Mediterranean Archaeology and Archaeometry, Vol. 17, No 3,(2017), pp. 137-148

DOI: 10.5281/zenodo.1005534

3D DOCUMENTATION OF PORTAL MUQARNASES IN ANATOLIAN MADRASAHS WITH DIGITAL CLOSE RANGE PHOTOGRAMMETRIC METHOD

Hakan Karabörk[1], Esra Yaldiz[2] and Lütfiye Karasaka[1]

[1] Selcuk University, Engineering Faculty, Department of Geomatics, Konya, Turkey
[2] Konya Necmettin Erbakan University, Engineering and Architectural Faculty, Department of Architecture, Konya, Turkey

Received: 11/06/2017
Accepted: 17/07/2017
Corresponding author: Esra Yaldiz (mimaresrayaldiz@gmail.com)

ABSTRACT

Muqarnases, which are one of the most significant building elements brought in the architecture by Islam art, are three dimensional and complex geometrical compositions that are made with prismatic elements constituted with specific rules in specific combinations, with both ornamental, bearing features. Therefore, the surveys of muqarnases require a long, fragile, dangerous and difficult process. At that point, photogrammetry works come in and make the process of survey short, free of danger and mistakes as a useful application. Digital close range photogrammetry is one of the most active and efficient methods among the works to protect and document the cultural heritage by the means of the improvements of digital technology. Within the scope of this study, the surveys of the muqarnases in the portals of the Anatolian Madrasahs in Konya, Karaman and Aksaray in Central Anatolia Region were obtained with the use digital close range photogrammetry technique and 3D documentation works were made. With the 3D works, morphological features and differences of the muqarnases were determined. It was aimed to contribute to works to protect and document Konya Karatay Madrasah, Karaman Hatuniye Madrasah and Aksaray Zinciriye Madrasah.

KEYWORDS: Documentation; close range photogrammetry; cultural heritage; muqarnas; 3D modelling

1. INTRODUCTION

Securing the cultural heritage in the name of maintaining the sustainability with the care to keep the cultural values coming from the past alive and hand them down to the next generations is defined as conservation phenomenon (Anonymous 2000). The conservation concept is defined in World Heritage Treaty as "*to understand the cultural heritage defined by monuments, building grups and sites; maintain the preservation of its material and if necessary use all methods to promote, to restore and to improve*" [URL 1]. The first and one of the most important phases in the process of the conservation and restoration of historical and cultural heritage is undoubtfully to document and to archive these artworks sensitively and reliably. Both traditional and innovative methods are currently used in documentation studies to maintain these artworks, to have successful conservation applications and to hand them down to next generations. In this context In ICCROM (International Centre for the Conservation and Restoration Of Monument), ICOMOS (International Council for Monuments and Sites), CIPA (International Committee for Architectural Photogrammetry), ISPRS (International Society for Photogrammetry and Remote Sensing) and UIA (International Union af Architects) which were all founded by UNESCO (United Nations Educational, Scientific and Cultural Organization) are quite efficient international organizations in the area of cultural heritage conservation. These instutions and organizations emphasize the conservation of the cultural heritage, the conservation with scientific methods and the use of all the opportunities offered by technology in the documentation works. This brings the need to develop new methods and tools for the studies for determination and documentation of the cultural entities depending on technological improvements. Executing documentation and determination studies in the light of scientific truths will be possible only when the current situation of the architectural building(s), to be conserved, are determined with sensitive measurements and their surveys are made (Keleş 2010). The significance of the advanced technology in documentation studies increased as the traditional methods used in surveys are slow, unsensitive and they provide limited data about the artworks.

Digital close range photogrammetry technique, which is one of the advanced technological methods, is a method that has been used for the documentation of historical and cultural heritage, archeological measurements and the documentation of historical artworks for years (Peña-Villasenín, Gil-Docampo and Ortiz-Sanz 2017). In literature, when the studies on conservation and documentation of historical and cultural artworks are examined (Arias et al. 2006; Yilmaz, Yakar and Yildiz 2008; Uslu et al. 2016; Zaitceva et al. 2016; Altuntas et al 2014, 2017), recently 3D methods to obtain numerical data (Yastikli 2007; Salonia et al. 2009; Ordonez et al. 2010; Riveiro et al. 2011; Barazzetti et al. 2011; Chiabrando et al. 2011; Sahin et al. 2012; Zlot et el. 2014; Quagliarini et al. 2017; Georgopoulos 2016; Salama et al. 2017) are observed to be frequently used.

The muqarnases which are special to Islamic art, were studied by mathematician Al-Kashi in 1400s (Dold-Samplonius and Harmsen 2005) and the muqarnas cells, the geometries forming the cells and their proportions were determined. Later on, for muqarnases in Anatolia, the geometrical schemes in the formation of the muqarnases were examined (Ödekan, 1977), muqarnas components were defined with angles and (Hamsen 2006). Therefore, the surveys of muqarnases require a long, fragile, dangerous and difficult process. The muqarnas documentation studies for which advanced technological methods are used were made as the analytical evaluations on two dimensional traditional drawings and three dimensional models by simplifying the complex geometry with digital technology (Garofalo 2010; Gherardini and Leali 2016; Dold-Samplonius and Hamsen 2005). In some other muqarnas documentation studies, only the advantages and disadvantages of the terrestrial photogrammetry method and traditional method in technical drawings were exposed (Yakar et al., 2009)

The main research goal of this article is to evaluate the documentation works of the muqarnases, special to Islamic architecture; in portals of Anatolian Madrasahs those have both ornamention and bearing features and complex geometrical structure by digital close range photogrammetry, which is a revolutionary method with its computerized graphic equipment, 3D modelling codes and skills of three dimensional scanning. In addition to other studies, the aim of the study in terms of digital close-range photogrammetry is to determine morphological features of muqarnases in portals of Anatolian madrasahs with similar architectural features in Konya, Karaman and Aksaray and 3D documentation of their geometrical structures. In the direction of this purpose, the morphological similarities and differences of Anatolian muqarnases are presented, along with their 3D documentation works.

Along this aim, the muqarnases in portals of 3 Anatolian Madrasahs are modelled by using digital close range photogrammetry and the usage areas of method are depicted.

2. THE SITES AND METHODS

Photogrammetry is a technique that determines the dimension, shape and location of an object in three-dimensional space by photos without any physical contact it. Digital close range photogrammetry, on the other hand, is one of most common methods that are recently used among the works of modeling the cultural heritage in 3D numerical data form and its documentation. Especially, the problems such as that the documentation works of big architectural buildings and their complex details with traditional methods is quite time-consuming and exhausting and that it is sometimes impossible to reach the object directly have made the method of digital close range photogrammetry popular (Pierdicca et al. 2016). Accordingly, with the use of digital close range photogrammetry in architectural survey works, the field works that require so much time and effort in traditional architectural survey works have been made easier. Digital close range photogrammetric measurement and evaluation has made it possible to document the building elements which are hard to reach and dangerous like muqarnases by 3D modeling with the help of image pairs taken from different angles and epipolar geometry which is the geometry of stereo view.

The digital close range photogrammetry works are general done in the steps explained below:

1. Planning survey
2. Camera calibration
3. Setup geodetical network to measure the ground control points on the object
4. Acquire images
5. Process images/Triangulated and orient images
6. Deliverables/stereo model, textures, orthoimages, object/surface models in CAD

2.1. *The study area and equipments*

The cities of Konya, Karaman and Aksaray are located in Central Anatolian Region. The city of Konya, which used to be the capital city of Anatolian Seljuk Empire, and the neighbor cities Karaman and Aksaray host Anatolian Madrasahs as important artworks from that era.

Figure 1. Study Areas (Google Maps)

A series of photogrammetric measurements were made for the works to determine the morphological features of muqarnases in the portals of the subject artworks and for 3D modeling and documentation of their geometrical structures. The most important equipment for the photogrammetric measurements is camera. Even though, it is recommended to use metrical cameras with high resolution especially for photogrammetric works, the high costs of these cameras have directed the users to the non-metrical cameras for digital close-range photogrammetry applications.

In the study, Nikon D3100 digital camera with 14.8 megapixels (4608*3072) resolution and Canon Eos Rebel T3 digital camera with 18 megapixels (5184*3456) resolution were used.

In order to access the 3D coordinate information of the objects from the image pairs, the external orientation parameter of stereo images and scale factor between object and image coordinate spaces must be known (Ordonez et al. 2010). Exterior orientation elements are the position and rotation of the camera at the moment of exposure. Whereas (X_0, Y_0, Z_0) of orientation elements, composed of 6 parameters, refer to the central projection coordinates according to

the ground coordinate system, (ω,φ,χ) signify the rotation parameters between ground coordinate system and image coordinate system.

Ground control points, which helps the connection between image coordinate system and ground coordinate system to be established, is needed to find out these parameters. These points are determined by reference the ground coordinate system in terrestrial photogrammetry. Direction and distance measurements are made by establishing points around the object to define the ground coordinate system. So, that the control points used to solve the unknowns are defined in the referenced coordinate system. Laser total stations that allow for measurements without reflectors are used to make detailed measurements especially in the situations where it is impossible to establish points on the surface of the object. In the study, Topcon 3007 Total Station, which can make reflectorless distance measurement, was used instead of targets because of both the difficulty of establishing control points on the artworks and the aim of avoiding any kind of damage.

2.2. *System calibration*

Digital close-range photogrammetry is a central projection and uses collinearity equations to calculate object coordinates from known image coordinates. The cameras used in digital photogrammetric applications are metric cameras to ensure the rule of central projection. In metric cameras, the center of projection, camera focus distance and position of the principal point are known. These parameters that determine the metric features of the camera are known as interior orientation elements and presented to users as a report determined by camera calibration process. The cameras, interior orientation elements of which are unknown, are non-metric cameras. Non-metric cameras are mostly used for digital close-range photogrammetry applications because of their low costs. The calibration of these cameras is realized by using a simple test pattern. The test pattern is a plane consists of grids. The camera parameter are determined with camera calibration process taking a few convergent pictures of the calibration test pattern from different positions, angles and bundle adjustment of the rays of the points on the grid plane. In this study, the muqarnases in the portals of Anatolian Madrasahs were photographed by using Nikon D3100 and Canon Eos Rebel T3i digital cameras. The calibrations of the cameras were made by using the camera calibration module of Photomodeler Pro5 with 8-12 photos taken from different angels and locations of grid plane (Table 1).

Table 1. Camera calibration parameter for Nikon D3100 and Canon Eos Rebel T3i

	Nikon D3100	**Canon Eos Rebel T3i**
Focal lenght	18.4091	18.9313
Principal point	(12.0323, 7.9026) mm	(11.3858,7.5283) mm
Sensor format	(24.0062, 16.000) mm	(25.6768,15.1130)mm
Distortion parameter : K1	0.00008012000	0.0004848000
Distortion parameter : K2	-0.00000007998	-0.0000008241
Distortion parameter : P1	-0.00377200000	-0.0001257000
Distortion parameter : P2	-0.00001665000	0.0001442000

2.3. *Data acquisition*

For 3D modeling studies by terrestrial photogrammetry, a well-planned geodesic network should be set up and image capture operation should be done. In the study, fixed ground points were setup in the position to see each other clearly around the artworks, photogrammetric measurements and evaluations of which were to be made. Fixed ground points were measured with Topcon GPT 3007 reflectorless total station. Some of the pictures of the object were printed out, hard-edged points were marked on these pictures and, the coordinates of these points were measured with the total station device installed on the fixed ground points based on the land. It was paid to attention to distribute control points, that would be used in photogrammetric evaluation, on the artworks homogenously and determine them easily via the photographs.

The convergent images of the artworks in the study were taken with overlapped taking into account the fact that every detail point determined and measured on the artworks appears in at least three pictures.

2.4. *3D Modelling*

The photogrammetric evaluation and 3D modelling of the artworks were made with Photomodeler software. A different project was created for each artwork. The pictures of the artworks, interior orientation elements, meaning camera calibration parameters, and the coordinates of ground control points were transferred to the program for the evaluation process. And then, images were connected to each other with the operation called relative orientation step. The bundle block adjustment was made with the help of the ground control points and relation between image coordinate system and ground coor-

dinate system was made by resolving the location of the camera and orientation elements during exposure. As a result, of the adjustment, root mean square error of Karatay Madrasah Portal Muqarnas project is 4.10 pixels for Karaman Hatuniye Madrasah Portal Muqarnas project is 3.12 pixels; for Aksaray Zinciriye Madrasah Portal Muqarnas project is 3.58 pixels. As a result, of these values, 3D drawings of the artworks were made in Photomodeler software and plan plane was obtained in accordance with these drawings. Besides, the adjusted plan planes of the artworks were made by making use of the current information of the object (Table 2, Table 3 and Table 4).

3. 3D DOCUMENTATION OF PORTAL MUQARNASES IN ANATOLIAN MADRASAHS WITH DIGITAL CLOSE-RANGE PHOTOGRAMMETRIC METHOD

While the etymology of the word "muqarnas" is not know for sure, it is stated as a architectural element developed in Syria towards the end of 8th century, in Iran in 9th century (Garofalo 2010) and in North Africa in 10th century, along with Iran and Iraq. And it has become one of the prevalent features of Islamic architecture in Muslim territory since the 11th century (Dold-Samplonius and Harmsen 2005; Ünal 1982).

Muqarnases, which have been developed as an ornamentation type unique to Islamic architecture, is a 3D architectural ornamentation element composed of prismatic elements placed side by side and overlapped, projected outside angle by angle and arranged in a symmetrical order (Ödekan 1977; Garafalo 2010; Anonymous 2012). In the architecture, it provides opportinuties for creating three-dimensional decorated lines on the wall surface, the transition from one surface to another surface in a forward or backward plane or from a different geometric shape to another geometric shape (Ödekan 1977; Kuban 2006). Its main feature is that it becomes a 3D modul from two dimensional forms. In each case, the depth of modul and composition is different (Dold-Samplonius and Harmsen 2005). The elements in muqarnases are coordinated to create both two dimensional and 3D systems. The shape and dimension of each element is a modulor design product made of a unit square (Gherardini and Leali, 2016). Their dimensions and forms could differ in terms of the geographical region in which they are located, the period in which they were built, the building section in which they are applied and the material which they were made of (Garofalo 2010).

The usage areas of muqarnases, which are frequently used in Anatolian Turkish Architecture, are quite wide (Ödekan 1988). It is observed that muqarnases are used in different areas like cornices, column heads, niches, mihrabs, portals, minaret balconies, the ornamentation of vaults and domes, the surfaces functioning as transition between wall and top-cover, corner of streets, tombstones and water fountains.

Regardless of wherever they are used, the main principle of a muqarnas is to make the concave-return kavsara surface, which narrows at the top, meets the rectangular plane on the floor and connect the horizontal and the vertical with a curved surface (Mülayim, 1988). While the teeth of early-period muqarnases are quite big and array-sliced (Ögel, 1987), they reach to the top set by set with hexagon, octagon and dodecagon cornered stars in following periods. Especially the muqarnases placed in the portals, are ornamented with array-sliced grooves, hexagon and octagon cornered stars, are arranged as horizontal lines of 7, 9 or 14 (Ünal, 1982).

2a. Konya Karatay Madrasah Portal

2b. Karaman Hatuniye Madrasah Portal

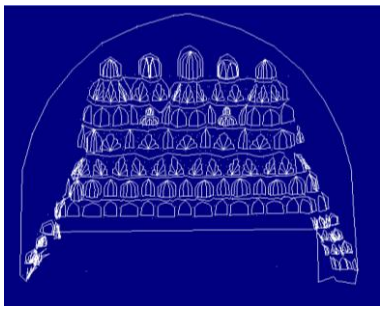
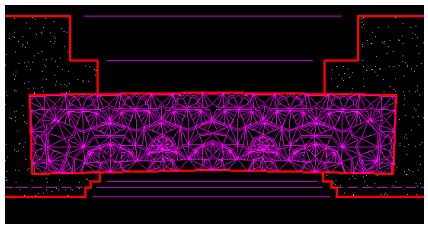
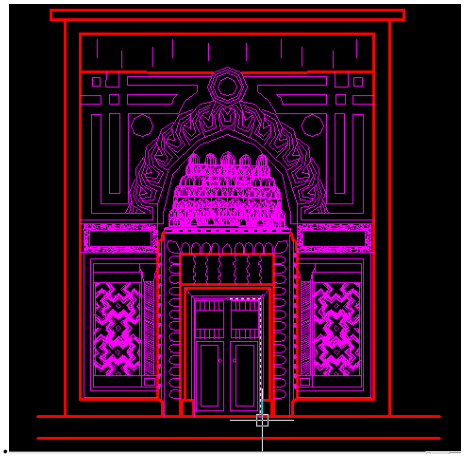
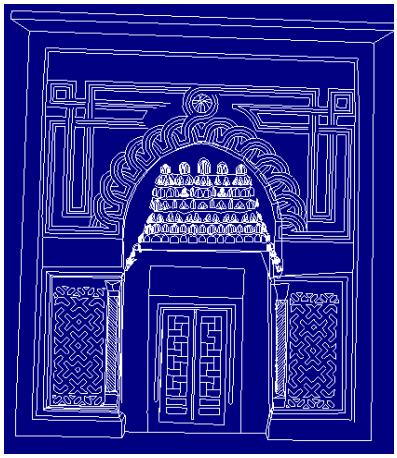
2c. Kayseri Sahabiye Madrasah Portal

2d.Aksaray Sultanhanı Portal (General Directorate for Foundations Archive

Figure 2. Examples of muqarnases in portal

Muqarnases are used as both bearer elements and ornamentation in kavrasas of portals. It is hard to reach and measure them as they are building elements that have prismatic components with different geometrical schemes and 3D compositions. Therefore, survey works done by setting wharfs and taking projections with traditional methods also cause a lot of complications. Digital close-range photogrammetric measurements make it possible to realize too high or too low measurements in the historical buildings and elements that are hard or dangerous to reach. The photographs make it quite easy to measure the desired parts of the buildings and this gives opportunity to document muqarnases with 3D modelling.

Table 2. Karatay Madrasah Portal Muqarnas Survey Work

<table>
<tr>
<td rowspan="3"> 
Karatay Madrasah Portal</td>
<td>  </td>
</tr>
<tr>
<td>Three dimensional view of Konya Karatay Madrasah portal</td>
</tr>
<tr>
<td> 
Konya Karatay Madrasah muqarnas plan plane (schematised with the measurements taken from erdermir 2001 and the measurements from photogrammetric data)</td>
</tr>
<tr>
<td> 
Konya Karatay Madrasah muqarnas portal view (Schematised with the measurements taken from Erdermir 2001 and the measurements from photogrammetric data)</td>
<td> 
Konya Karatay Madrasah muqarnas 3d view as a result of photogrammetric survey</td>
</tr>
</table>

3.1. Digital close-range photogrammetric survey of Karatay Madrasah Portal Muqarnases

It is understood from inscription placed in Karatay Madrasah Portal that it was built by Celaleddin Karatay, one of the statesmen of Anatolian Seljuks, in h-649/g-1251-52. The establishment of Karatay Madrasah Portal does not adapt to Seljuk Portal traidition. The effects of the pre-islam regional architecture are observed in its composition (Erdemir 2001). While, muqarnases generally narrow more and more as they go up and are finished as a single line in Seljuk Portals, here they are finished as 5 lines side by side. There are seven line muqarnases on top of eachother in portal (Tuncer 1986). Octangular stars and octagons are used in the hori-zontal profiles of stone lines (Ödekan 1977)

The survey studies of Portal Muqarnas in Karatay Madrasah are obtained by the means of photogrammetric method as determined in sections 2.2, 2.3 and 2.4. They are shown in Table 2 together with the surveys prepared with traditional method.

Konya Karatay Madrasah Portal, which is a 13th century building, is not located in the middle axis of the facade unlike the other selected examples. Along with the stone, marble craftsmanship draws attention in the portal as well. A different style is observed in the composition of muqarnas. Whereas muqarnases narrow more and more as they go up and are finished in a single line at the top in other selected examples' portals, there are 7 lines muqarnas series on top of eachother in Karatay Madrasah portal and are finished 5 lines side by side. Geometrical units are aligned on diagonals.

3.2. Digital close range photogrammetric survey of Karaman Hatuniye (Nefise Sultan) Madrasah portal muqarnas

According to the inscription in its portal, it was built in the name of Nefise Sultan who was wife to Karamanoğlu Alaaddin Ali Bey and daughter to Murad I Hüdavengidar (Sözen 1970; Dülgerler 2006; Konyalı 1967) in H 783/ G 1381-1382 1382 (Doğan 2006). While the structure of Karaman Hatuniye Madrasah portal mostly reflects the features of Seljuk period, it is observed that herbal decoration is intensified in the ornamentation and is dominated by a different style, quite higher than the surface (Konyalı 1974). The muqarnases in the portal on the facade, are of 14 lines and sliced deeply like a fan, and shaped as little cells consist of cornered stars (Kuban 2002). The top is reached by narrowing dimensions of rectangle area with using hexagon, hexangular stars, octagon, octangular stars in 14 lines of the muqarnas (Ödekan 1977). The last line of the muqarnas serie is ended with a half dome.

The survey studies of Portal Muqarnas in Karaman Hatuniye Madrasah are obtained by the means of photogrammetric method as determined in chapter 2.2, 2.3 and 2.4. They are shown in Table 3 together with the surveys prepared with traditional method.

The portal structure of Karaman Hatuniye Madrasah, a building of 14th century, mainly reflects Seljuk Madrasah portal features. The muqarnases of the portal, located on the middle axis of the facade, are made of 14 lines and are shaped like little cells consist of deep, fan-shaped slices of angular stars. The top is reached by narrowing dimensions of rectangle area with using hexagon, hexangular stars, octagon, octangular stars in 14 lines of the muqarnas. The geometrical shapes on the diagonal are octagon and octangular stars that are located parallel to portal wall. The last line of the muqarnas serie is ended with a half dome.

3.3. Digital close range photogrammetric survey of Aksaray Zinciriye Madrasah portal muqarnas

It is accepted that it was made in the time of Şüca-ed-din Mirza Halil (H 738/ G 1337-38), son of Bedrüd-din Mahmud, who was one of the rulers of Karamanoğulları (Konyalı 1974). Anatolian Madrasah traditions can be seen in the work of Zinciriye madrasah portal. The muqarnasses in the portal are composed of 9 series and they narrow towards the peak point. Geometrical shapes consist of twelve cornered star and dodecagon are used in the horizontal profiles of stone series of Aksaray Zinciriye Madrasah (Ödekan 1977). The last two lines of the series are finished with half dome.

The survey studies of Portal Muqarnas in Aksaray Zinciriye Madrasah are obtained by the means of photogrammetric method as determined in chapter 2.2, 2.3 and 2.4. They are shown in Table 4 together with the surveys prepared with traditional method.

Table 3. Karaman Hatuniye (Nefise Sultan) Madrasah Portal Muqarnas Survey Work

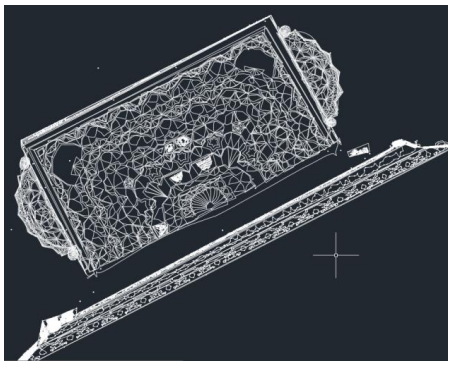
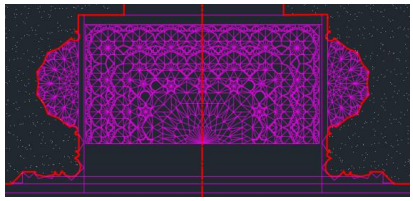
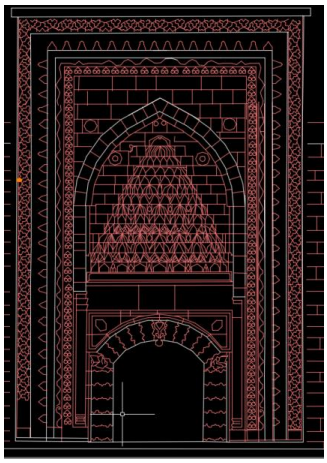
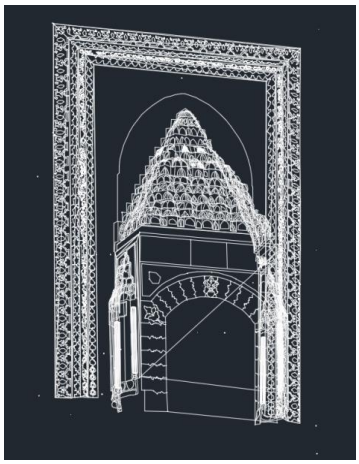
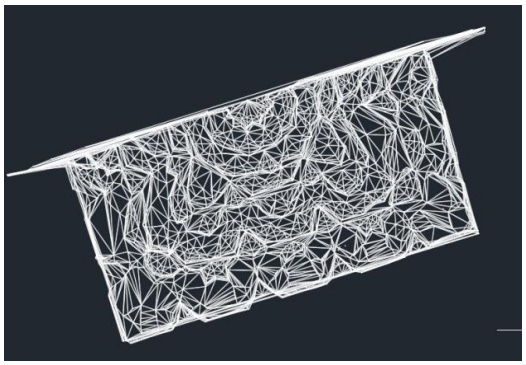
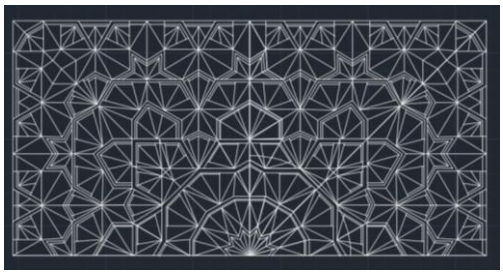
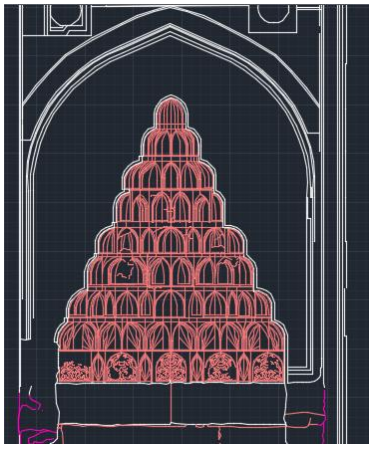
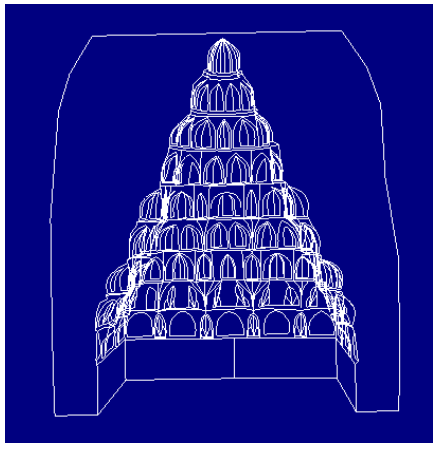
<table>
<tr><td rowspan="3"> 
Karaman Hatuniye (Nefise Sultan) Madrasah Portal</td><td>  </td></tr>
<tr><td>*Karaman Hatuniye (Nefise Sultan) Madrasah Muqarnases Unadjusted Plan Plane Made With Photogrammetric Survey*</td></tr>
<tr><td> 
Karaman Hatuniye (Nefise Sultan) Madrasah Muqarnas Plan Plane (Schematised With The Measurements Taken From General Directorate For Foundations And The Measurements From Photogrammetric Data)</td></tr>
<tr><td> 
Karaman Hatuniye (Nefise Sultan) Madrasah muqarnas portal view (Schematised with the measurements taken from General Directorate for Foundations and the measurements from photogrammetric data)</td><td> 
Karaman Hatuniye (Nefise Sultan) Madrasah Muqarnas 3d View As A Result Of Photogrammetric Survey</td></tr>
</table>

Table 4. Aksaray Zinciriye Madrasah Portal Muqarnas Survey Work

<table>
<tr><td rowspan="3"> 

Aksaray Zinciriye Madrasah Portal</td><td>  </td></tr>
<tr><td>*Unadjusted Plan Of Aksaray Zinciriye Madrasah Muqarnas*</td></tr>
<tr><td> 

Aksaray Zinciriye Madrasah Mukarnas Plan (schematized according to the measurements taken from the archives of General Directorate for Foundations and measurements from photogrammetric data.)</td></tr>
<tr><td> 

Aksaray Zinciriye Madrasah Portal Muqarnas View (Schematized According To The Measurements Taken From The Archives Of General Directorate For Foundations And Measurements From Photogrammetric Data)</td><td> 

Aksaray Zinciriye Madrasah Portal Muqarnas 3 D View According To Photogrammetric Survey</td></tr>
</table>

In the formation of the Aksaray Zinciriye Madrasah Portal, which is estimated to be made in the 14th century by using stone material, Anatolian Madrasah traditions can be seen and it makes a projection towards the front. The muqarnases in the Portal of Aksaray Zinciriye Madrasah are composed of 9 series which narrow towards the peak point and end with one series. In the horizontal profiles of stone series, geometric shapes such as twelve cornered star and dodecagons are used. Geometric forms stand on top of the diagonals. The last two lines of the series are ended with a half dome. There are 3 geometrical unit centers in the half dome that stands in the last two lines.

4. CONCLUSION

In the study, Konya Karatay Madrasah portal muqarnases, Karaman Hatuniye Madrasah portal muqarnases, Aksaray Zinciriye Madrasah portal muqarnases have been documented with digital close range photogrammetric method, and the formal characteristics of the muqarnases and the geometry used in them have been resolved via three dimensional models. The selected structures were built in the beginning of 13th and 15th centuries, and although there are differences in terms of plan schemes, there are similarities in terms of the location of entrance portals, and both similarities and differences in terms of formation.

Geometrical and formal differences have been discovered in the muqarnases of the buildings' portals which were selected as the study area. While the geometrical units that shape the muqarnases of Konya Karatay Madrasah and Karaman Hatuniye Madrasah are octagons and octagonal stars, dodecagons and dodecagonal stars are used in Aksaray Zinciriye Madrasah. This shows us that simpler and clearer geometrical schemes are used in the early era portal muqarnasses while in the late era geometrical shapes come together and form more complex compositions. The geometrical units stand on the diagonals in the selected examples. Karaman Hatuniye Madrasah and Aksaray Zinciriye Madrasah portal muqarnases with 14, 9 and 5 series which narrow towards the peak point and end with one line differ from Konya Karatay Madrasah with 7 lines of muqarnas series, 5 series in a row.

The plan, section and facades of the portals and muqarnases of the selected buildings were made by General Directorate for Foundations using the traditional method in the survey works. Moreover, three dimensional models of these muqarnases were made. 3D values of the muqarnases were attained successfully with the method of digital close range photogrammetry. It appeared that, in order to attain the plans, sections and different facades of the muqarnas, it is required to make adjustments in another environment (CAD software) other than photogrammetry software.

As a result, the data to use as the base in restitution and restoration studies of muqarnases is constituted with the obtained 3D models.

ACKNOWLEDGEMENTS

This Work Was Supported by The Selcuk University, Scientific Research Projects Coordination Unit [Project Numbers: 15401184]

REFERENCES

Anonymous. (2000) Values and Heritage Conservation, Research Report, The Getty Conservation Institute, Los Angeles.

Anonymous. (2012) Ulusal Meslek Standardı Tarihi Eser Koruma Ve Restorasyon Elemanı, Seviye 4, Resmi Gazete Tarih-Sayı / 05.12.2012 – 28488 (Mükerrer).

Altuntas, C., Yildiz, F. and Baygul, E. (2014) Documentation of Historical Structures in the Courtyard of Mevlana Museum by Terrestrial LIDAR and Photogrammetry. *Mediterranean Archaeology and Archaeometry*, 14, 249-258.

Altuntas, C, Hezer,S and Kırlı, S (2017) Image Based Methods for Surveying Heritage of Masonry Arch Bridge with the Example of Dokuzunhan in Konya, Turkey, *SCIENTIFIC CULTURE* Vol 3, No 2, 13-20

Arias, P. Ordóñez, C., Lorenzo, H., Herraez, J. (2006) Methods for documenting historical agro-industrial buildings: a comparative study and a simple photogrammetric method, *Journal of Cultural Heritage* 7 (4) (2006) 350–354.

Barazzetti, L. Bindab, L., Scaionia, M., Tarantob, P. (2011) Photogrammetric survey of complex geometries with low-cost software: Application to the 'G1 temple in Myson, *Vietnam*, 12 (2011) 253-262.

Chiabrando, F. Nex, F., Piatti, D., Rinaudo, F. (2011) UAV and RPV systems for photogrammetric surveys in archaelogical areas: two tests in the Piedmont region (Italy), *Journal of Archaeological Science 38, 697-710.*

Doğan, N. (2006) Kültürel Etkileşim Üzerine Karamanoğulları Memlük Sanatı, Hacettepe University Faculty of Literature Journal.

Dold-Samplonius, Y., Harmsen, S. L. (2005) *The Muqarnas Plate Found at Takht-I Sulayman: A New Interpretation*, Muqarnas, Vol. 22, pp. 85-94. Published by: Brill, Stable.

Dülgerler, O. N. (2006) Karamanoğulları Dönemi Mimarisi, Atatürk Kültür Dil Ve Tarih Yüksek Kurumu, *Turkish History Institution* , Vı. Serie, Issue, 66, pp:112-113, Ankara.

Erdemir, Y. (2001) Karatay Medresesi Çini Eserler Müzesi, T.C. Konya Governorship, Directorate of City Culture, Konya.

Garofalo, V. (2010) A Methodology for Studying Muqarnas: The extant examples in palermo. In: *Muqarnas Vol. XXVII: An Annual on the Visual Culture of the Islamic World,* 357–406.

Georgopoulos, A. (2016) Photogrammetric automation: Is it worth? *Mediterranean Archaeology & Archaeometry (16), No.5, 11-17*

Gherardini, F. Leali, F. (2016) A framework for 3d pattern analysis and reconstruction of persian architectural elements, *Nexus Netw J*, 18:133–167 (doi:10.1007/s00004-015-0287-z)

Gomez-Lahoz, J., Gonzalez- Aguilera, D. (2009) Recovering traditions in the digital era: the use of blimps for modelling the archaeological cultural heritage, *Journal of Archaeological Science*, 36, 100-109.

Harmsen, S. (2006) *Algorithmic Computer Reconstructions of Stalactite Vaults - Muqarnas – in Islamic Architecture*, Doctorate thesis , University of Ruprecht Heidelberg, Germany.

Harmsen, S. (2006) *Algorithmic computer reconstructions of stalactite vaults - muqarnas – in Islamic architecture*, Doctorate Thesis, University of Ruprecht Heidelberg, Germany,

Keleş, S. (2010) Fotogrametrik Yöntemlerle Cephe Rölövesi Alımı; Şevket Bey Konağı Örneği, KATU, IAS, Unpublished Master Thesis, Trabzon

Konyalı, İ. H. (1967*) Abideleri Ve Kitabeleri İle Karaman Tarihi, Ermenek Ve Mut Abidleri*, 466 p, İstanbul.

Konyalı, İ. H. (1974) Abideleri ve Kitabeleri İle Niğde Aksaray Tarihi, Volume 1, pp:1353, Fatih Publisher Printery.

Kuban, D. (2002) Selçuklu Çağında Anadolu Sanatı, Yapı Kredi Publisher, İstanbul.

Kuban, D. (2006) Mimarlık Kavramları(Tarihsel Perspektif İçinde Mimarlığın Kuramsal Sözlüğüne Giriş), Yapı Endüstri Merkezi Yayınları.

Lezzerini, M., Antonelli, F., Columbu, S., Gadducci, R., Marradi, A., Miriello, D., Parodi, L., Secchiari, L., Lazzeri, A. (2016) Cultural Heritage Documentation and Conservation: Three-Dimensional (3D) Laser Scanning and Geographical Information System (GIS) Techniques for Thematic Mapping of Facade Stonework of St. Nicholas Church (Pisa, Italy), *International Journal of Architectural Heritage*, 10:1, 9-19 (DOI: 10.1080/15583058.2014.924605).

Mülayim, S. (1988) TDV İslam Ansiklopedisi, Volume 31, Page 127, Türkiye Religious Foundation Publish, Ankara.

Ödekan, A. (1977) Osmanlı Öncesi Anadolu Türk Mimarisinde Mukarnaslı Portal Örtüleri, İTU, IAS, PhD Thesis, İstanbul.

Ödekan, A. (1988) Mimarbaşı Kocasinan - Yaşadığı Çağ Ve Eserleri, Vol.2, pp.476, General Directorate for Foundations Publish, Editor Sadi Bayram, Ankara, 1988

Ögel, S. (1987*) Anadolu Selçukluları Taş Tezyinatı*, Ankara,

Olga Zaitceva, Mikhail Vavulin, Andrey Pushkarev, Evgeny Vodyasov *(2016)* Photogrammetry: from field recording to museum presentation (timiryazevo burial site, western Siberia). *Mediterranean Archaeology and Archaeometry*, Vol.16, No 5, 97-103.

Ordóñez, C., Martínez, J., Arias, P., Armesto, J. (2010) Measuring building façades with a low-cost close-range photogrammetry, *Automation in Construction*, 19, 742-749.

Peña-Villasenín, S., Gil-Docampo, M., Ortiz-Sanz, J. (2017) 3-D Modelling of Historic Facades Using SFM Photogrammetry Metric documentation of different building types of a historic centre, *International Journal of Architectural Heritage,* DOI: 10.1080/15583058.2017.1317884

Pierdicca, R., Frontoni, E., Malinverni, E.S., Colosi, F. (2016) Virtual reconstruction of archaeological heritage using a combination of photogrammetric techniques: Huaca Arco Iris, Chan Chan, Peru, *Digital Applications in Arhaeology and Cultural Heritage*, 3 (2016) 80-90.

Quagliarini, E., Clini, P., Ripanti, M. (2017) Fast, low cost and safe methodology for the assessment of the state of conservation of historical buildings from 3D laser scanning: The case study of Santa Maria in Portonovo (Italy*), Journal of Cultural Heritage*, 24, 175–183.

Riveiro, B., Caamano, J.C., Arias, P., Sanz, E. (2011) Photogrammetric 3D modelling and mechanical analysis of masonry arches: An approach based on a discontinuous model of voussoirs*, Automation in Construction* 20, 380-388.

Sahin, C., Alkis, A., Ergun, B., Kulur, S., Batuk, F., Kılıç, A. (2012) Producing 3D city model with the combined photogrammetric and laser scanner data in the example of Taksim Cumhuriyet square, Optics and Lasers in Engineering 50, 1844–1853.

Salama, K.K, Ali, M.F (2017) Reconstruction of Monastery Saint Jeremiah Computer-Aided Design Model. *Scientific Culture* , Vol 3, No.1, 11-14 (DOI: 10.5281/zenodo.192839)

Salonia, P., Scolastico, S., Pozzi, A., Marcolongo, A., Messina, T. L. (2009) Multi-scale cultural heritage survey: Quick digital photogrammetric systems, Journal of Cultural Heritage, 10, 59-64.

Sözen, M. (1970) Anadolu Medreseleri, Selçuklular Ve Beylikler Devri, Volume I, S:49-57, İstanbul.

Tuncer, O.C. (1986) *Anadolu Selçuklu Mimarisi ve Moğollar*, pp:20-21, Ankara.

Ünal, R. H. (1982) *Osmanlı Öncesi Anadolu Türk Mimarisinde Taç Kapılar*, İzmir.

Uslu, A., Polat, N., Toprak, A.S., Uysal, M. (2016) Kültürel Mirasın Fotogrametrik Yöntem ile 3 Boyutlu Modellenmesi Örneği, Harita Teknolojileri Elektronik Dergisi, 8(2), 165-176. (doi: 10.15659/hartek.16.08.302)

Yakar, M., Yılmaz, H.M., Güleç, S.A., Korumaz, M. (2009) Advantage of digital close range photogrammetry in drawing of muqarnas in architecture. *Information Technology Journal* 8 (2): 202-207,2009.

Yastikli, N. (2007) Documentation of cultural heritage using digital photogrammetry and laser scanning, *Journal of Cultural Heritage*, 8, 423-427.

Yilmaz, H.M., Yakar, M., Yildiz, F. (2008) Documentation of historical caravansaries by digital close range photogrammetry, *Automation in Construction* 17 (2008) 489–498 .

Zlot, R., Bosse, M., Greenop, K., Jarzab, Z., Juckes, E., Roberts, J. (2014) Efficiently capturing large, complex cultural heritage sites with a handheld mobile 3D laser mapping system, *Journal of Cultural Heritage* 15, 670–678.

LINKS :

URL 1: http://whc.unesco.org./en/conventiontext [Acssesed:04.05.2017)