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Documentation of centennial structures in Istanbul via Terrestrial Laser Scanning technology

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ABSTRACT

Historical buildings are the most important structures of cultural heritages, as they carry a long history and reflects the culture of the nation. In Turkey, some historical structures are more than 1500 years old and they were significantly damaged through natural disasters, wars, weather changes, human negligence, and effects of decay. It is an essential issue that concerns the protection of these cultural heritages for our descendants. This paper examines the importance of cultural heritage documentation via Terrestrial Laser Scanning (TLS) technology, which allows acquiring data accurately and in a short period of time. Based on a 3-dimensional (3D) data in form of point cloud, it is possible to construct 3D model of the structure, create an accurate digital archive and orthophotos, which can be used in further restoration works. This paper provides two case studies from Istanbul (Turkey). As the result of this study, 3D point cloud models, orthophotos, and façade drawings of the structures were produced.

1. INTRODUCTION

3D documentation of historical structures has been well recognized over recent years and it became more and more pragmatic to preserve them digitally. TLS provides a geospatial database which a third party can use for restoration, risk assessment, maintenance and addressing the need for the sustainability of existing building.

Laser scanning method has been successfully used in many applications concerning the documentation studies until today. In (Safkan et al. 2014), the side of Istanbul Technical University Foreign Languages Academy was scanned with a TLS in order to create an architectural documentation. Whiting this framework, architectural drawings were created in CAD software based on the point cloud data. 3D modelling of cultural heritage using LiDAR is shown in (Alionescu et al. 2018) on the example of Timisoara city in Romania. The comparison of TLS technology is made, and classic photogrammetric method is applied in the study (Kıvanç 2019). The author stated the advantages and disadvantages of both methods compared to each other. In (Vasilakos et al. 2018), the aim of the study was to compare the hand-held DSLR camera with the ground laser scanning tool, and to assess the post-earthquake building damage and structural deformations. As the study area, the affected town of Vrisa was selected after the earthquake of Mw 6.3 in Greece. In the study (Uray et al. 2015), 3D digital data of Diyarbakir Castle and its walls were created using TLS. It was observed that TLS technology has become an increasingly preferred measurement technique for the 3D documentation, and it offers more information and rich content compared to classical surveying techniques. In the framework of (Lepere and Lemmens 2019), 4 different iconic structures in Paris, Syria, Pagoda and Alaska were documented using TLS. (Ulvi et al. 2020) used point cloud data to create a 3D model of the Red Church located within the borders of Aksaray province by digital photogrammetry technique.

In this study, 3D documentation of two case studies was carried out using TLS technology. The first case study is almost 150 years old building of 1st Men's Dormitory of Boğaziçi University, and the second case study is a part of Istanbul Walls which are 1500 years old. As a consequence, a 3D point cloud model was created by processing the data. Furthermore, the CAD drawings of façade were created based on orthophotos.

2. STUDY AREA

This paper provides two case studies from Istanbul, Turkey: the first case study is the 1st Men's Dormitory of

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Boğaziçi University and the second case study is the Land Walls, which can be seen in Fig. 1.

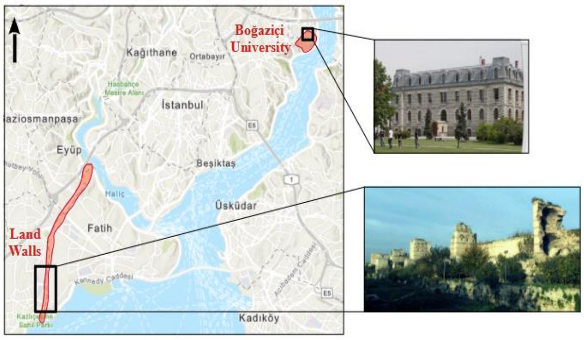


Figure 1. Location of Land Walls and Boğaziçi University on the Istanbul map

2.1. Case Study Area 1

The 1st Men's Dormitory is the oldest building of Boğaziçi University (located at South Campus) that has served as a men's dorm since 1871. It is also known as Hamlin Hall, named after Dr. C. Hamlin, who was the first President of Robert College.

2.2. Case Study Area 2

Being a part of Roman, Byzantine, Latin, and Ottoman Empires, the Land Walls of Istanbul have a significant historical value at the present time. This structure was built in 413 A.D. for the defensive purposes and it is located on the Historical Peninsula of Istanbul. The length of Land Walls is approximately 7.5 km. Today, this structure is a part of Historic Areas of Istanbul and has been added into the UNESCO World Heritage List.

3. MATERIALS AND METHODS

3.1. Terrestrial Laser Scanner Used in Application

The main focus of the study is to perform the 3D documentation of two historical structures using TLS technology. For this, TLS FARO Focus 330 HDR was chosen, which technical specifications are shown in Table 1. A number of studies were carried out using FARO instrument and they proved that this TLS is one of the most profitable for scanning the historical structures (Uray et al. 2015; Redweik et al. 2020; Hepyörük 2015; Temizer et al. 2013).

Table 1. Performance specifications of FARO Focus 330 HDR

Type	Phase-based
Scanning range	0.6 – 300 m indoor and outdoor scanning
Speed of measurement	122,000/244,000/488,000/976,000
Field of view	Vertical 300^0 Horizontal 360^0
Range error	± 2mm
Ambient temperature	5 – 40^0 C
Laser class	Laser class 1
Wavelength of laser	1550 nm
Beam divergence	Typical 0.19 mrad (0.011^0)

3.2. Methodology

The methodology of the current study was organized according to the flowchart shown in Fig. 2.

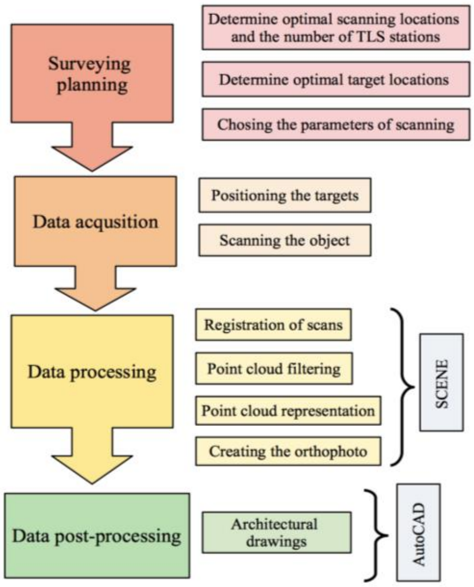


Figure 2. Workflow of TLS application in 3D documentation

3.2.1. 1st Men's Dormitory of Boğaziçi University

The 1st Men's Dormitory of Boğaziçi University is located at the South Campus, which is usually very crowded. However, due to pandemic of COVID-19 there were not any obstructions, such as parking cars or crowds of passing people, that may prevent from clean sight of view. Two walls of the structure were fully accessible for scanning: the north-west and the north-east walls. The wall lying on the south-east were visually obstructed by tress and the south-west wall was only accessible through a narrow passage. 18 scans were used in order to capture the structure in detail and scanning was performed from approximately 10 m from the structure. One station was located on the roof of a nearby building. Fig. 3 shows the configuration of scanning in relation of building.

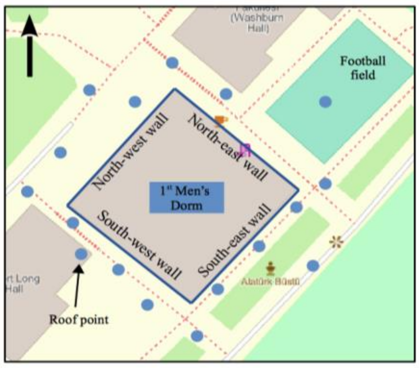


Figure 3. Sketch showing the study building and TLS' positions

The scanning resolution was chosen as 1/4 meaning that the total number of scan points is 43.7 MPns with point distance of 6.1 mm on 10 m, and quality was chosen as 1x, which means that every point was fired 1 time by a laser beam. These settings are required for 3D documentation (Redweik et al. 2020). It took approximately 10 minutes to scan the structure from one each station, that makes 3 hours in total.

Due to the size of the building (the perimeter is almost 140 meters), it was decided not to use any targets and all scans were registered together using cloud-to-cloud registration method resulting in mean point error of 4.7 mm. After the registration process, redundant data outside the building were removed and 3D model of point cloud was created.

3.2.2. Istanbul Land Walls

In this study, a part of Land Walls (approximately 200 m) was scanned for the documentation purposes. In the first step, area to be surveyed was analyzed. In front of walls there was a gardening zone and it was decided to perform scanning from sidewalk that is approximately 40 m away from the structure. Land Walls were scanned from 8 positions using spherical targets. The scanning parameters were chosen the same as for the previous study: resolution 1/4 and quality 1x. Fig. 4 shows the study area and the scanning geometry.

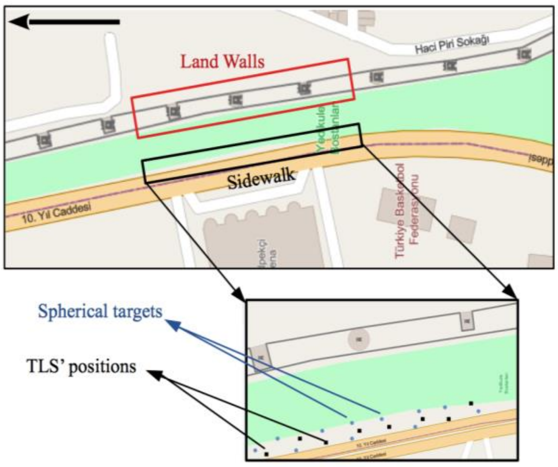


Figure 4. Sketch showing the study area, TLS' and targets' positions

In order to register scans together the target-based method was implemented. The mean distance error and the mean horizontal error were 0.8 mm, and the mean vertical error was equal to 0.1 mm. After the registration, data was cleaned from unnecessary points and then 3D point cloud model was made. These processes were done in the SCENE software, which is a manufacturer software delivered with the scanner.

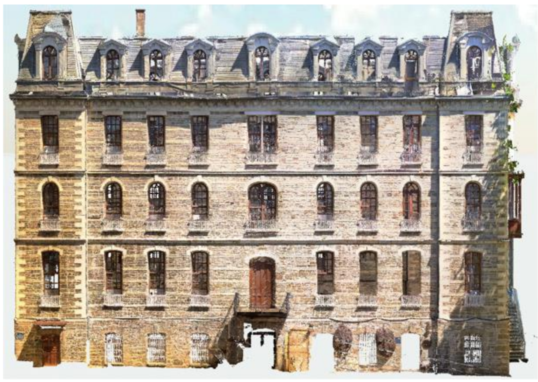
4. RESULTS AND DISCUSSIONS

4.1. 1st Men's Dormitory of Boğaziçi University

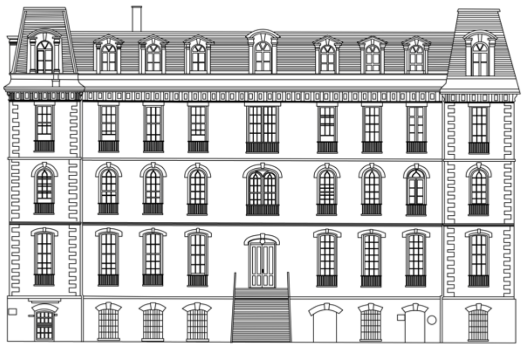
As the results of this study, a 3D point cloud model with more than 400,000,000 points was obtained which is shown in Fig. 5.

Figure 5. 3D point cloud model of the 1st Men's Dormitory buildings

Orthophoto images of building façade served as a base for architectural drawings, which were done in AutoCAD software and can be seen in Fig. 6.



(a)



(b)

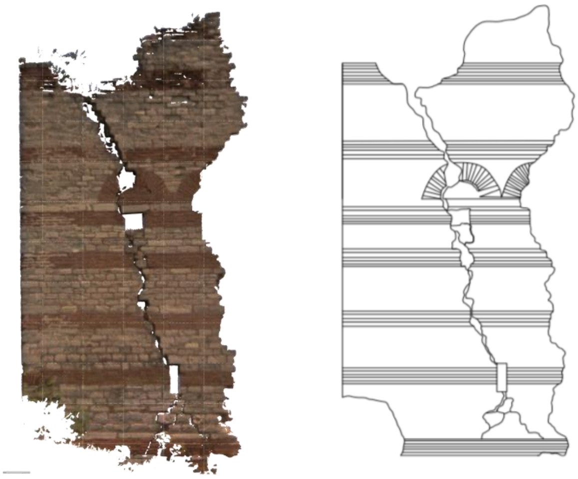
Figure 6. The deliverables of the TLS surveying: **(a)** an orthophoto of façade of the 1st Men's Dormitory building; **(b)** an architectural drawing of the 1st Men's Dormitory building drawn over the orthophoto

4.2. Istanbul Land Walls

In total, more than 500,000,000 points were involved in the 3D point cloud model, which is shown in Fig. 7.

Orthophoto images obtained from the point cloud data allow for mm accuracy and preserve all details of the façade. In the current study, orthophotos were created in SCENE software and then transferred in AutoCAD environment, where, in its turn, they were scaled at 1:1 scale. Fig. 8a and 8b shows the orthophoto and the CAD drawings respectively for the tower of Istanbul Land Walls.

Figure 7. 3D point cloud of the part of Istanbul Land Walls



(a) **(b)**

Figure 8. The deliverables of the TLS surveying: **(a)** an orthophoto of Land Walls' Tower; **(b)** an architectural drawing of Land Walls' Tower drawn over the orthophoto

5. CONCLUSION

In this paper, we performed a 3D documentation of two heritages that has a historical meaning for Istanbul. For this purpose, TLS was used, and this instrument showed itself as a good tool that allows for the dense point cloud acquisition and can provide an accurate realistic orthophoto image of the scanned object.

We have devised a clear methodology for the entire work and suggest that careful attention must be paid while planning work. To be more precise, surveyed area must be carefully studied in order to avoid mistakes during the data acquisition. We believe that our method could be used as guideline in the field of 3D documentation concerning historical structures.

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