



## ANALYSIS OF DOCUMENTATION OPPORTUNITIES OF CULTURAL HERITAGE SAMPLES WITH TERRESTRIAL PHOTOGRAMMETRY METHODS

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**ABSTRACT:** Nowadays, as in many sectors, natural and cultural resources face the danger of extinction due to misuse and consumption-oriented life in tourism. Within the framework of the sustainability tourism principle, these resources should be determined, protected, and developed. With the advance technology, the use of photogrammetry offers new methods for surveying natural and cultural resources. In this study, the photographs of two historical sites were taken with a high-resolution handheld camera in order to evaluate the potential of terrestrial photogrammetry approach in the cultural heritage. Then, these photographs were used to develop three-dimensional models of the two sites using two different software-Agisoft Metashape and 3D Zephyr Free. For this study, two important cultural and historical heritages were selected; both located in the center of Giresun province in Turkey. The 3D models of the heritages developed using two software were compared to evaluate the capability of the software. In the evaluation process, 13 photographs for the historical door and 50 photographs for the shrine were used to generate 3D models. According to the evaluation of the models, it was observed that the model generated for the front surface of the Public Garden door provided more detailed and accurate results in both software. When these two programs are compared for the shrine, Agisoft Metashape produced a better 3D model than 3D Zephyr. The results also showed that the photographs obtained from a low-cost handheld camera could provide highly accurate and precise data for documentation of historical and cultural heritages.

**Keywords:** Cultural heritage; Terrestrial Photogrammetry; 3D Modelling; Digital Heritage

## **KÜLTÜREL MİRAS ÖRNEKLERİNİN YERSEL FOTOGRAMETRİ YÖNTEMLERLE KAYIT ALTINA ALINMA IMKANLARININ ANALİZİ**

**ÖZET:** Günümüzde birçok sektörde olduğu gibi doğal ve kültürel kaynaklar yanlış kullanım ve turizmde tüketim odaklı yaşayış nedeniyle yok olma tehlikesi ile karşı karşıya kalmaktadır. Tuzim de sürdürülebilirlik ilkesi çerçevesinde bu kaynakların tespit edilmesi korunması ve geliştirilmesi gerekmektedir. İlerleyen teknoloji ile birlikte tespit aşamasında fotogrametrik yöntemlerde kullanım imkanları ortaya çıkmıştır. Çalışmada yersel fotogrametrik yöntemlerin miras niteliği taşıyan kaynakların kayıt altına alınmasında potansiyelini değerlendirmek amacıyla iki örnek tarihi yapının yüksek çözünürlüklü kamera ile fotoğrafları çekilmiştir. Daha sonra, Agisoft ve 3D Zephyr Free programı yardımıyla fotoğraflar işlenerek üç boyutlu modelleri oluşturulmuştur. Çalışmada, Giresun ili merkezde bulunan önemli kültürel miras örneklerinden Giresun Millet Bahçesi girişindeki tarihi kapı ve Seyyit Vakkas Türbesi incelenmiştir. Modelleme sırasında kapı için 13 ve türbe için 50 olmak üzere farklı fotoğraf sayıları kullanılmıştır. Programlarla model oluşturma sırasında kullanılan noktalar ve ara yüzler incelenmiştir. Modellere ilişkin değerlendirmelere göre Millet Bahçesi kapısının ön yüzeyi için oluşturulan modelde her iki programında detaylı sonuç verdiği gözlemlenmiştir. Bu iki program türbe için kıyaslandığında ise Agisoft Metashape 3D Zephyr'e göre daha iyi bir model ortaya çıkarmıştır. Sonuçlar kültürel miras niteliği taşıyan tarihi yapıların kayıt altına alınmasında yersel fotogrametrik yöntemlerin yüksek doğrulukta ve hassasiyette veriler sağlayabileceğini göstermiştir.

**Anahtar kelimeler:** Kültürel miras, yersel fotogrametri, 3d modelleme, dijital miras.

### **INTRODUCTION**

Sustainable tourism can be defined as managing all resources in a way that economic, social, and aesthetic needs of the human being can be met while maintaining cultural and natural resources, essential ecological processes, biological diversity, and life support systems without any alteration or degradation (Ruoss and Alfarè, 2013). In order to protect natural and cultural resources, it is necessary to define the natural and cultural heritage accurately. Cultural heritage is divided into three groups by UNESCO: monuments, building groups, and areas (UNESCO et al., 2011). Monuments, architectural works, monumental sculptures, and paintings, cave houses are structures with superior universal value in history, art, and science. Building groups, including separate or connected building groups due to their architecture, homogeneity, or landscape, are structures that have superior universal value in history, art, and science. Areas are defined as archaeological sites with historical, aesthetic, ethnological, and anthropological features that have superior universal value, formed by human beings or both human and nature together (UNESCO et al., 2011).

Protecting cultural value first begins with determining the culture of the nations who lived or have lived on the land, and then recording this culture for the future of the nations (HKMO, 2002). Therefore, documentation of cultural and natural heritage is crucial. Digital photogrammetry has been used in determining and documentation of the cultural heritage in these days. With digital photogrammetry, some of the information, related to the heritage, such as making measurements can be recorded remotely or without causing and damages. In particular, this information obtained from digital photogrammetry can be useful for restoration projects to see the previous situation of the heritage (Yakar et al., 2008; Yılmaz et al., 2007). Advanced technology increases the efficiency of digital photogrammetry and offers a more

economical method for three-dimensional documentation of cultural heritages. Because two-dimensional images with drawings and reports are not sufficient to interpret the object under all circumstances, interests in multi-image photogrammetry (MIP), which allows generating a three-dimensional model of an object, has been increased. MIP, often used as a substitute for Structure from Motion (SfM) technique, enables to produce the 3D models using a series of two-dimensional overlaid photographs for the selected object, structure or terrain (Turan, 2004; McCarthy, 2014; Sarıtürk et al., 2017; Acuna et al., 2019). Unlike stereo pairs, this technique can combine a large number of images from a different distance rather than pairs from a certain distance and can generate more detailed and accurate three-dimensional models. This makes the technique more cost-effective, user-friendly, and powerful. Consequently, there is an increase in the number of open-source or commercial SfM based programs (e.g. Visual SFM, Agisoft Metasahpe, Regard 3D, MicMac, 3D Zephyr, Photomodeler Colmap) on the market. Based on the rise of SfM based software, the number of studies in generating 3d models has also been increased. The previous studies have been conducted for documentation of the cultural heritage along with generating 3D model using various software and the images that obtained from different sources (Yılmaz et al., 2007; Yastıklı 2007; Yakar et al., 2008; Korumaz 2011; Samaan et al., 2013; McCarthy, 2014; Pérez Ramos et al , 2015). In this study, two SfM based software with imagery from handheld cameras were used to compare results and evaluate the applicability of the 3D model in the documentation of two cultural heritage sites for the future study.

## MATERIAL AND METHODS

### *Study Area*

Two cultural and historical heritages - historical National Garden door and Seyyit Vakkas shrine - located in the city center of Giresun Province of Turkey were evaluated in this study.



The Public Garden has a monumental arched door with two drinking water fountains. There are three inscriptions at the door (one is at the top, and two of them are at each side of the arch) and states that the door was built in 1900 (h 1318). The entrance door is in a vertical rectangular shape with a round-arched and has a metal door leaf (Figure 1a). The second cultural heritage is Seyit Vakkas shrine that was built in the 19th century. The shrine has a unique Ottoman architecture tomb feature (Figure 1b) with an octagonal shape (Anonym, 2020).

a)

b)

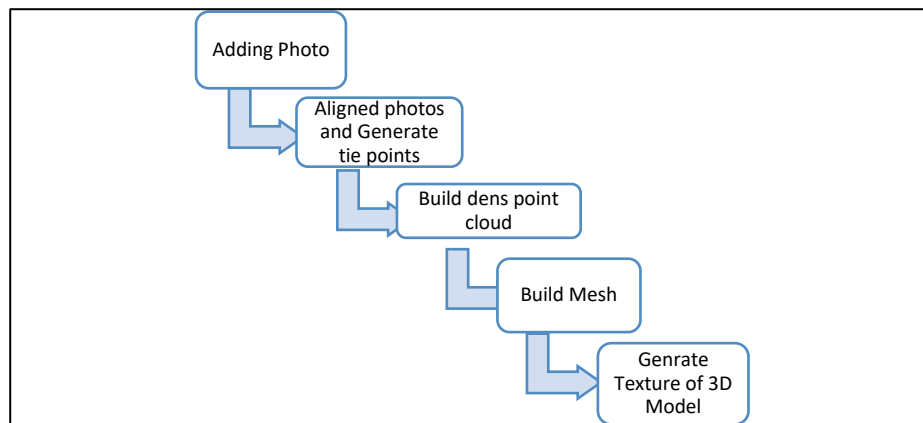
**Figure 1.** The Cultural Heritages: Public Garden Entrance (A) And Seyit Vakkas Shrine (B)

**Methods**

A 3D model was developed for documentation of two cultural heritages using close-range photogrammetry. The images of the cultural heritages were acquired using a low cost 24.2-megapixel Canon EOS 200D handheld camera. For the Public Garden door and Seyit Vakkas shrine 13 images and 50 images were obtained, respectively. Agisoft Methashape Standard (Agisoft LLC, St. Petersburg, Russia) and 3D Zephyr Free (3DFLOW S.R.L., Verona, Italy) were used to process the images and generate a 3D model for documentation of two cultural heritages.

Agisoft Metashape is a software product that processes digital images and generates 3D data that can be used in GIS applications, documentation of cultural and natural heritages, visualization of objects in conjunction with the indirect measurement at various scales (Agisoft LLC, 2020). Similarly, 3D Zephyr Free software automatically generates the 3D model using digital images. Both software is easy to use and allow users for editing and making measurement from the generated model and recording video and animation of the model as an output. Also, 3D Zephyr Free allows users to load the video directly and obtain images from this video to generate the model (3DFLOW S.R.L.,2019)

A 3D model was generated using the same images that were collected for the door (13) and the shrine (50) within both software. Both software showed similarities in processing the images while generating the model. The following steps were performed; adding photographs into the software, aligned photos, create tie points, build dense point cloud, build mesh, and texture (Figure 2).

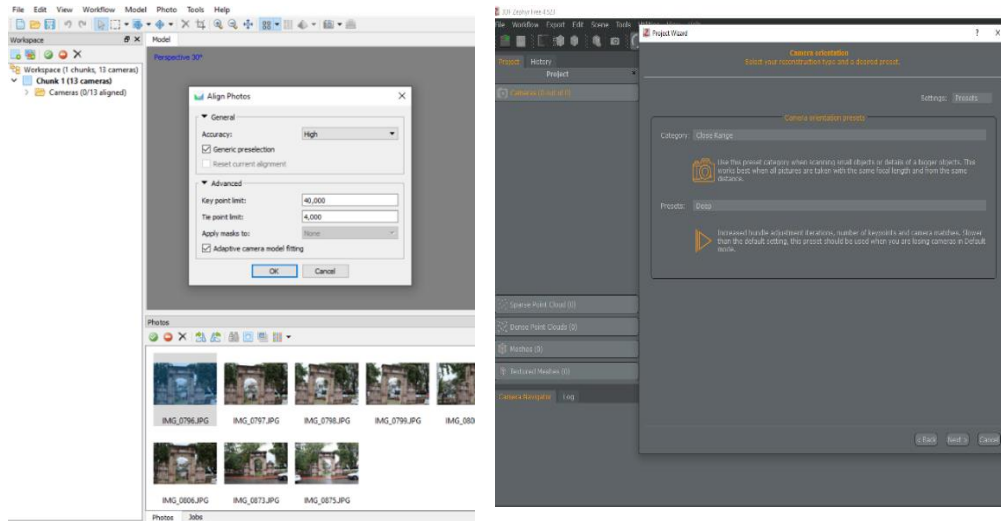


**Figure 2.** The flowchart for generating the 3D model

**Aligning Photos and Generating Tie Points**

After loading images into Agisoft Metashape software, they need to be aligned for detecting camera position and orientation of each image and building tie points. At the first stage of generating the 3D model for the Public Garden door, high accuracy was used among the accuracy setting (Highest, High, Medium, Low, Lowest) (Figure 3a). Higher accuracy settings work with the original size of the images and estimates camera position more accurately. Thus, it is usually recommended to use for research purposes (Agisoft LLC, 2020). High accuracy setting usually requires more image processing time compared to other accuracy settings (medium and low), but in this study using only 13 images for the model did not take that much

time. Except for the accuracy, default parameters were used for other settings. For Seyit Vakkas shrine, low accuracy settings were preferred for generating tie points because high accuracy setting produced fewer aligned images and tie points than low accuracy setting and was not time efficient.



a)

b)

Figure 3. Aligning photographs and generating tie points with Agisoft Metashape (a) and 3D Zephyr (b)

### ***Building dense point cloud***

In 3D Zephyr Free software, there are three different options (Preset, Advance, and Custom) to aligned images and build tie points. The preset option is a default setting and offers multiple options under different circumstances (general, urban, close range, air, human) in order to generate the 3D model fast. Similar to Agisoft Mehashape, 3D Zephyr has different accuracy settings (fast, default, and deep) in “Preset” option. “Advance” and “Custom” options allow users to generate the model with detailed parameter settings (3DFLOW S.R.L., 2019). For the Public Garden door, “Preset” option with close range category and deep (high) accuracy setting were used to align images and build tie points. The close-range category with default setting and urban category with the deep accuracy setting were tested. After visual comparison, the close-range category with the deep setting was also used. Similar to the Public Garden door, the same parameters (Preset > close range and deep) at the first stage of generating the 3D model of Seyit Vakkas shrine were used.

The obtained tie points from the aligned photographs were used in building a dense point cloud, which is the second step of generating a 3D model. In Agisoft Metashape, while building dense point cloud for the Public Garden door, high was used as quality parameter that generates detailed and more accurate geometry for the model compared to low and medium quality parameters (Rahaman and Champion 2019, Kingsland 2019, Agisoft LLC, 2020). Similar to the previous step, it requires more time to build a dense point cloud with high quality parameter compared to other quality parameters. Also, the depth map of each image was calculated at this stage of the model. In this calculation, the depth filter was used to remove outliers among the points. Thus, the recommended mode of “aggressive” was preferred in the filtering stage (Kingsland 2019, Agisoft LLC, 2020) (Figure 4a). For the Seyit Vakkas shrine, the same parameters (quality: high, Depth map: aggressive) that were used for the door were applied to building dense point clouds.

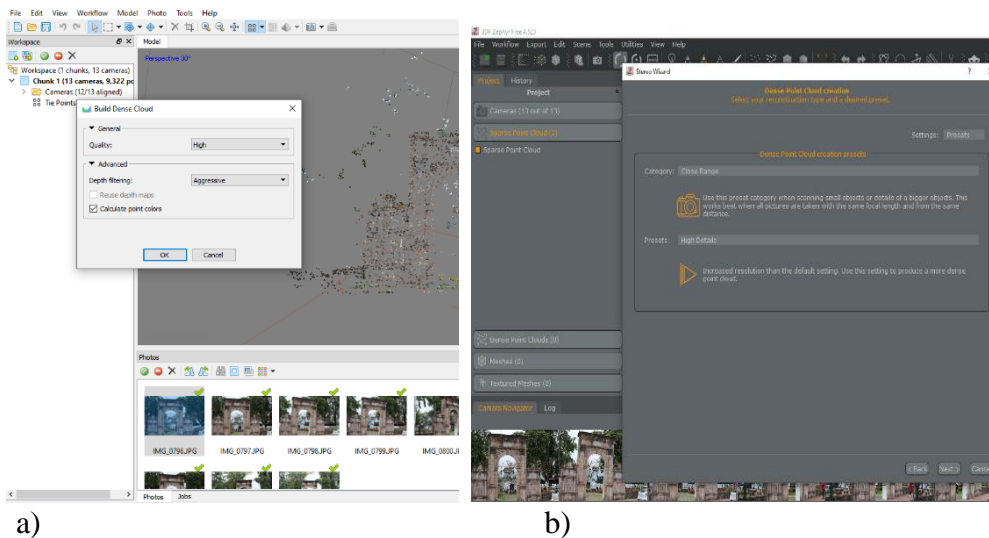


Figure 4. Building dense point cloud with Agisoft Metashape (a) and 3D Zephyr (b)

For 3D Zephyr software, tie points were also used to build a dense point cloud at the second stage of the model. Similar to the previous step, the close range and high details parameters were used from default parameters (Preset) that provide quite dense point clouds for the detailed and accurate model generation for both the Public Garden door and the Vakkas Seyit shrine (Figure 4b)

### ***Build Mesh and Texture***

After building the dense point cloud, these points need to be connected to generate the face of the 3D model. In this stage, “Building Mesh,” connected points generates polygon or surface for the model construction. For the Public Garden door, while generating polygon from dense point cloud, high and aggressive parameters were selected as quality parameters and filter mode, respectively (Figure 5a). Besides point clouds, tie points can be used in building mesh step, but the quality of the output could not be high compare to the dense point cloud (Agisoft LLC, 2020).

As a surface type, default parameters (arbitrary) were preferred as they produce a better result for close objects, buildings, and monuments. The last step of generating a model is to cover the surfaces with the images – generate texture. At this stage, default parameters were used to generate the model (Figure 6a). The same parameters were used to build mesh and texture for generating a model for the Seyit Vakkas shrine in Agisoft Metashape Software.

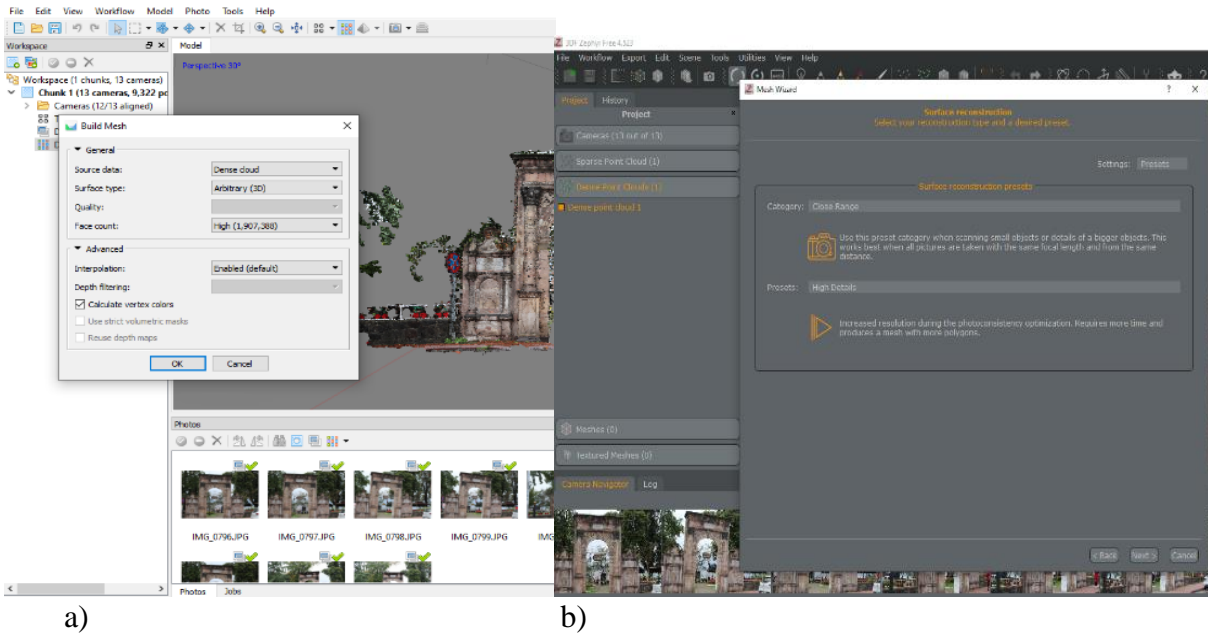


Figure 5. Building Mesh with Agisoft Metashape (a) and 3D Zephyr (b)

In 3D Zephyr Free software, newly generated dense point clouds were used at the stage of building mesh with the parameters (Figure 5b) that been used in the previous step (Preset > Close range > High details). For the last step of generating texture for the 3D model, the “Advance” option with aggressive filter mode was used (Figure 6b) instead of the preset option in order to have a similar model result with the model from Agisoft Metashape software. These parameters were applied to both the door and the shrine. Both software offers different parameters for each stage of generating a 3D model. These options were tested to select the best parameters which produced a detailed and time-efficient and accurate 3D model

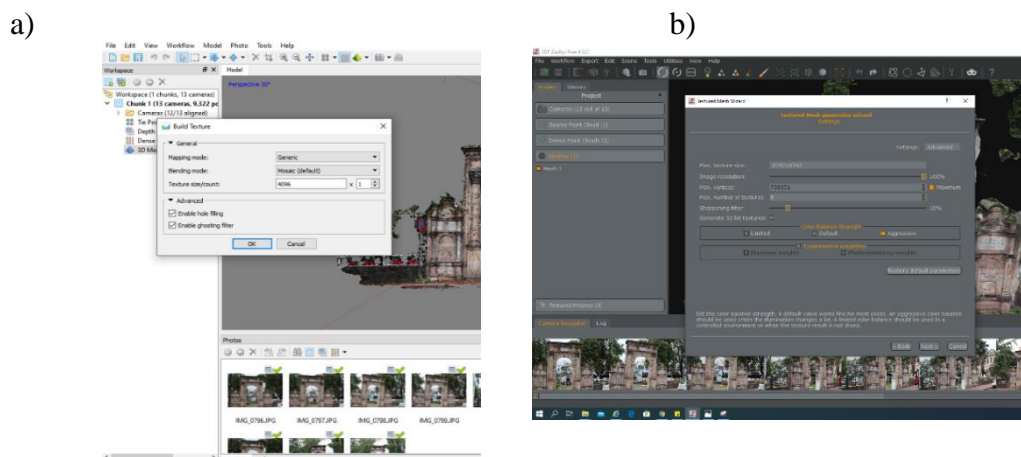


Figure 6. Generating texture for 3D Model with Agisoft Metashape (a) and 3D Zephyr (b)

## **Comparison Between Dense 3D Point Clouds By Cloudcompare Software**

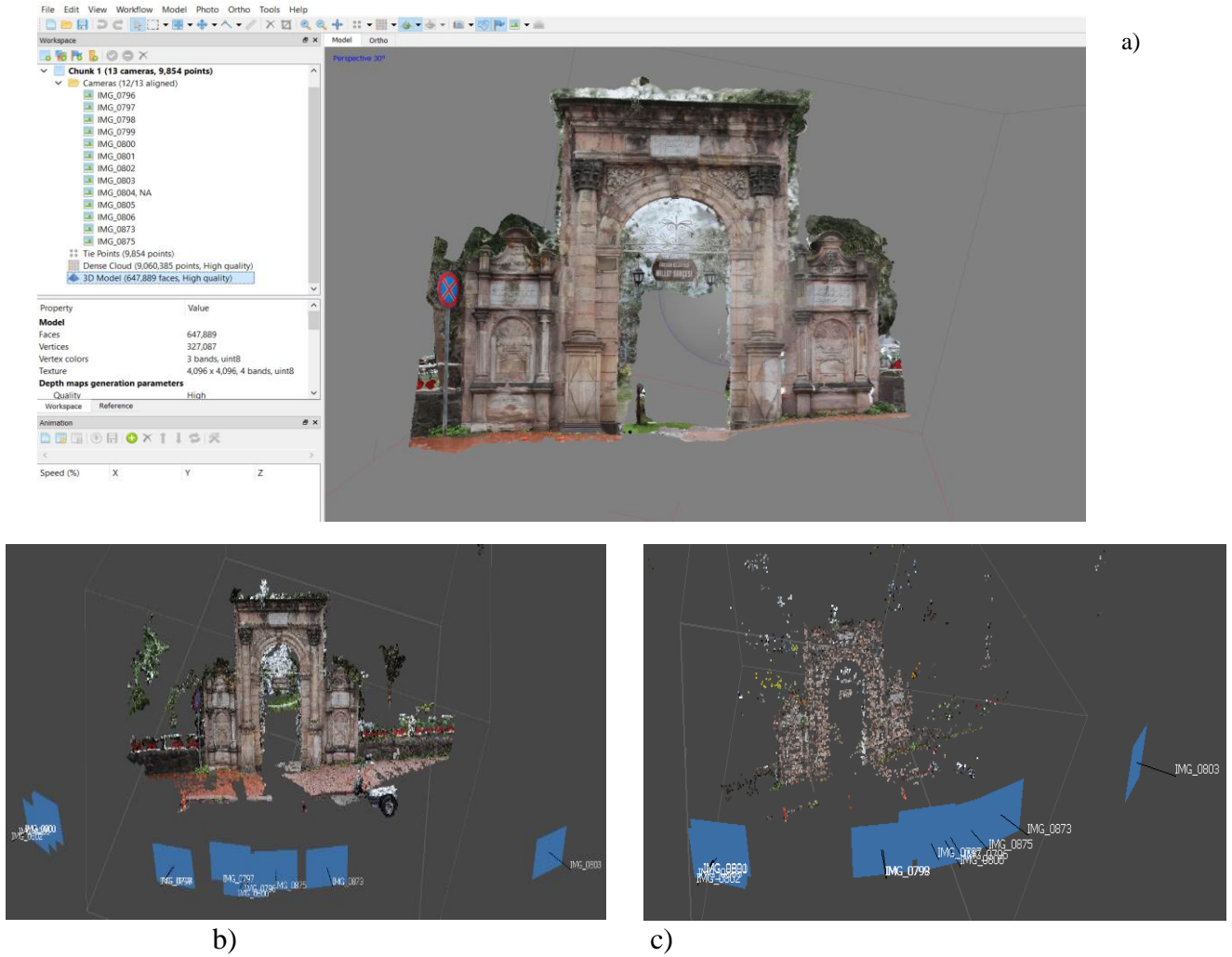
Although our main objective was to develop a 3D model that visually represents real objects for documentation of cultural heritage, we also compared the models, developed with two different software (Agisoft Metashape and 3D Zephyre), using CloudCompare software. CloudCompare is open-source, 3D point cloud and triangulated solid model editing and processing software developed by Daniel Girardeu. It is designed to compare dense clouds of 3D points or 3D mesh models by relying on a specific octree structure (Saritürk ve Şeker 2017, CloudCompare, 2020).

## **RESULTS AND DISCUSSION**

### ***The Result for The Public Garden Door 3D model with Agisoft Metashape***

The obtained photographs with Canon EOS 200D were used in Agisoft Metashape software (Figure 7a) to generate a 3D model for the National Garden door. At the first stage of generating a model, 12 out of 13 photographs were aligned, and these aligned photographs generated 9,830 tie points (Figure 7b). After that, these tie points were used to build dense point clouds, and 9,003,020 points were generated in total (Figure 7c).





**Figure 7.** The view from Agisoft Metashape software interface (a), tie point view of Public Garden door generated form the software (b), and dense point cloud view (c)

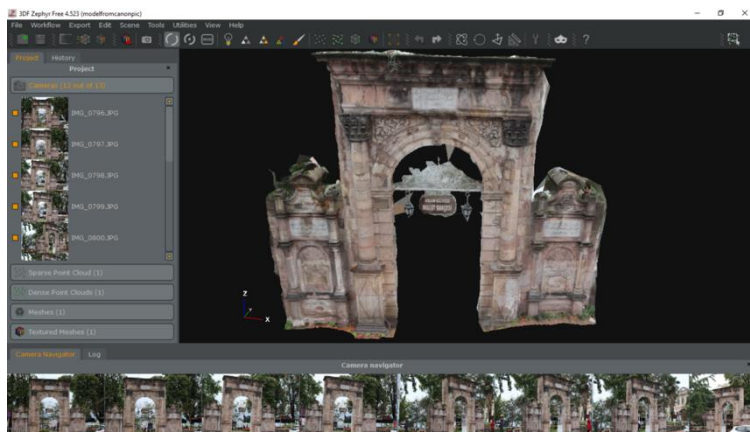
At the last step of the model, mesh – generating surface or polygon was built by connecting points, and then texture-covering of these surfaces was performed with the door images. The total number of the generated surface was 1,800,591. Figure 8 shows the 3D model view of the Public Garden door, generated using Agisoft Metashape, from different perspectives.



**Figure 8:** The 3D model view of the Public Garden door from different perspective

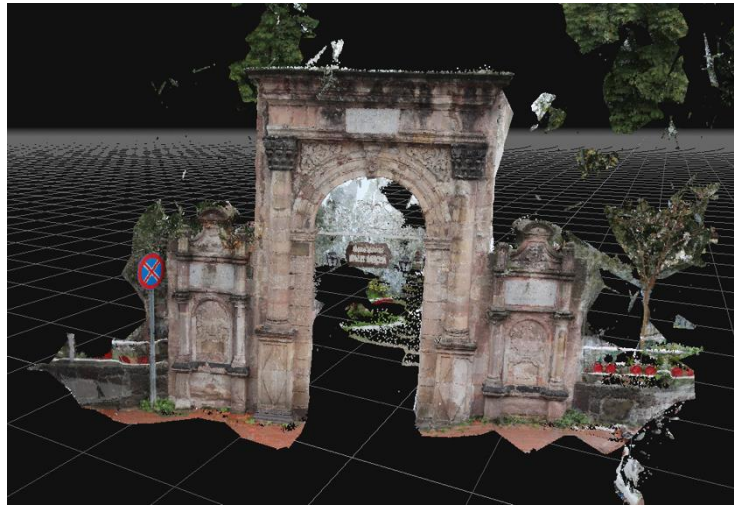
### **3D model with 3D Zephyr Free**

3D Zephyr Free software showed similarities with Agisoft Metashape in processing photographs to generate a 3D model. It was observed that even the interface of the software shows similarities (Figure 9). After loading the photograph into software, the work order



indicated in Figure 2 was followed. Likewise, Agisoft Metasahpe was used the same 13 photographs to generate the model. At the first step, all 13 photographs were aligned, and these aligned photographs generated 4,269 tie points. After that, these tie points were used to build dense point clouds, and 705,146 points were generated in total (Figure 10).

**Figure 9:** The view from 3D Zephyr Free software interface



**Figure 10:** Dense point cloud view of The Public Garden door from 3D Zephyr Free software

These dense point clouds were connected to generate surface and then texture for the model at the last stage. The total number of the generated surface was 1,800,591. It seems that 3D Zephyr generated less dense point clouds and surfaces compared to Agisoft Metashape. However, it can be observed that the 3D model from 3D Zephyr demonstrated architectural details of the Public Graden door quite well and clear. These findings show similarities to the study by [19] that compared five software and concluded that 3D Zephyr software provides higher visual quality compared to others, including Agisoft Metashape (Figure 11).

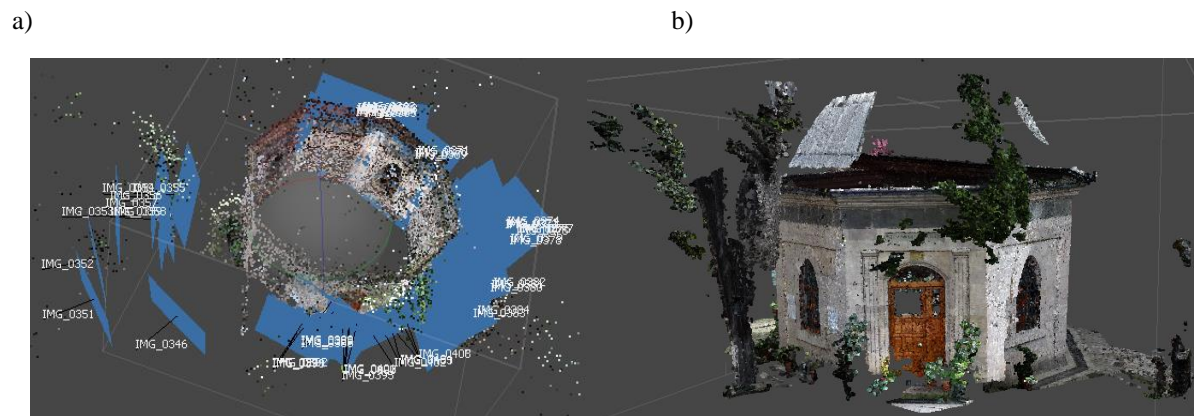


**Figure 11:** The 3D model views from 3D Zephyr Free software

## ***The Result for Seyit Vakkas Shrine***

### ***3D model with Agisoft Metashape***

For the second cultural heritage object-Seyit Vakkas shrine, the same procedures were followed as in generating the 3D model of National Garden door (Figure 2). The photographs acquired with Canon EOS 200D and 50 photographs were used in Agisoft Metashape software to generate the 3D model for the Seyit Vakkas shrine. At the first stage of generating a model, all 50 photographs were aligned, and these aligned photographs generated 32,152 tie points (Figure 12a). After that, these tie points were used to build dense point clouds in which 73,512,189 points were generated in total (Figure 12b). At the last stage, these dense point clouds were connected to generate surface and then texture for the model. The total number of the generated surface was 3,613,831. Figure 13 shows the 3D model view of the Seyit Vakkas shrine from different perspectives.



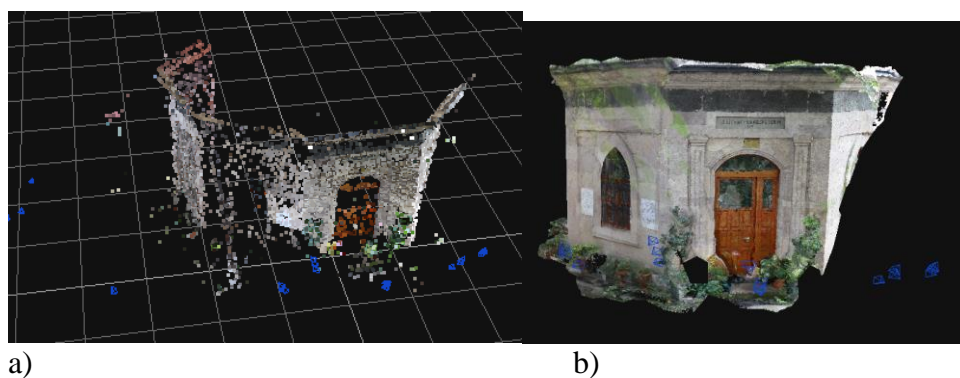
**Figure 12:** Tie point view (a) and dense point cloud view (b) of the Seyit Vakkas Shrine generated



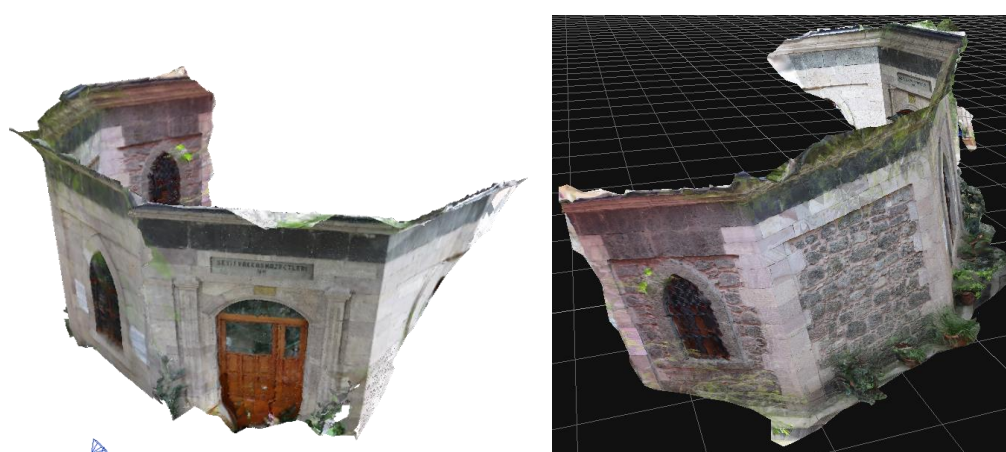
**Figure 13:** The 3D model view of the Seyit Vakkas Shrine from different perspectives

### **3D model with 3D Zephyr Free**

For 3D Zephyr free software, the same 50 photographs were processed to generate the model as in the Agisoft Metashape application. Only less than half of the photographs (24 out of 50) were aligned and resulted in 10,886 tie points (Figure 14a) and 3,518,245 dense point clouds (Figure 14b). As the last step, the dense point cloud was used to generate surface (7,048,571) and then the texture of the model. Although the number of the surface generated using 3D Zephyr was almost two times more than the number of the surface generated using Agisoft Metashape, 3D Zephyr was able to generate the model for only small pieces of the shrine compared to the model generated with Agisoft Metashape (Figure 15).



**Figure 14.** Tie points view (a) and dense point clouds view (b) of the Seyit Vakkas Shrine generated by 3D Zephyr software



**Figure 15.** The 3D model view of the Seyit Vakkas shrine from different perspectives in 3D Zephyr software

Table 1. The result from 3D model of Public Garden door and Seyit Vakkas shrine generated using Agisoft Metashape and 3D Zephyr.

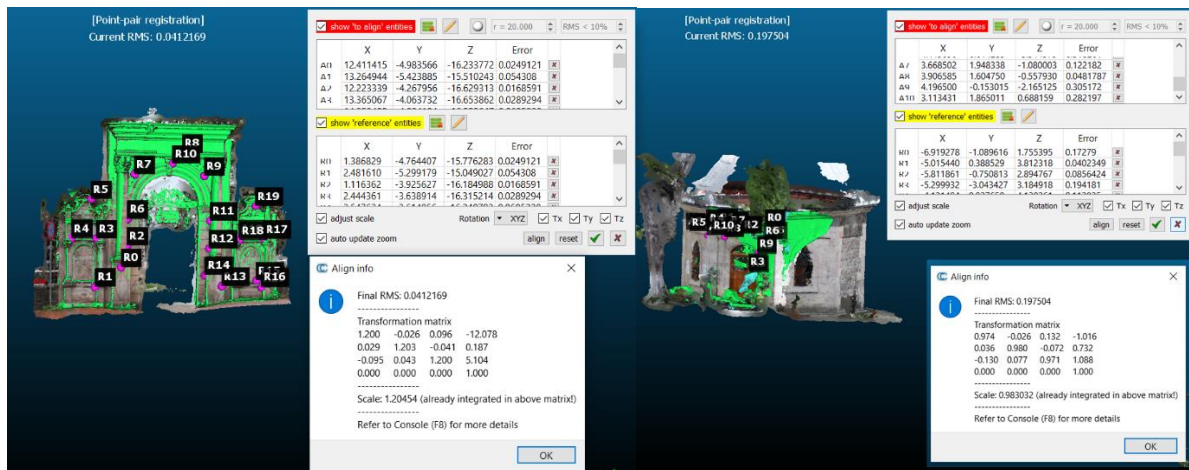
	Public Garden Door				Seyit Vakkas Shrine					
	N. of photos	Aligned Photos	Tie points	Dense Point Cloud	N. of Surface	N. of photos	Aligned Photos	Tie points	Dense Point Cloud	N. of Surface
AgiSoft	13	12	9.830	9.003.020	1.800.591	50	50	32.152	73.512.189	3.613.831
3D Zephyr	13	13	4.269	705.146	1.397.373	50	24	10.886	3.518.245	7.048.571

Table 1 shows the outputs from both software for each step of the model. The result of the study indicated that two software produced a quite similar 3D model for the Public Garden door. However, for the Seyit Vakkas shrine, 3D Zephyr aligned fewer photographs compared to Agisoft Metashape. In parallel with these, it was not possible to develop a complete 3D model for the shrine. In the study, when compared to the photographs obtained for the Public Garden door and the Seyit Vakkas shrine, it can be observed that the distance between object and camera varies more for the shrine. Therefore, it is thought that Zephyr software underperformed in generating a 3D model for the shrine. The similar result has been reported by Adamopoulos et al. (2019) in a study conducted to evaluate low-cost imaged-based modeling. It was concluded that even though 3D Zephyr was use similar algorithms with Agisoft Metashape, it was not able to reconstruct all datasets. Also, Barrile et al. (2017)

compared three different software, including, Visual SFM, Bundler/PMVS2 and Agisoft, using the photographs taken by handheld camera and Agisoft provided the best results after TLS.

### 3D models comparison with CloudCompare

Two models were uploaded to CloudCompare, and the models were aligned with point pairs-picking options for registration. It requires at least 3-point pairs for registration, but more point pairs reduce the error and increase the accuracy. The 3D models from the Agisoft Metashape were used as a reference for both objects. Also, more than the required point pairs were used in our study. After the alignment process was completed, the models from the two different software were compared using the distance computation tool (Cloud-to-Mesh Distance) (Figure 16).



**Figure 16.** The results of the align process with point pairs (RMS and transformation matrix) for (a) The Public Garden door (b) Seyit Vakkas Shrine

Figure 16 showed point pairs, the Root Mean Square Error (RMS), and the transformation matrix for both cultural heritage objects. RMS was lower for the door (0.041), while it is about 0.19 for the shrine. The 3D model of the door was well-conducted and relatively the same for both models. Thus, the 3D model comparison of the door with the distance computation tool indicated that these two models generated from two different software were almost the same. However, the 3D model of the shrine was incomplete for both software; especially, a small piece of shrine was modelled from 3D Zephyr software. This affected picking point pairs for alignment and produced higher RMS. Still, the 3D model of the shrine from 3D Zephyr (only generated model for three walls of the shrine) was quite matched with the 3D model of shrine from Agisoft Metashape.

Although the photographs from the handheld camera are commonly used for building a 3D model of cultural heritage, it brings out some limitations such as not able to cover the top of the objects or due to environmental obstacles (vegetation, other building, etc.), not able to take enough photographs for construction 3D model. Thus, to eliminate these problems and construct a complete 3D model for the cultural heritage objects, studies integrated terrestrial photographs with TLS data (Guarnieri et al. 2006, Guarnieri et al. 2010, Owda et al. 2018) or UAV data (Lo Brutto et al. 2018, Lumhann et al. 2020, Themistocleous et al. 2020) for building a complete and accurate 3D model. All these studies indicated that combining terrestrial photographs with TLS or UAV data improves the model.

## CONCLUSION

The use of photogrammetry for documentation of cultural heritage has increased due to the low cost and ease of use. The applicability of 2D photographs with reports remained incapable of cultural heritage documentation. Instead, generating a 3D model using photogrammetry helps to document a better description of cultural heritages. Hence, these types of documentation studies allow detecting any structural deformation of the cultural heritages for restoration studies (Yakar and Bilgi, 2019). In this study, the opportunity of using digital photogrammetry was examined for documentation of two cultural heritage sites in Giresun Province. It was aimed to produce a 3D model for two cultural heritage sites (the door at the entrance of Giresun Public Garden and Seyyit Vakkas shrine) using two different software. When examining the results, it was observed that two software produced a detailed 3D model for the Public Garden door. In both 3D models of the door, the inscription on the door can be seen and read clearly, and details of stone carving on the door can be seen as well. For the Seyit Vakkas shrine, both software was not capable of generating a complete model of the shrine due to lack of images from top of the shrine and four sites; the walls of the other buildings and vegetation blocked the view. However, the results indicated that Agisoft Metashape generated a better 3D model when compared to 3D Zephyr for the shrine. Accuracy is an important decision variable in modeling processes. According to the comparison results, especially in the shrine structure results, it was concluded that Agisoft offers better outcomes than 3D Zephyr. However, both options can be considered for the 3D modelling depending on the study's purpose and size. These two software-Agisoft Metashape and 3D Zephyr- show similarities in developing a 3D model procedure with a user-friendly interface. 3D Zephyr software allows users to combine all stages of model generation procedures to one procedure that the users need to set all parameters at the beginning stage. Also, 3D Zephyr can load a video of the object into software and generate a model from this video. In particular, if the images do not have enough overlay, it would be better to use the video to develop an accurate and detailed model instead of photographs. Although Agisoft Metashape and 3D Zephyr software did not produce the complete model for both cultural heritages mainly due to some obstacles, the methodology presented here can be useful for surveying and documentation of cultural heritages and early detection of any deformations on the heritages.

## AUTHOR CONTRIBUTIONS

**Ebru Bilici:** Obtaining and organizing the data, writing the manuscript. **Zennure Uçar:** Analyzing the data, editing the manuscript. **Abdullah E. Akay:** Supervising the study. **Musa Genç:** Reviewing the manuscript.

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