of Athens in collaboration with the University of Athens undertook the task of documenting the whole complex of the Church of the Holy Sepulchre.

Drawings of the Aedicule were created with the combination of geodetic measurements and photogrammetry (Balodimos & Georgopoulos, 2019). A survey on the seismic risk of the structures of the Holy Sepulchre was conducted by the University of Florence from 2007 until 2011. The technique of terrestrial laser scanning (TLS) was implemented for the first time regarding the three-dimensional representation of the Aedicule (Tucci & Bonora, 2011). In May 2015 the works for the diagnostic study of the Aedicule of the Tomb of Christ was initiated by the National Technical University of Athens. Data acquisition included geodetic measurements, digital image acquisition and terrestrial laser scanning (TLS) around and inside the monument (Moropoulou et al., 2019).

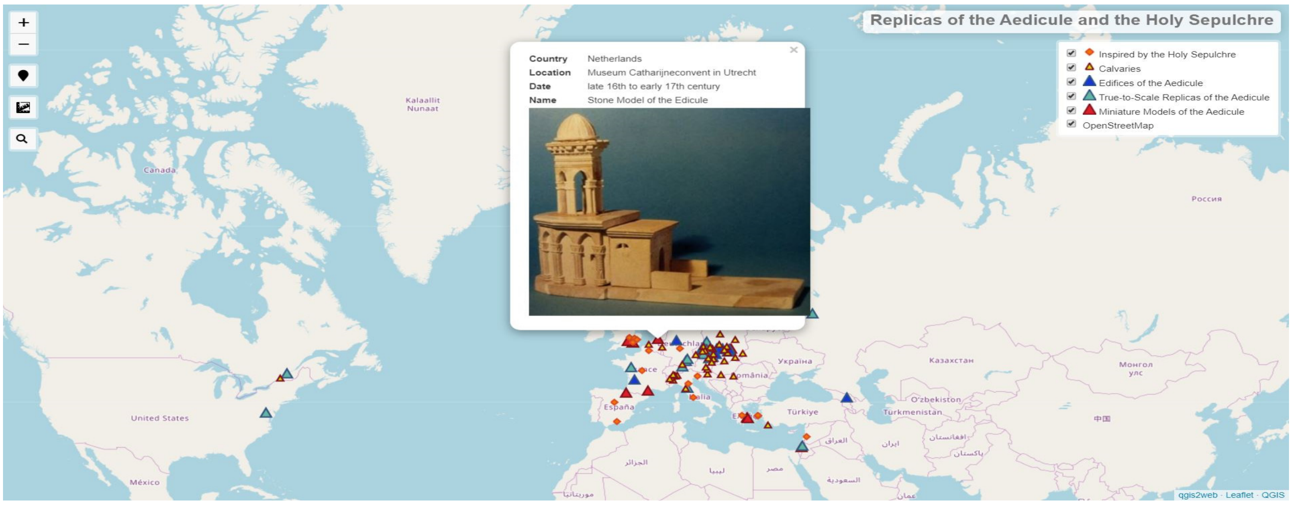

Figure 3: The online web map of the replicas of the Aedicule and the Holy Sepulche © Author 2020.

4.2. Point Cloud from Analogue Data

An attempt was made for the construction of a three-dimensional model using part of the analogue imagery data acquired during the National Technical University of Athens survey in 1995.The specific photographs were captured with classical stereoscopic processing in mind and concerned the Rotunda and not the Aedicule itself. Printed photographs, films and slides were acquired with various analogue cameras, either coloured or grayscale. In the end, four sets of data were formed:

1) Hasselblad 6 x 6 colour slides with 50 mm focal length (29 of them)
2) Canon AE-1 35 mm SLRB&W negatives with 50 mm focal length (15 of them)
3) WILD P31 metric camera B&W negatives (10 x 12.50 cm^2) with 45,21 mm focal length (7 of them)
4) Printed colour photographs from an unknown camera (14 of them)

All the analogue images were scanned in order to be digitized, with a resolution of 1200 dpi. Every scanned photograph had distinct dimensions and size, so they were cropped according to the group that they were classified. The parameters of the interior orientation were necessary to be attached to every image. Therefore, the EXIF (Exchangeable Image File format) file of the scanned photographs and slides was edited in Zoner Photo Studio X (Zoner Photo Studio, 2019) and information such as the focal length, the maker and the model of the camera were added. Eventually, the photographs were imported into the photogrammetric software Metashape (Agisoft Metashape, 2019) and they were divided into separate camera groups so that they could be processed correctly.

The construction of a 3D model of the Aedicule was initially attempted using only the colour images. First step was the categorization of the photographs in various groups (chunks) according to which part of the Aedicule they were depicting. Afterwards, the alignment of each group was performed, for the computation of the camera position, orientation for each photo and the creation of the sparse point cloud. The results of every alignment were inspected, and incorrectly positioned photos were removed or realigned. In some cases, markers were added or removed depending on their effect to the total error of the alignment.

After adjusting the volume bounding box by resizing or rotating the region and removing from the sparse point cloud all the spots or areas that appear as displayed imperfections in the image (noise) (IGI Global, 2020), the preferred reconstruction parameters for this procedure were selected. As a result, the dense point cloud of each chunk was generated and visualized (Fig. 4). It is obvious that the dense point cloud is very incomplete and that the image coverage is not adequate.

A second attempt was carried out with the aim of processing the B&W photographs. Taking into consideration that this kind of photographs were very few, the colour photographs were converted to greyscale images in Photoshop (Adobe Photoshop, 2019) so that they could be combined all together. Moreover, since the negatives were scanned in order to create digital images, some photographs that were in grayscale had to be edited as well and converted into photo positive. Then, the images were imported into Metashape again and separated into several chunks. Subsequently, the dense point clouds representing different parts of the Aedicule were created, following the same processing as previously (Fig. 5). It is again observed that the result is rather unsatisfactory.

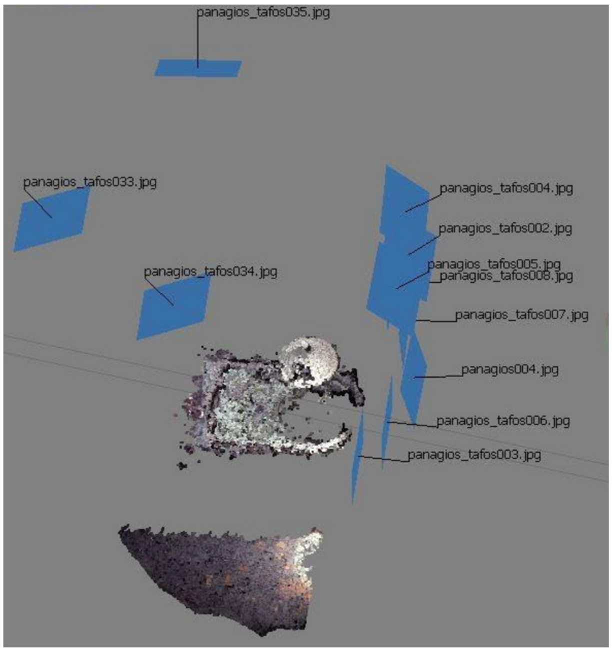

Figure 4: The dense point cloud of the top view of the Aedicule from colour photographs © Author 2020.

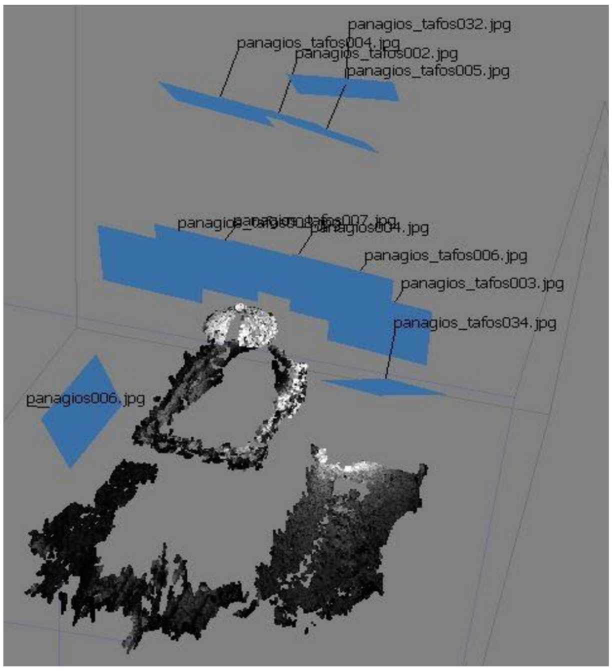

Figure 5: The dense point cloud of the top view of the Aedicule from grayscale photographs © Author 2020.

Even though more photographs were aligned, 40 in this case, as opposed to 31 colour photographs, the result of the dense point cloud based on the grayscale photographs was not better or more precise than the dense point cloud from the color photographs. It is obvious that the results are not correct from a metric point of view. One is only able to obtain an idea of the shape and the form of the edifice.

The specific photographs have many drawbacks concerning the photogrammetric procedures. First of all, a major obstacle was the absence of sufficient overlap between the photographs, which is the main essential condition for photogrammetry. What is more, most of the photographs were not of high resolution. Furthermore, the lack of Ground Control Points (GCP) or of a measured distance of the Aedicule affects both the geometry and the scale of the final constructed point cloud. It is also important that the camera-to-object relative positioning varied even if the same camera model or the same focal length was used. Additionally, the fact that the photographs were not taken from different viewpoints, the bad lighting conditions and the continuous population hiding the monument resulted in the loss of information. Unfortunately, a better outcome could not be achieved by processing only these photographs which were apparently not suitable for reconstructing the Aedicule, since the geometry of the dense point clouds was not identical to the geometry of the edifice.

4.3. Point Cloud Comparison

During the two last surveys that took place in Jerusalem and focused on the geometric documentation of the Aedicule of the Tomb of the Christ, three-dimensional models were constructed through terrestrial laser scanning (TLS). The specific method constitutes an effective technique for Cultural Heritage Digitization, because of the high acquisition rate, the relatively high accuracy and the high spatial density (Lichti, Gordon, Stewart, Franke, & Tsakiri, 2002). Therefore, both of the three-dimensional models depict precisely the state of the Aedicule. The GECO Laboratory of the University of Florence visited the monument in 2007 and performed the first survey with the application of a laser scanner. Some years later in 2015 the National Technical University of Athens with the collaboration of the Laboratory of Photogrammetry produced several 3D models of the Aedicule during the different stages of the restoration again with measurements that were acquired with the same method.

Both the Italian point cloud and the Greek point cloud, which was constructed before the restoration of the monument, are accurate representations of the Aedicule in different time periods. Therefore, their comparison and the assessment of its outcome could provide important information about the condition of the structure through these years. The same resolution and reference system are essential for a precise comparison between the two 3D models. As a result, the Greek point cloud was decimated. Also, a rigid body transformation, which preserves the size and the shape, was applied. This kind of transformation typically consists of a translation and a rotation in 3D space.

Regarding the rigid body transformation, the Greek point cloud was selected to be the reference and the Italian point cloud would be transformed. Only two common points in both reference systems with known coordinates were detected. Consequently, it was assumed that three translations and one rotation angle around the Z-axis were required for the transformation. The parameters were calculated, and the Italian point cloud was transformed. The Global Registration, which uses the ICP algorithm, was applied for the improvement of the outcome. As a result, the point clouds were registered, and their comparison was possible through the creation of sections and the implementation of the M3C2 algorithm. It should be noted that the comparison concerns the relative differences of the two-point clouds and not their deviations from any ground truth, as there was no such data available.

4.3.1. Creation of Sections

Four sections were created for each point cloud: a horizontal section with 1.60 meters elevation, a transverse section at the Chapel of the Angel, a longitudinal section and a longitudinal section with the orientation of the Tomb Chamber. The purpose of the production of these sections was the comparison of the main dimensions of the Aedicule through the measurements of relative distances. From every pair of sections ten (10) measurements of common distances in different parts of the Aedicule were performed. An approximation of the deviation of the data was estimated by calculating the *RMS* error for each pair of sections. The formula of the error is presented below in Eq. (1):

$$RMSE = \sqrt{\frac{\sum_1^{10}(d_i - d_j)^2}{N-1}} = \sqrt{\frac{\sum_1^{10}(d_i - d_j)^2}{9}} \quad (1)$$

where

d_i = Italian measurements

d_j = Greek measurements

Eventually, four *RMSE* values were estimated (Fig. 6), one for each type of section, namely that of (i) the horizontal section error (0.0040 m), (ii) the transverse section error (0.0064 m), (iii) the longitudinal section error (0.0173 m) and (iv) the longitudinal section error with the tomb chamber orientation (0.0164 m).

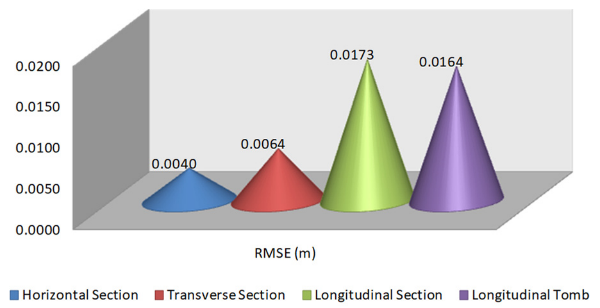

Figure 6: Values of the RMS error in meters © Author 2020.

It was noticed that the deviation of the measurements had larger values for the two longitudinal sections than for both the horizontal and the transverse section. A possible cause for this outcome could be the specific part of the Aedicule that these measurements refer to. Most of the dimensions in the longitudinal sections belonged to the interior of the structure, while most of the dimensions in the horizontal and transverse section referred to the exterior. Therefore, two additional errors were estimated, which would define the deviations of the interior (average of the errors of the longitudinal sections, Eq. (2)) and the exterior (average of the errors of the horizontal and transverse section, Eq. (3)) of the structure:

$$RMSE_{interior} = \frac{(0.0173+0.0164)}{2} = 0.0168\ m \quad (2)$$

$$RMSE_{exterior} = \frac{(0.0040+0.0064)}{2} = 0.0052\ m \quad (3)$$

The total error derived from the average of the overall deviation errors and is equal to Eq. (4):

$$RMSE_{total} = \frac{(0.004+0.0064+0.0173+0.0164)}{4} = 0.0110\ m \quad (4)$$

All things considered, the result of the estimated total deviation error could be justified due to the combination of both the uncertainty of the previous processing stages of the point clouds and the state of the Aedicule through the eight years that had passed from the earliest to the latest survey (2007-2015).

Moreover, during the survey of the National Technical University of Athens in 2015 deformations were noticed at the external lower part of the southern side of the Aedicule. In order to investigate if these deformations existed in 2007 or they were formed later due to decaying, two new horizontal sections were created with 0.80 meters elevation (Fig. 7). From the comparison of these sections, it was obvious that the walls of the Aedicule generally did not have any differences. On the other hand, the columns seemed to have been deformed but it cannot be defined in which way exactly.

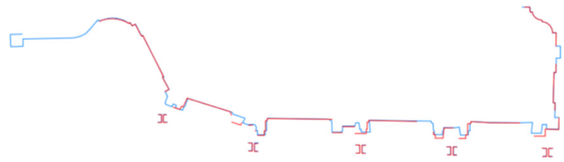

Figure 7: Comparison of the horizontal sections at +0.80 meters © Author 2020.

4.3.2. M3C2 Algorithm

When it comes to the comparison of point clouds that were constructed through laser scanning, the best method that is able to manage big data sets is the multiscale Model to Model Cloud Comparison (M3C2). The specific algorithm computes the local distances between two point clouds, for detecting 3D variations in surface orientation and estimates for each distance measurement a confidence interval depending on point cloud roughness and registration error (Lague, Brody & Leroux, 2013). When there is no point correspondence there is also no distance computation. The units of the measured distances are equivalent to the units of the point cloud, which in this case are in meters (Barnhart & Crosby, 2013). The Greek point cloud was chosen to be the reference cloud and the Italian point cloud the compare cloud. The outcome was a new coloured point cloud, with each colour representing a specific distance value (Fig. 8). The colour scale was chosen to present distances from 0.000 meters to 0.144 meters and the Nan points (no correspondence points) were invisible. The distance values ranging from 0-1.8 cm were depicted with green colour. The different shades of red, yellow and blue colour represent distance values from 1.8 cm - 14 cm. Hence, regarding the exterior of the Aedicule, the only parts with significant differences are the Coptic Chapel, the benches, the entrance above the door, which are justified due to decorations or unstable structures. Big distance values could be also noticed at the lower parts of the columns at the southern side of the edifice and at the decorative columns placed around the roof and the cupola, which might be proof of deformation.

A longitudinal section of the original M3C2 distance point cloud was created in order to examine the results at the inner part of the Aedicule (Fig. 9). Apart from the Coptic Chapel, bigger distance values were detected at the Chapel of the Angel and the Tomb Chamber. Due to the existence of many decorations, oil-lamps and candles, there were big distance values at the wall above the passage and above the tomb's self. Many differences were also displayed at the domes of both chambers. Furthermore, the west part of the tomb was not depicted, which meant that the distance values were even bigger than 14 cm. Further investigation proved that the Italian point cloud had some gaps at the specific areas and as a result the distance computation was not correct. These gaps were justified since none of the decorations were allowed to be removed during the data acquisition with the laser scanner. Therefore, these distance values should not be taken into account.

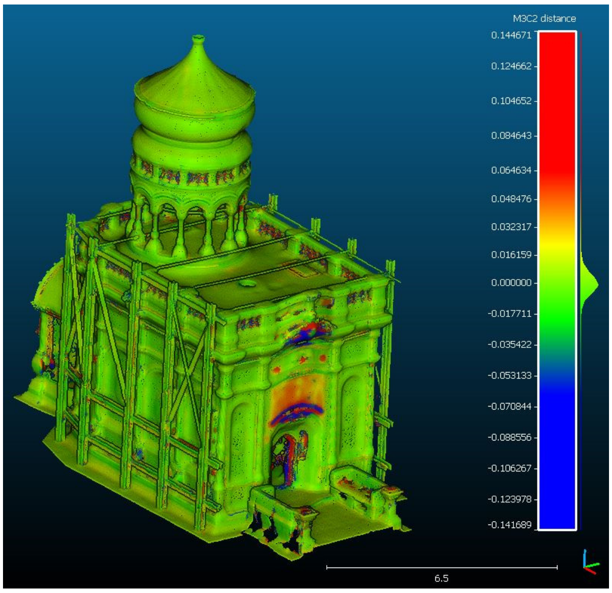

Figure 8: Result of the M3C2 algorithm for the exterior of the Aedicule © Author 2020.

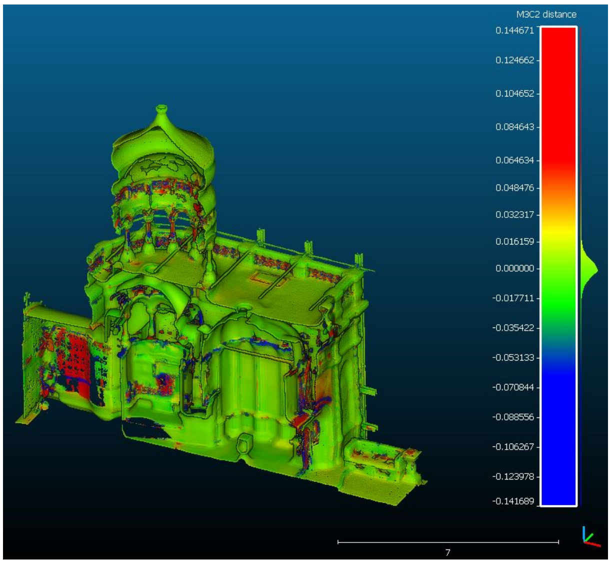

Figure 9: Result of the M3C2 algorithm for the interior of the Aedicule © Author 2020.

5. Discussion and Concluding Remarks

The significance of the Aedicule of the Tomb of Christ can be identified through the numerous three-dimensional representations of this small edifice. Based on the research for the replicas of the monument, it was noticed that there was massive construction of certain types or its physical representations, such as the calvaries and the true-to-scale replicas. The edifices of the Aedicule are the type of replicas with the fewest reconstructions worldwide. Based on these results it is obvious that the number of replicas for each type depends on their similarity to the original. The better the correspondences, the more replicas of this type were constructed.

Most of them were created during the 16th and 17th century and can be detected in places either far away or close to Jerusalem. The countries where several replicas have been constructed are 23 in total and they are situated in Europe, Asia, North and South America. Those with the biggest number of replicas are Poland (22 replicas), Czech Republic (18 replicas), Italy (14 replicas) and England (10 replicas).

The online web map provides additional information for the types of replicas constructed in each region. For example, most of the true-to-scale copies are located in Czech Republic and in Germany. Also, the majority of the calvaries are detected in Poland and in Northern Italy. As a result, it is possible to obtain the global impact of the Holy Aedicule through the combination of the replicas dataset and their geographical relations with the visualization of a web map.

Apart from the replicas, there are digital three-dimensional representations of the Aedicule of the Tomb of Christ. These forms of representations were mainly created for the geometric documentation of the monument and are characterized by high accuracy. One method for the construction of a 3D model, which is a form of digital documentation, is the photogrammetric processing of analogue photographs. For a precise outcome, several parameters should be taken into consideration. For example, the site of interest should be captured from different positions and angles. Moreover, sufficient overlap, high resolution and good lighting conditions are necessary. Also, GCP points or a known distance are essential for the correct scale and geometry of the 3D model.

An even more accurate technique that recent surveys have adapted is terrestrial laser scanning. The assessment of the comparison of the point clouds of the Aedicule indicates its deformations. Eventually, the outcome of the comparison computed by the algorithm is similar to the distance deviations which derived from the sections. The condition of the structure had remained in general the same from 2007 until 2015. The only major deformations which were detected are those of the columns at the southern side of the Aedicule and those of the small columns around the roof and the cupola.

5.1. Future Work

A suggestion for future work is the enrichment of the replicas' database through Crowdsourcing, which is the open call for online participation of a group of people in order to voluntarily undertake a task (Estellés-Arolas, González & Guevara, 2012). For the specific case, religious communities, researchers or scholars related to the Aedicule could provide information. For this reason, the online web map should also be easily modified by the user, so that all the existed replicas could eventually be detected.

Furthermore, the monitoring of the Aedicule would be possible through future geometric documentations of its condition and the comparison with the existed 3D model. The evaluation of the results could provide information for its maintenance and potential restoration.

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