PHOTOGRAMMETRIC WIREFRAME AND DENSE POINT CLOUD 3D MODELLING OF HISTORICAL STRUCTURES: THE STUDY OF SULTAN SELIM MOSQUE AND YUSUF AGA LIBRARY IN KONYA, TURKEY

C. Altuntas [1,] *, S. Mert [1], G. Yaman [1], Y. Cengiz [1], M. Sonmez [2]

[1] Konya Technical University, Faculty of Engineering and Natural Science, 42075 Selcuklu, Konya, Turkey – caltuntas@ktun.edu.tr – (mertsezaii, yasincengizd, gokhanyamanharita)@gmail.com
[2] Selcuk University, Engineering Faculty, Department of Geomatics 42075 Selcuklu, Konya, Turkey – mesutayser@windowslive.com

Commission II

KEY WORDS: Photogrammetry, 3D Modelling, Point Cloud, Documentation, Wireframe Model, Historical Structure

ABSTRACT:

The photogrammetry enables to getting high accuracy measurement with low-cost and easy application in documentation of historical structures. The object details are signified with lines in cultural heritage documentation by photogrammetry. The combination of all the lines create 3D wireframe model of the measurement object. In addition, patch surfaces of the wireframe are mapped with the texture from the images for more realistic visualization. On the other hand, the progress on computer vision and image processing techniques is allowing automatically perform the photogrammetric process. A large number of points that are called dense point cloud can be measured from coverage area of multi view images. The dense point cloud represents the object shape with small space measured points while the wireframe photogrammetry is representing the object with lines. In this study these two photogrammetric methods were evaluated with respect to visualization, cost, labour and measurement time through 3D modelling of historical structures of Sultan Selim Mosque and Yusuf Aga Library.

1. INTRODUCTION

The historical structures have cultural and technological savings of their communities in the era of their created. They should be transferred to the next generations for maintain the connection to pass and next generations. Three-dimensional (3D) measurement enables visualization of the object with their real dimensions in cultural heritage documentation. The close-range photogrammetry has been used in cultural heritage documentation for many years. The image acquisition and processing in the photogrammetry have been turned into the digital environments for about forty years. Digital environments had been created new easy methods in application of mathematical relations of the photogrammetry and 3D visualization. By this means, the photogrammetry has been practised in many aims such as medicine, industry, cultural heritage documentation, 3D modelling and etc. (Scaioni et al., 2015; Altan et al., 2001). Nowadays, image matching and measurement by photogrammetry can be performed automatically using structure from motion (SfM) algorithm (Granshaw and Fraser, 2015; Remondino et al., 2014). Thus dense point cloud data can be created from set of the images by photogrammetry in a short time. This image based measurement is called different names e.g. image based dense point cloud measurement, computer vision photogrammetry, multi view photogrammrty and etc. Dense image based point cloud measurement is attractive method in 3D modelling through its easy and low cost application.

Wireframe 3D model has been created by means of close-range photogrammetry. The close range photogrammetry have been used in documentation of cultural heritage (Altuntas et al., 2006; Kulur and Yilmazturk, 2005; Dorffner et al., 2000). The Anatolia has many historical structures e.g. caravansary, mosque, bridge and etc. The Zazadinhan Caravansary, that has 32x25m dimensions, was measured by the photogrammetric method, and wireframe model was created (Altuntas et al., 2006). Another wireframe 3D model was crated for Beysehir Mosque, Konya, Turkey by means of photogrammetric method (Yakar and Yildiz, 2005). The photogrammetry has also been exploited for the shape of arches and complex details. The created 3D model can be transferred into geographic information system after matching image texture data onto them (Duran and Toz, 2003; Arca et al., 2018).

Dense point cloud is created from stereo or multi view images automatically. It is popular for 3D measurement and modelling task thanks to its easy and fast application. More complex details and large topographies can be measured by this method (Shao et al., 2016; Barazzetti et al., 2010). Dense point cloud method is also extensively used in documentation of cultural heritage (Maivald et al., 2017; Previtali et al., 2011).

In this study Sultan Selim Mosque and Yusuf Aga Library that was located in the cultural valley around the Mevlana Museum in Konya, Turkey were measured by photogrammetry and dense point matching methods.

2. STUDY OBJECT

Sultan Selim Mosque and Yusuf Aga Library were located West side to Mevlana Tomb in Konya City, Turkey (geographical coordinates are 37°52'13.34"N latitude, 32°30'14.82"E longitude). The Sultan Selim Mosque was built by Great Architect Sinan in sixteen century. The structure has traditional Ottoman mosque style, which has circle dome on the centre. It has two minarets on the north side, tree circle domes on the East and West sides and half circle dome on the south. The door on the north has magnificent marble decorations and circle dome. The dimensions are 37x34 meters. Its first restoration had been made in the year of 1690. Then it had been restored and repaired about ten times until the twentieth century. The last restoration has been completed in the year of 2018. The library was built adjacent the mosque by Yusuf Aga in eighteen century, and it was called his name. It has square shapes that have 15 meter dimensions. Its façade was built in harmony to the adjacent Sultan Selim Mosque (Fig. 1).

Figure 1. From Nort side visualization of Sultan Selim Mosque (left) and Yusuf Aga Library (right)

3. METHODS

3.1 Data Acquisition

The object images were recorded by Canon EOS 550D camera that has 5184x3416 pixel array and 22.3x14.9 mm sensor dimensions. The 208 images were recorded from 15 meters distances away. The 127 images of them were used in wireframe evaluation and all of them used in dense point cloud creation. The north side of the mosque which has very small figures and complex shapes were imaged from many points of view with close distances. The eight traverse points were located around the structure for measuring ground based coordinates of the control points (CPs) that were selected on the object. CPs were selected from significant corner on the object. Close-range photogrammetry requires least three control points for registering wireframe project data into object coordinate system. But this condition is current for ideal condition only. On the other hand wireframe model of all the façade can not be created in one work file. Thus the building façade was divided multiple parts, which will be merged end of the studies. Total 51 control points were measured on the object. The coordinates of traverse and CPs were measured with Topcon OS-103 totalstation that has ability the measurement without reflector up to 500 m. The OS-103 totalstation has 3 mm+2 ppm measurement accuracy on reflectorless mode .

3.2 Close-range Photogrammetry

Close-range photogrammetry uses the stereo images of the object for measuring the object in order to derive its shape and location. One image enables image reconstruction according to a reference coordinate system for 2D interpretation and measurement. The main purpose of the photogrammetric measurement is the three dimensional reconstruction of an object in digital form. Three dimensional visualization and measurement can be performed from a stereo area of least two or more photographs. The photographs have to be created from central projection. Their deviations from central projection must be modelled for high accuracy measurement by the photogrammetric measurement. The estimations of these deviations are named interior orientation, and it is first step in photogrammetric evaluation. The second step in a photogrammetric evaluation is relative orientation of the stereo images. The last step is three-dimensional reconstruction and data registration that has scale assignment.

Interior orientation parameters are principal point coordinates (x_o,y_o), focal length (f), distortion parameters and pixel dimensions. They can be estimated by camera calibration before or after taking of the images (Remondino and Fraser, 2006). The calibration is carried out with bundle adjustment of more images of special designed test grid or sheet that has target points with known locations.

The relative orientation is translation and rotation of the stereoscopic images so as to catch a relative image taking position with respect to the other. It is realized by co-planarity condition at least five conjugate points (Altuntas, 2013). The object point, projection center and image point are lie in a line, and the relationship between them is called collinearity condition. A point which will be measured in stereo area of two images have to be ensure this condition. The object point imaging lines from two images have to be on the same plane, which has been called co-planarity, in stereoscopic visualization (Fig. 2).

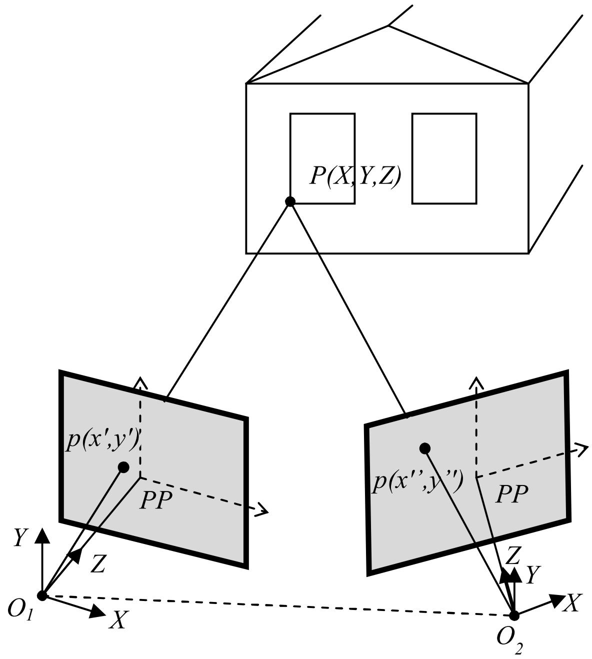

Figure 2. Close-range stereo photogrammetric measurement

The collinearity condition is expressed by two equations which were called collinearity equations (Eq.1).

$$x = x_o - f\frac{r_{11}(X - X_o) + r_{21}(Y - Y_o) + r_{31}(Z - Z_o)}{r_{13}(X - X_o) + r_{23}(Y - Y_o) + r_{33}(Z - Z_o)}$$
$$y = y_o - f\frac{r_{12}(X - X_o) + r_{22}(Y - Y_o) + r_{32}(Z - Z_o)}{r_{13}(X - X_o) + r_{23}(Y - Y_o) + r_{33}(Z - Z_o)} \quad (1)$$

Where (x,y) are image coordinates, f is camera focal length, subscript r is component of rotation matrix that have nine elements. The object coordinates XYZ are computed by common solving of two collinearity equations from two images. The relative orientation parameters of more than two images have been estimated simultaneously by bundle adjustment procedure.

The scale is computed with absolute orientation or ratio of distances in model and object spaces. The absolute orientation is performed by least three common points that have object and model coordinates, and it makes registration to the model into the object coordinate system.

3.3 Dense Point Cloud

Image based dense point cloud creation is computer vision approach to photogrammetric processes. It is also named multi view photogrammetry or computer view photogrammetry. Dense image based point cloud has been created from two or multi view stereo images automatically. At first, the procedure uses structure from motion (SfM) algorithm for matching of unordered images. SfM algorithm uses a technique to resolve the camera and feature positions within a defined coordinate system. This procedure does not require the camera to be pre-calibrated. The camera calibration parameters, image positions and 3D geometry of a scene are automatically estimated by an iterative bundle adjustment. The relationship between the images is established by the keypoints which were automatically detected and matched. The matching results are generally sparse point clouds, which are then used as seeds to grow additional matches and dense point cloud creation. The 3D spatial coordinates for all matched keypoints are generated according to the intrinsic local reference coordinate system without the scale. Dense point cloud is then generated by estimating 3D coordinates for additional matches between these images. Generated CPs allow us to obtain a scale for the 3D point cloud model and register it into an object based coordinate system.

4. RESULTS

4.1 3D Wireframe Model

The photogrammetric wireframe model was created by using Photomodeler software (Fig. 3). The object facade was divided several parts so as to not depend on computer hardware capacity in working. Then all of the wireframe models were combined by the photomodeler *merge* command (Fig. 4). The georeferencing were made by the 41 CPs. The maximum point marking residual is five pixels. The wireframe model of door has been created independent from the façade because it has small and complex details (Fig. 5, Fig. 6).

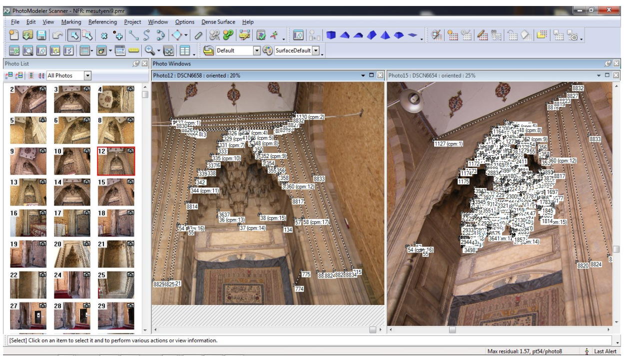

Figure 3. Stereo photogrammetric processes

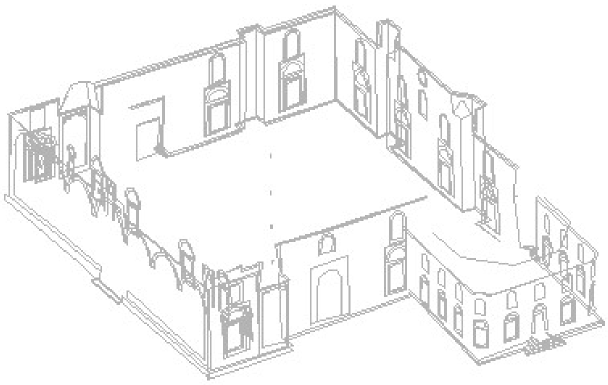

Figure 4. Photogrammetric wireframe model

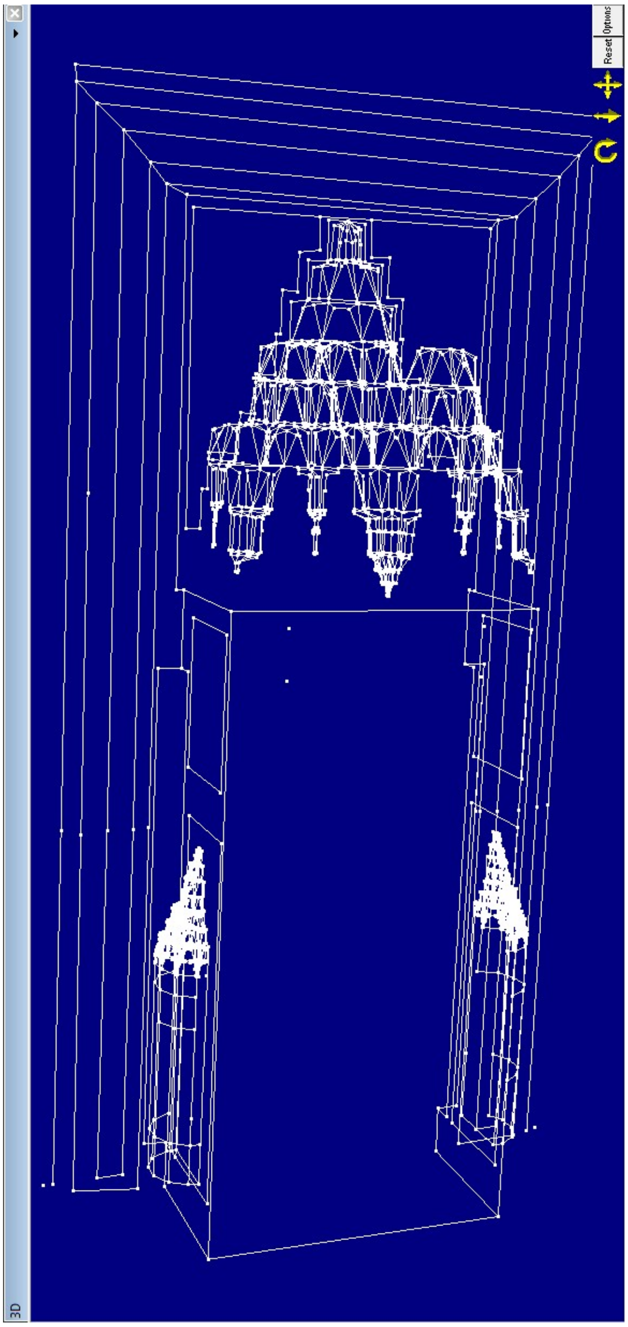

Figure 5. The wireframe model of mosque door that has complex shapes

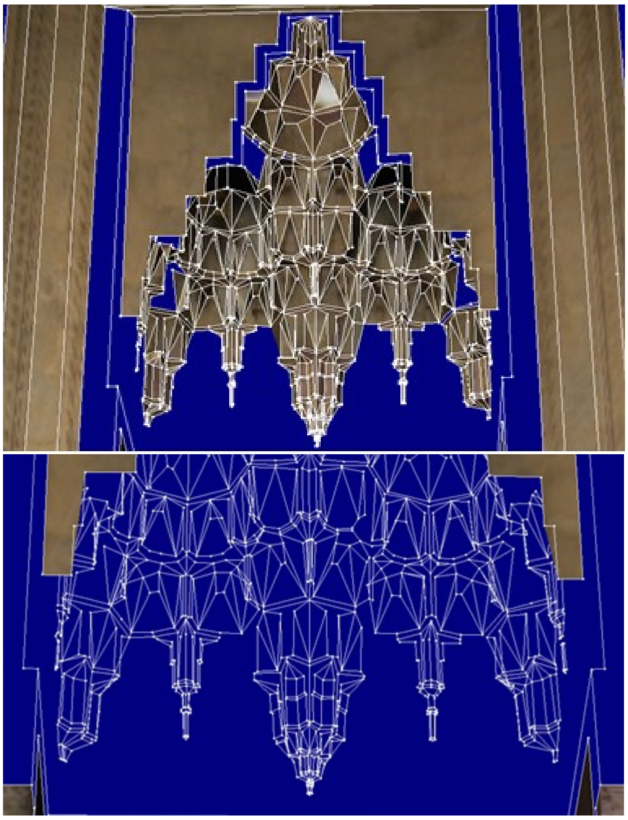

Figure 6. Wireframe 3D model of decorated door

4.2 3D dense point cloud model

The image based dense point clouds were created by using Agisoft Photoscan software (Agisoft, 2017) (Fig. 7, Fig. 8). The georeferencing and also scale assignment were made with the control points. The processing results are giving on Table 1. Digital elevation model was also created from point cloud data (Fig. 9).

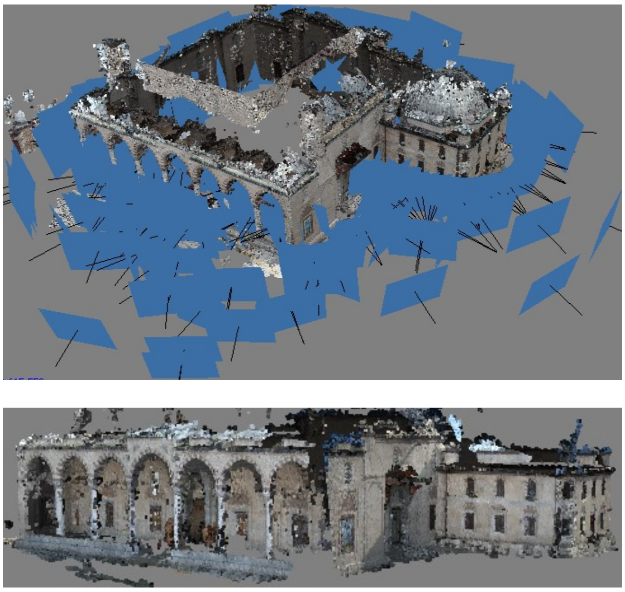

Figure 7. Dense point cloud model

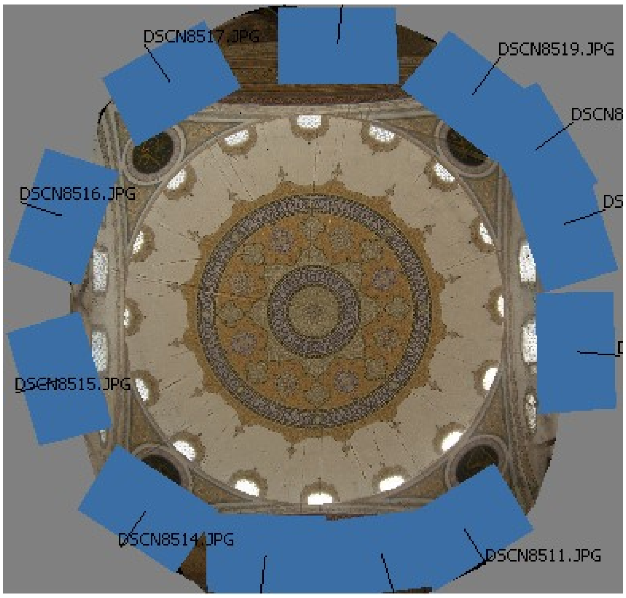

Figure 8. Dense 3D point cloud model of central circle dome

Table 1. Dense point cloud creation results

Image #	208
Imaging distance	15 m
Ground resolution	3.16 mm/pix
Coverage area	545 m^2
Tie points	166360
Projections	714444
Reprojection Error	1.61 pix
Max. reprojection error	36.68 pix

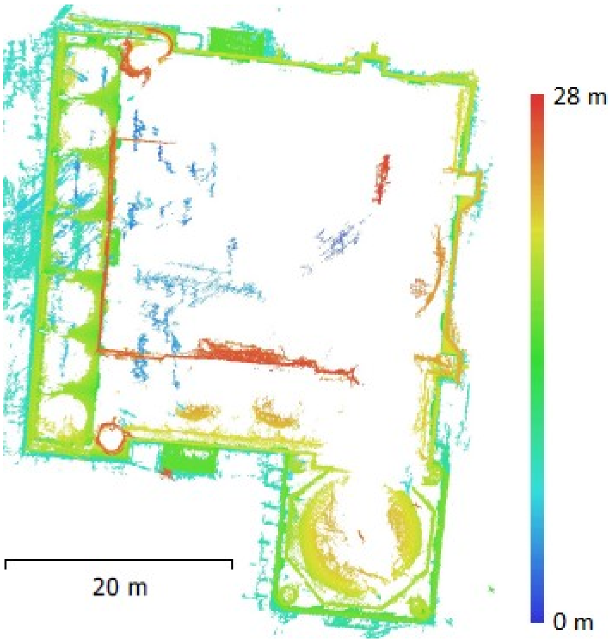

Figure 9. Digital elevation model (Top view)

5. DISCUSSION

Opposite to creating dense point cloud, stereo photogrammetry requires immense effort for representing object shapes with lines. The wireframe model shows geometric details with lines. The similar information can be extracted from dense point cloud with post processes. However, real word measurement data such as volume, cross section, area can be extracted from dense point cloud model precisely. Dense point cloud represents the object surface with uniform spatial data, whereas photogrammetry creates spatial data for significant details only. Texture data can be mapped onto the created measurement data in order to rich visual presentation of the object. In this situation object surface represented by the triangles which were generated from measured points. More points have more triangles that represents to the small shapes. Thus dense point cloud is ability visualization of the object to close the real world. Stereo photogrammetry requires immense efforts for definition with triangles to small shapes.

Stereo photogrammetry needs proper image geometry for high accuracy in 3D reconstruction. The roof can not be imaged from proper image stations that close to the object. Thus dense point cloud was created from the images that were taken from far away distances. The roof dense point cloud model was combined to the façade photogrammetric wireframe model (Fig. 10).

The tie points for relative orientation of the images are selected manually in stereo close-range photogrammetry. It is time consuming and tedious especially in surface deprived of detail. In addition every detail points, that will be drawn, must also be defined manually in two images. However dense point cloud matching and measurement data creation has been performed automatically. It creates spatial point data from image covered area of two or more images, but undesirable points should be removed manually. The both methods have enough level of accuracy for 3D documentation of cultural heritages. These measurement methods have about equal time for field work. The time consuming in office study for measuring is main criteria for selecting one of these measurement methods. Dense point cloud method is so fast relatively to close-range photogrammetry.

In this study, since the study object is large scale dimensions, the wireframe model was created in a few project file, and used more control points than dense point cloud method. The photogrammetric evaluations have been done with fifty control points while four or more control points enough for registering the dense point cloud into the object coordinate system.

Table 2. Comparison of measurement methods

	Close-range photogrammetry	**Dense point cloud**
Measurement data	3D wireframe with 3143 points	3D point cloud with 20615553 points
Image #	127	208
Time for insitu data acquisition	1 day	1 day
Time in processes	1 month	3 hours
Accuracy	Max point tightness is 0.06 m	$RMSE_X$=25.11cm $RMSE_Y$=25.66cm $RMSE_Z$=7.10cm
Georeferencing with CPs	3 or more CPs (41 CPs)	3 or more CPs (6 CPs)
Texture mapped model	Yes/Low resolution	Yes /High resolution
Orthophoto	Low accuracy	High accuracy

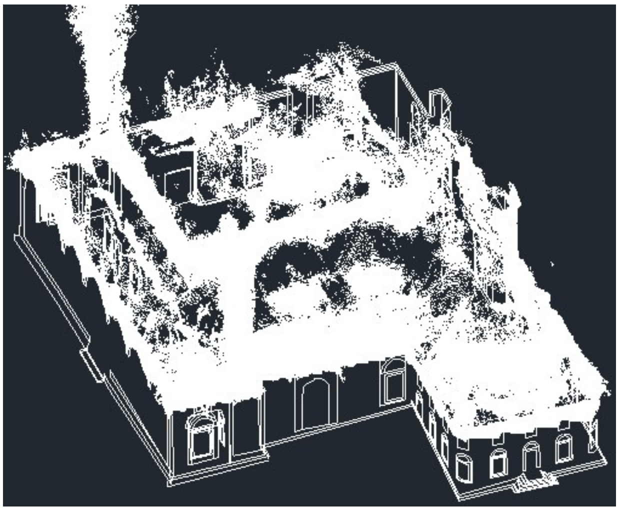
Figure 10. The combination of facade wireframe and dense point cloud of dome

6. CONCLUSION

In this study, historical Sultan Selim Mosque and Yusuf Aga Library in Konya, Turkey were modelled by means stereo and computer vision photogrammetry. As a consequence, both stereo and computer vision photogrammetric methods enable high accuracy three-dimensional measurement in documentation of cultural heritage. These measurement methods can be preferred according to an excellent property in respect of easy use, fast application, low labour, visualization and accuracy. Stereo photogrammetry creates wireframe model that represent main characteristics of the object while computer vision photogrammetry is creating dense spatial data. Dense point cloud is very fast measurement method to creating 3D model. It also enables to creating digital elevation model that is very useful for documentation of complex and small details of cultural heritage.

REFERENCES

Agisoft, 2017. Photoscan Professional (Ver.:1.3.2.4205).

Altan, O., Toz, G., Kulur, S., Seker, D.Z., Volz, S., Fritsch, D., Sester, M., 2001. Photogrammetry and geographic information systems for quick assessment, documentation and analysis of earthquakes, ISPRS Journal of Photogrammetry and Remote Sensing 55(5/6): 359-372.

Altuntas, C., 2013. Keypoint based automatic image orientation and skew investigation on tie points, Kybernetes, 42(3): 506-520.

Altuntas, C., Yildiz, F., Yakar, M., Karabork, H., Karasaka, L., Yilmaz, H.M., 2006. Photogrammetric methods in documentation of cultural heritage in macro dimension: A case study of the Zazadin Inn, In Proc. Fifth International Symposium Turkish-German Joint Geodetic Days, 28-31 March, Berlin, ISBN 3-9809030-4-4, 6 pages

Arca, D., Şeker, DZ., Alkan, M., Serkan, K., Bayık, Ç., Acar, H., 2018. Development of WebBased GIS for the Cultural Heritage of Safranbolu, Turkey. International Journal of Environment and Geoinformatics (IJEGEO). 5(3): 368-377. DOI: 10.30897/ijegeo.457184

Barazzetti, L., Remondino, F., Scaioni, M., 2010. Automation in 3D reconstruction: Results on different kinds of close-range blocks. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII, Part 5, pp. 55-61.

Dorffner, L., Kraus, K., Tscannerl, J., Altan, O., Külür, S., Toz, G., 2000. Hagia Sophia-Photogrammetric record of a world cultural heritage. International Archives of Photogrammetry and Remote Sensing. Vol. XXXIII, Part B5, pp. 172-179.

Duran, Z., Toz, G., 2003. Documentation of cultural heritage by means of photogrammetric methods and transfer to GIS. itüdergisi/d 2(6): 19-30.

Granshaw, S.I., Fraser, C.S., Computer vision and photogrammetry: Interaction or Interospection?, *Editorial*, The Photogrammetric Record 30(149): 3-7.

Kulur, S., Yilmazturk, F., 2005. 3D-reconstruction of small historical objects to exhibit in virtual museum by means of digital photogrammetry. CIPA 2005 XX International Symposium, 26 September – 01 October, 2005, Torino, Italy.

Maiwald, F., Vietze, T., Schneider, D., Henze, F., Münster, S., Niebling, F., 2017. Photogrammetric analysis of historical image repositories for virtual reconstruction ın the field of digital humanities. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XLII-2/W3, pp. 447-452.

Previtali, M., Barazzetti, L., Scaioni, M., 2011. Multi-step and multi-photo matching for accurate 3D reconstruction. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII-3/W22, pp. 103-108.

Remondino, F., Spera, M.G., Nocerino, E., Menna, F., Nex, F., 2014. State of the art in high density image matching. The Photogrammetric Record, 29(146): 144–166.

Remondino, F., Fraser, C. 2006. Digital camera calibration methods: considerations and comparisons. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (IAPRS), Vol. XXXVI, Part 5, pp. 266-272.

Scaioni, M., Feng, T., Barazzetti, L., Previtali, M., Lu, P., Qiao, G., Wu, H., Chen, W., Tong, X., Wang, W., Ron Li, 2015. Some applications of 2-D and 3-D photogrammetry during laboratory experiments for hydrogeological risk assessment. Geomatics, Natural Hazards and Risk 6(5-7): 473–496, http://dx.doi.org/10.1080/19475705.2014.885090

Shao, Z., Yang, N., Xiao, X., Zhang, L., Peng, Z., 2016. A Multi-View Dense Point Cloud Generation Algorithm Based on Low-Altitude Remote Sensing Images. Remote Sensing, 8, 381; doi:10.3390/rs8050381

Yakar, M., Yildiz, F., 2005. Digital photogrammetric methods in documentation of cultural heritages and Beysehir example. CIPA 2005 XX International Symposium, 26 September–01 October, Torino, Italy.