3D MODELLING OF A HISTORIC WINDMILL: PPK-AIDED TERRESTRIAL PHOTOGRAMMETRY vs SMARTPHONE APP

*R. Eker[1], N. Elvanoglu[2], Z. Ucar[1], E. Bilici[3,4], A. Aydın[5]

[1] Izmir Katip Celebi University, Faculty of Forestry, Department of Forest Engineering, Izmir, Turkey – (remzi.eker, zennure.ucar)@ikc.edu.tr
[2] Izmir Katip Celebi University, Faculty of Engineering and Architecture, Department of Architecture, Izmir, Turkey – nihal.elvanoglu@ikc.edu.tr
[3] Giresun University, Dereli Vocational School, Forestry Department, Giresun, Turkey – ebru.bilici@giresun.edu.tr
[4] University of Idaho Experimental Forest College of Natural Resources, Moscow, ID 83844, USA - ebilici@uidaho.edu
[5] Düzce University, Faculty of Forestry, Department of Forest Engineering, Remote Sensing & GIS Laboratory, Düzce, Turkey – aaydin@duzce.edu.tr

Commission II, WG II/8

KEY WORDS: 3D Modelling, Cultural Heritage, Historic Building, Photogrammetry, Smartphone, PPK.

ABSTRACT:

Cultural heritage (CH), what we inherited from the past generations, is a precious asset connecting the past to the present. It has many demonstrable benefits to nations around the world. For many countries, it has been a part of national identity as well as a key driver of the economy. However, CH is under constant threat of demolition due to wars, natural and human-induced hazards, and negligence. Therefore, documentation of CH has become very essential. Recent advancements in remote sensing technology have improved upon approaches for the surveying and structural modelling of the CH. This paper examines two close-range photogrammetry approaches in modelling a historic windmill. In the first approach, to generate a 3D model of the windmill, the images were obtained with a PPK-aided system and then processed through the Structure-from-Motion (SfM) method in Agisoft Metashape software. The second approach utilized a smartphone app both to capture the images and then generate the 3D model of the windmill with SfM. The 3D models of windmills, generated with two different methods, were compared in CloudCompare software using the cloud-to-mesh distance (C2M) tool. Two models were aligned with point pairs-picking for registration and the result showed that the models are quite similar and distance between the two models ranged from -5cm to +5cm.

1. INTRODUCTION

Cultural heritage (CH) refers to monuments, buildings, or sites that have both intangible and tangible heritage values (UNESCO Institute of Statistics, 2022). They are a unique and valuable asset to humankind as they establish strong ties between the present and the past. However, CH around the world is being threatened by war, natural and human-induced hazards, and negligence. Thus, the documentation of CH has become very crucial. The recording of CH has many benefits in terms of understanding its intrinsic value, evaluation of significance, conservation, and management (Principles for the Recording of Monuments, Groups of Buildings and Sites, 1996).

Various studies related to the recording of CH have examined different uses of documentation and its related benefits. For instance, a 3D documentation technique is employed to monitor and evaluate the environment-related deformation of the interior decorative elements of the Užutrakis palace (Sužiedelytė-Visockienė et al., 2015). Another study on the 3D documentation of CH benefits from the drone images to record three historic buildings located in the Republic of Iraq, where heritage resources had been under threat of war and now are being neglected in the war-ravaged country (Alsadik, 2021). Recent studies also investigate the use of 3D modelling in archaeological sites (Al-Ruzouq and Dabous, 2017; Pérez-García et al., 2019; Fernandez-Hernandez et al., 2015). The use of Geographic Information Systems (GIS) and Global Positioning System (GPS) in 3D modelling techniques allows heritage conservators and archaeological heritage management professionals to manage and monitor the changes in archaeological sites. Furthermore, these emerging technologies accelerate the decision-making process in any planning project.

3D documentation and modelling techniques fall into three main categories: image-based, non-image based, and combinative methods (Hassani, 2015). Image-based techniques use photographs of objects, buildings, or sites to generate three-dimensional models. Close-range photogrammetry, which is the subject of this paper, is one of the most efficient image-based approaches in 3D modelling of the CH sites. While it is cost-effective and straightforward, close-range photogrammetry can perfectly capture the details of the objects or buildings. Thus, it is a preferable method to generate 3D models. Non-image-based methods make use of range-based tools like laser scanners. Unlike photogrammetry, laser scanning can be expensive. However, it is highly effective in the documentation of complex structures. Combinative methods utilize tools that have characteristics of both image-based and non-image-based methods (Hassani, 2015). In the literature, there are numerous studies that employ different techniques to document CH. Several techniques are generally used collectively to achieve a higher level of accuracy than any single technique can ensure (Luhmann et al., 2019). In the case study of Banteay Srei Temple at Angkor in Siem Reap, for example, three different methods were used to survey the historic temple: close-range

* Corresponding author

https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-787-2022

photogrammetry, Terrestrial Laser Scanning (TLS), and Unmanned Aerial Vehicle (UAV) photogrammetry (Zhang et al., 2020). Similarly, UAV-based photogrammetry and TLS were used collectively to record Magoksa Temple in Republic of Korea. The reason for implementing the UAV-based photogrammetry method was to record the details at the top of the roof, which could not be captured completely through the TLS system (Jo and Hong, 2019).

Advances in remote sensing enable to use of different sensors, such as RGB and multispectral cameras in UAV-based and terrestrial photogrammetry (Guidi et al. 2015; Bakirman et al. 2020), Airborne, Terrestrial and Mobile Laser Scanning (Borrmann et al., 2015; Hyyppä et al., 2013; Von Schwerin et al., 2016), to record, catalogue, and analyse CH sites. In UAV-based photogrammetric systems, multi-frequency, and multi-constellation GNSS receivers (i.e., Real-Time Kinematic (RTK) and Post-Processing Kinematic (PPK)), which enable accurate measurement of camera positions, have been widely used recently. In the PPK system, an alternative to the RTK system, all required calculations for position correction need to be done after the survey in the office environment. This study compares two different close-range photogrammetry techniques; a PPK-aided system, and a smart phone app (Polycam). These techniques were employed to develop the 3D model of a historic windmill in Foça, İzmir.

2. MATERIAL AND METHOD

2.1 Study Area

The historic windmill selected for 3D modelling is in Foça (Phocaea), a tourist town located northwest of Izmir, Turkey. The historic windmill is standing on Değirmenli Hill and overlooking downtown Foça along with its two counterparts (Figure 1). It is assumed that the windmill dated back to the 17th century and was operated by Greeks, who founded Phocaea, and Ottoman Turks. The windmill was restored to its 17th century appearance in 2012. The municipality of both İzmir and Foça and the Ministry of Culture and Tourism collaborated in the restoration project. The windmill is circular in shape and made of locally quarried tuff stone. It has three levels, and visitors can climb up to the top story through a wooden staircase.

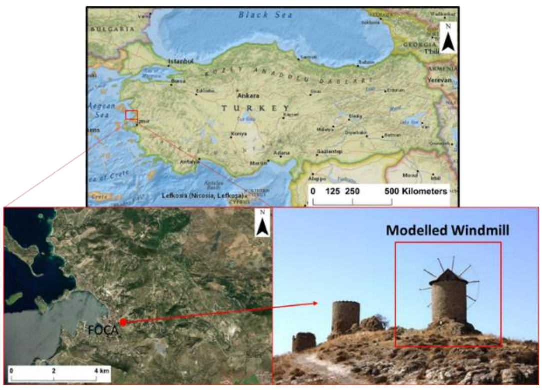

Figure 1. Location of the historic windmill.

2.2 Methods

In this study, two close-range photogrammetry approaches were used: a PPK-aided system and a smartphone app. The PPK-aided close-range photogrammetric system was designed, drawing an inspiration from UAV systems that include differential GNSS receivers. The designed system consists of an Emlid Reach M2 GNSS module connected to Sony Alpha 6000 (20-Megapixel) camera with a hot shoe port. The whole system was mounted on a solid frame (Figure 2). Emlid Reach M2 module, as a rover in PPK mode, can trigger the camera and register camera events. The mobile application called ReachView (Android) was used to control all the features of the Reach module (Figure 2). The camera was triggered with a remote controller manually. However, the remote controller has an automatic triggering mode based on a defined time interval.

Photogrammetric processing includes Structure-from-Motion (SfM) and Multiview Stereopsis (MVS) techniques, using overlaid images to generate a three-dimensional object model. The SfM process starts by acquiring sufficient overlapped photographs (e.g., 80-90%) from multiple positions and/or angles (Lucieer et al., 2014). SfM does not require information on the position of cameras or multiple control points prior to image acquisition because the position, orientation, and geometry are reconstructed by automatic matching of features using multiple images (Westoby et al., 2012). Even though SfM based model has no proper scale, the model can be rectified later by using ground control points (GCPs) or GNSS-tagged imagery (Tomaštík et al., 2019). The use of GCPs is reliable for the positioning, but it can be labour-intensive and sometimes risky in rough or rugged topographies. However, direct georeferencing by tagged images with GNSS has a potential of avoiding or mitigating the need for GCPs. Especially, the availability of high precision differential GNSS receivers (i.e., multi-frequency and multi-constellation GNSS receivers) provides accurate measurement of position with real-time kinematic (RTK) mode and post-processing kinematic (PPK) mode. In PPK mode, as an alternative to RTK, required position corrections are calculated post-flight. For differential GNSS solutions, two receivers are required: a base station and a rover that moves between points of interest (Hofmann-Wellenhof et al., 2007). The base station broadcasts its exact location with the code and carrier measurements. Then, the rover is able to fix the phase ambiguities and determine its location relative to the base station with high precision. In this study, the Satlab SL600 GNSS receiver was used as a base station. The static survey was started about 15 minutes before taking images and continued until fifteen minutes after the completion of image capture process. The approach applied in here is called short baseline PPK-positioning. The static survey was saved in the internal memory of the receiver as a log file, a specific file format used by GNSS receiver. This log file has to be converted into RINEX observation data. Hence, Rinex Converter software provided by Satlab was used. In order to evaluate the model accuracy 4 GCPs were recorded by Satlab SL600 GNSS receiver.

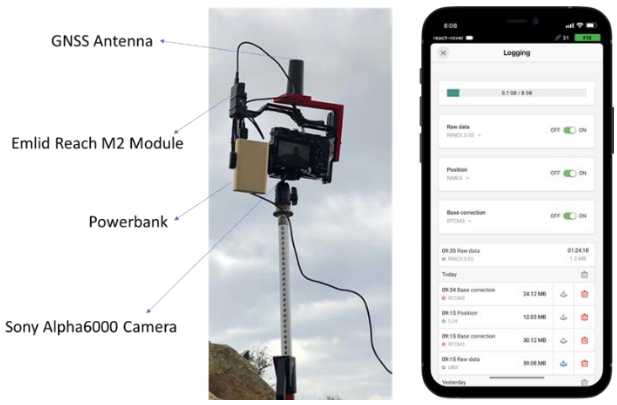

Figure 2. PPK-aided close-range photogrammetric system (left) and ReachView GUI (right).

The ReachView software allows downloading log files, which consist of the information about camera positions and raw data logs. PPK corrections and geotagging of images were carried out by Emlid Studio 1 Beta 10 (Figure 3). This software can add the geotags to the images' EXIF data. It is necessary to obtain the raw data logs from the base and the rover and the images to perform geotagging. To generate a 3D model of the windmill from the geotagged images, Agisoft Metashape software (Figure 4) was used in the photogrammetric process.

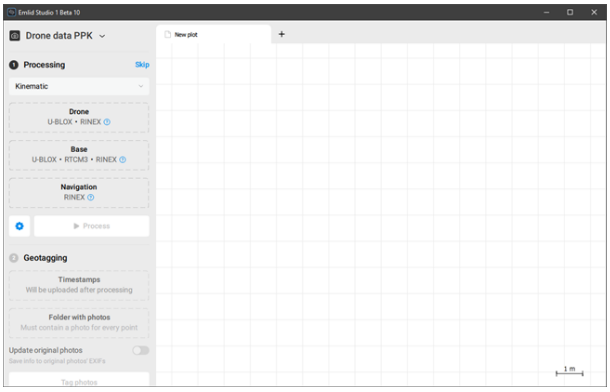

Figure 3. The GUI of Emlid Studio 1 Beta 10.

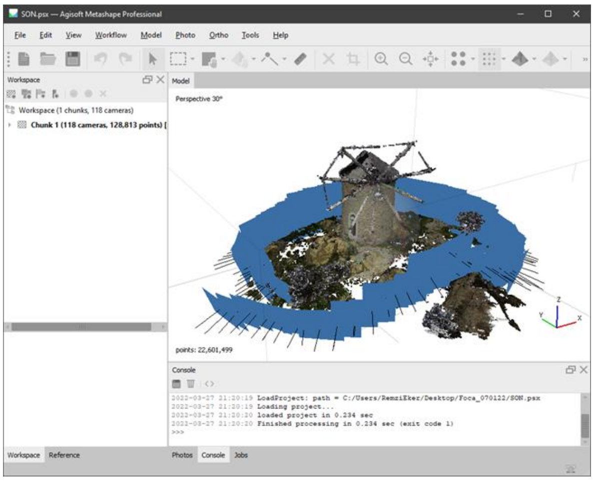

Figure 4. The GUI of Agisoft Metashape software.

In the second approach, a smartphone app, called Polycam, was used. The app was downloaded into iPhone 12 Pro (Apple Inc.), which contains a 12-megapixel camera system equipped with dual optical image stabilization, LiDAR scanner, and a 15.5 cm (6.1 inches) super retina XDR display. The point clouds of the windmill were generated from images obtained with iPhone 12 pro and then by processing within Polycam app. Similar to the modelling from the PPK-aided system, the app applies the SfM method to close-range images with certain overlapped (more than 50%) to generate the 3D model of the windmill. The app offers two options for capturing images: Manual and Auto mode. Also, while capturing the images, the users can switch between the modes. The app recommended auto mode with a single recording session while capturing the structure. Thus, we used auto mode in the study to build complete model without missing any details of the windmill. In the auto mode, the app can calculate the overlap rate automatically and then capture the images when it is necessary. After the images were obtained, Polycam processed the images on the cloud server to turn them into a 3D model. The app enables users to process the captured images through several modes, including optimized, medium, full, and raw (Figure 5). The raw mode is recommended for professional workflow since it provides a highly detailed model with high resolution. Processing a capture can take around 3-15 min depending on the size of the images and the details needed (Figure 6). In this study, the 3D models of the historic windmill were developed using the images that were obtained from two different techniques and processed in two different software programs, Agisoft Metashape, and Polycam. Then, the generated models were compared using CloudCompare software to evaluate whether these approaches produced similar results.

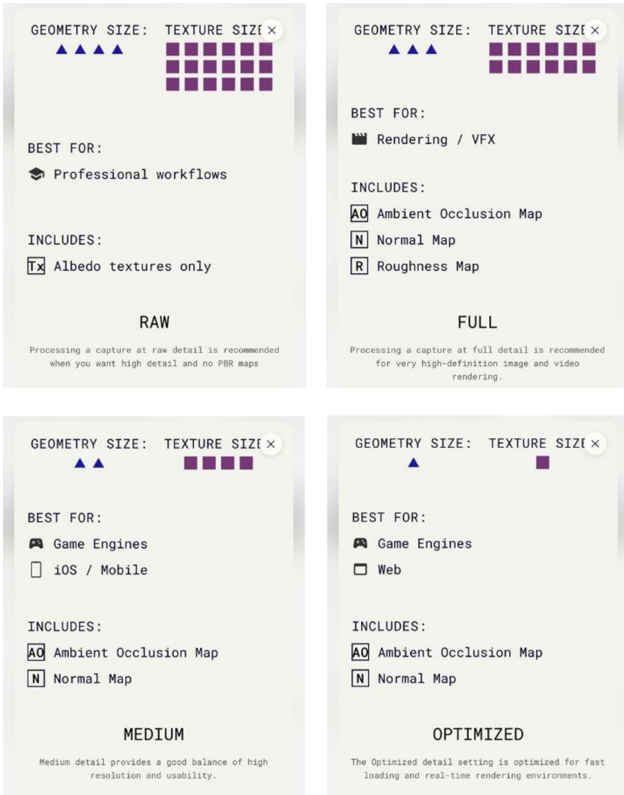

Figure 5. Some views of settings in the Polycam app

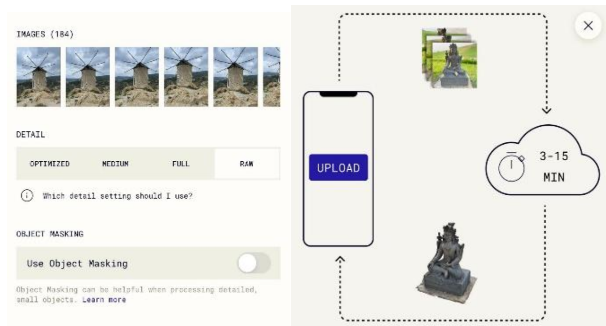

Figure 6. Cloud processing of the images via Polycam app

3. RESULTS AND DISCUSSION

In the present study, a PPK aided close-range photogrammetric technique and a smartphone app called Polycam were used to generate a 3D model of a historic windmill. In the first approach, all images were positioned as fixed, i.e., with accuracy lower than 2 cm, and were geotagged in Emlid Studio. A 3D model of the windmill was created from 118 images with a 2.20 cm total error of estimated camera location. The alignment process resulted in 128 813 tie points. A dense cloud was obtained with 22 601 499 points (Figure 7). The obtained model had 6.21 mm/pix resolution, and the point density was 2.59 points/cm^2. Georeferencing errors of the 3D model (*x*, *y*, *z*, and total) generated from PPK-aided photographs were 2.47 cm, 2.97 cm, and 3.79 cm for *x*, *y*, and *z*, respectively, compared to GCPs. Also, the total error was 5.41 cm. Although model accuracy can be affected by many factors, such as image quality, camera calibration, image acquisition strategy, surface texture, and the SfM algorithm (Eker et al. 2021), the generated 3D model from PPK-aided images is promising.

Figure 7. 3D model views of windmill from PPK-aided Terrestrial Photogrammetry approach

For the second approach, 184 images were taken with the Polycam app through smartphone. Then, the images were uploaded to cloud server and processed within the app to build a dense point cloud (8,214,340 points) model of the windmill (Figure 8). The app did not provide locational information (*x*, *y*, and *z* coordinate) unlike the 3D model generated using the images from PPK-aided system. However, it provided great details on masonry walls. Unfortunately, the roof part of the windmill was not constructed well with the app when compared to PPK-aided model. It is because a sufficient number of images could not be captured with the smartphone due to topography.

Figure 8. The 3D model view of windmill from smartphone app (Polycam).

The 3D models of the historic windmill generated from two different approaches were compared to evaluate how they are alike. Therefore, two models were uploaded to CloudCompare, and models were aligned with point pairs-picking for registration. Then, they were compared with cloud-to-mesh distance (C2M) (Figure 9). RMSE was relatively lower (0.035m), indicating that two models generated from two different sources were well-fit. When histograms graphics were analysed, the distance between the two models ranged from -5cm to +5cm. In particular, small differences were observed on the façade of the windmill, but differences were getting higher at the top of the windmill where the app could not completely build.

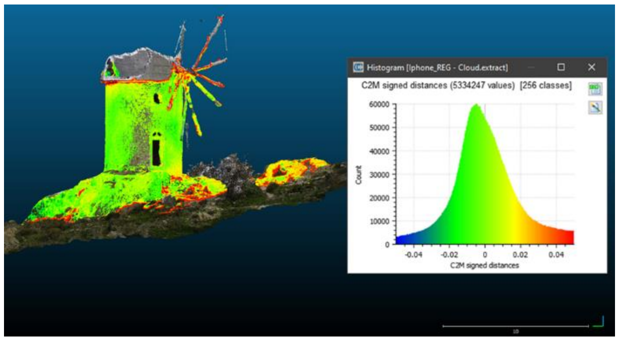

Figure 9. C2M distance analysis between 3D models

There are several documentation techniques available for the conservation of heritage monuments, including (Scherer 2002): I) traditional manual methods including tape measure, plumbs, and manual laser distance measurement, II) topographic methods including tachometers and/or total stations, III) close range photogrammetric methods, and IV) scanning methods based on 3D laser scanners. Photogrammetry has much more superiority over traditional methods in restoration projects due to the low cost and ease of use (Yilmaz et al. 2007). Unfortunately, the 2D photographs with reports are incapable of CH documentation. Instead, the use of photogrammetry to generate a 3D model helps to document a better description of CH. Hence, these types of documentation studies allow detecting any structural deformation of CH or restoration projects (Yakar and Bilgi, 2019).

The smartphone, embedded with digital cameras, have become the most popular and rapidly developing computing devices over the past twenty year. Some applications (apps) that use the smartphone camera or laser scanner have been developed to generate 3D model of any objects. Polycam app is one of them and easy to use and generated relatively accurate model. Also, the model developed with the Polycam app can be integrated with Augmented Reality (AR), which has a wide range of use in virtual tourism (Xiao et al., 2018).

Recent studies showed that close-range photogrammetry, Unmanned Aerial Vehicle (UAV) based photogrammetry, and laser scanning technology have been used progressively as individual or combined for CH documentation (Luhmann et al., 2019). Yet, the close-range photogrammetric methods in documentation of CH have not been used with PPK-aided system. This study showed that PPK-aided close range photogrammetric system can be used successfully for generating 3D models of a CH with quite accurate locational information, except the areas where GPS signals are blocked by obstacles, such as dense forest, deep valleys, and high-rise buildings. The photogrammetric methods can still be considered as an inexpensive technology compared to laser scanning technology. Thus, the proposed methods can be assumed as an advanced approach of traditional close-range photogrammetric method.

4. CONCLUSION

The area where the historic windmills are located is a famous visitor attraction, which offers an amazing view of the city, Foça. However, the windmills are undervalued in terms of their contribution to the cultural tourism, and city's economy. Thus, it is necessary to draw attention to the historic value of these structures through documentation.

As part of the documentation process, we modelled one of the historic windmills. For modelling the structure in 3D, we used PPK-aided terrestrial photogrammetry and the smart phone app, Polycam. The PPK aided system can be evaluated as a new technique in the modelling of CH. Our purpose was to compare these two distinct approaches and evaluate their applicability in CH documentation. The result was promising since the two models generated through different approaches were quite similar, and they can be used successfully. The study showed that while the end products were similar, each approach has their advantages and disadvantages. For instance, the Polycam app did not provide any locational information, but the PPK-aided system did. However, it should be pay attention that PPK aided system could be used only where GPS signal is not blocked. Both approaches are cost-effective and efficient in providing necessary details.

REFERENCES

Al-Ruzouq, R., Abu Dabous, S., 2017: Archaeological Site Information Modelling and Management Based on Close-Range Photogrammetry and GIS. *Conservation and Management of Archaeological Sites*, 19(3), 156-172.

Alsadik, B., 2021: Crowdsource Drone Imagery–A Powerful Source for the 3D Documentation of Cultural Heritage at Risk. *International Journal of Architectural Heritage*, 1-11.

Bakirman, T., Bayram, B., Akpinar, B., Karabulut, M. F., Bayrak, O. C., Yigitoglu, A., Seker, D. Z., 2020: *Implementation of ultra-light UAV systems for cultural heritage documentation*. Journal of Cultural Heritage, 44, 174-184.

Borrmann, D., Heß, R., Houshiar, H., Eck, D., Schilling, K., Nüchter, A., 2015: *Robotic mapping of cultural heritage sites*. Int. Arch. Photogramm. *Remote Sens. Spat. Inf. Sci.*, XL-5/W4, 9–16.

Chan, K.L., Qin K., 2017: Biomass burning related pollution and their contributions to the local air quality in Hong Kong. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLII-2/W7, 29-36. doi.org/10.5194/isprs-archives-XLII-2-W7-29-2017.

Eker, R., Alkan, E., Aydın, A., 2021: A Comparative Analysis of UAV-RTK and UAV-PPK Methods in Mapping Different Surface Types. *European Journal of Forest Engineering*, 7(1), 12-25. DOI: 10.33904/ejfe.938067

Fernández-Hernandez, J., González-Aguilera D., Rodríguez-Gonzálves, P., Mancera-Taboada, J., 2015: Image-based modelling from unmanned aerial vehicle (UAV) photogrammetry: an effective, low-cost tool for archaeological applications. *Archaeometry*, 57 (1), 128-145.

Guidi, G.; Micoli, L.L.; Gonizzi, S.; Brennan, M.; Frischer, B., 2015: Image-based 3D capture of cultural heritage artifacts an experimental study about 3D data quality. In Proceedings of the 2015 Digital Heritage, Granada, Spain, 28 September–2 October, pp. 321–324.

Hassani, F., Moser, M., Rampold, R., Wu, C., 2015: Documentation of cultural heritage; techniques, potentials, and constraints. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *40*(5), 207.

Hofmann-Wellenhof, B., Lichtenegger, H., Wasle, E.: 2007: *GNSS–global navigation satellite systems: GPS, GLONASS, Galileo, and more*. Springer Science & Business Media.

Hyyppä, J., Jaakkola, A., Chen, Y., Kukko, A., 2013: Unconventional LIDAR mapping from air, terrestrial and mobile. In Photogrammetric Week, 2013; Wichmann/VDE: Belin/Offenbach, Germany, pp. 205–214.

ICOMOS, 1996: *Principles for the Recording of Monuments, Groups of Buildings and Sites*, 1996. [ebook]. Available at: https://www.icomos.org/charters/archives-e.pdf. Accessed 28 March 2022.

Jo, Y.H., Hong, S., 2019: Three-dimensional digital documentation of cultural heritage site based on the convergence of terrestrial laser scanning and unmanned aerial vehicle photogrammetry. ISPRS *International Journal of Geo-Information*, 8(2), 53.

Lucieer, A., Jong, S. M. D., Turner, D., 2014: Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography. *Progress in physical geography*, 38(1), 97-116.

Luhmann, T., Robson, S., Kyle, S., Boehm, J., 2019: *Close-Range Photogrammetry and 3D Imaging*. Berlin, Boston: De Gruyter. https://doi.org/10.1515/9783110607253

Pérez-García, J. L., Mozas-Calvache, A. T., Gómez-López, J. M., Jiménez-Serrano, A., 2019: Three-dimensional modelling of large archaeological sites using images obtained from masts. Application to Qubbet el-Hawa site (Aswan, Egypt). *Archaeological Prospection*, *26*(2), 121-135.

Scherer M., 2002: About the synthesis of different methods in surveying. *XVIII International Symposium of CIPA*, Potsdam, Germany, p. 423–429.

Sužiedelytė-Visockienė, J., Bagdžiūnaitė, R., Malys, N., Maliene, V., 2015: Close-range photogrammetry enables documentation of environment-induced deformation of architectural heritage. *Environmental engineering and management journal*, *14*(6).

Tomaštík, J., Mokroš, M., Surový, P., Grznárová, A., Merganič, J., 2019: UAV RTK/PPK method—An optimal solution for mapping inaccessible forested areas?. *Remote sensing*, 11(6), 721.

UNESCO Institute of Statistics, 2022: *Cultural Heritage.* http://uis.unesco.org/en/glossary-term/cultural-heritage#:~:text=Cultural%20heritage%20includes%20artefacts%2C%20monuments,anthropological%2C%20scientific%20and%20social%20significance.

Von Schwerin, J., Richards-Rissetto, H., Remondino, F., Spera, M.G., Auer, M., Billen, N., Loos, L., Stelson, L., Reindel, M., 2016: Airborne LiDAR acquisition, post-processing and accuracy-checking for a 3D WebGIS of Copan, Honduras. *J. Archaeol. Sci. Rep.*, 5, 85–104.

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., Reynolds, J.M., 2012: 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, 179, 300-314.

Xiao, W., Mills, J., Guidi, G., Rodríguez-Gonzálvez, P., Barsanti, S.G., González-Aguilera, D., 2018: Geoinformatics for the conservation and promotion of cultural heritage in support of the UN Sustainable Development Goals. *ISPRS Journal of Photogrammetry and Remote Sensing*, *142*, 389-406.

Yakar, İ., Bilgi, S., 2019: *The Applicability of 3-D Models Obtained by Using Mobile Phones for The Protection of Cultural Heritage: A Case Study of III*. Ahmet Fountain Example, Photogrammetry Journal of Turkey, 1(1); 25-29.

Yilmaz, H.M., Yakar, M., Gulec, S.A., Dulgerler, O.N. 2007: Importance of digital close-range photogrammetry in documentation of cultural heritage. *Journal of Cultural Heritage*, *8*(4), 428-433.

Zhang, L., Wang, F., Cheng, X., Li, C., Lin, H., Song, Y., 2020: 3D Documentation of Cultural Heritage: The case study of Banteay Srei Temple in Angkor, Siem Reap. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 43, 919-923.