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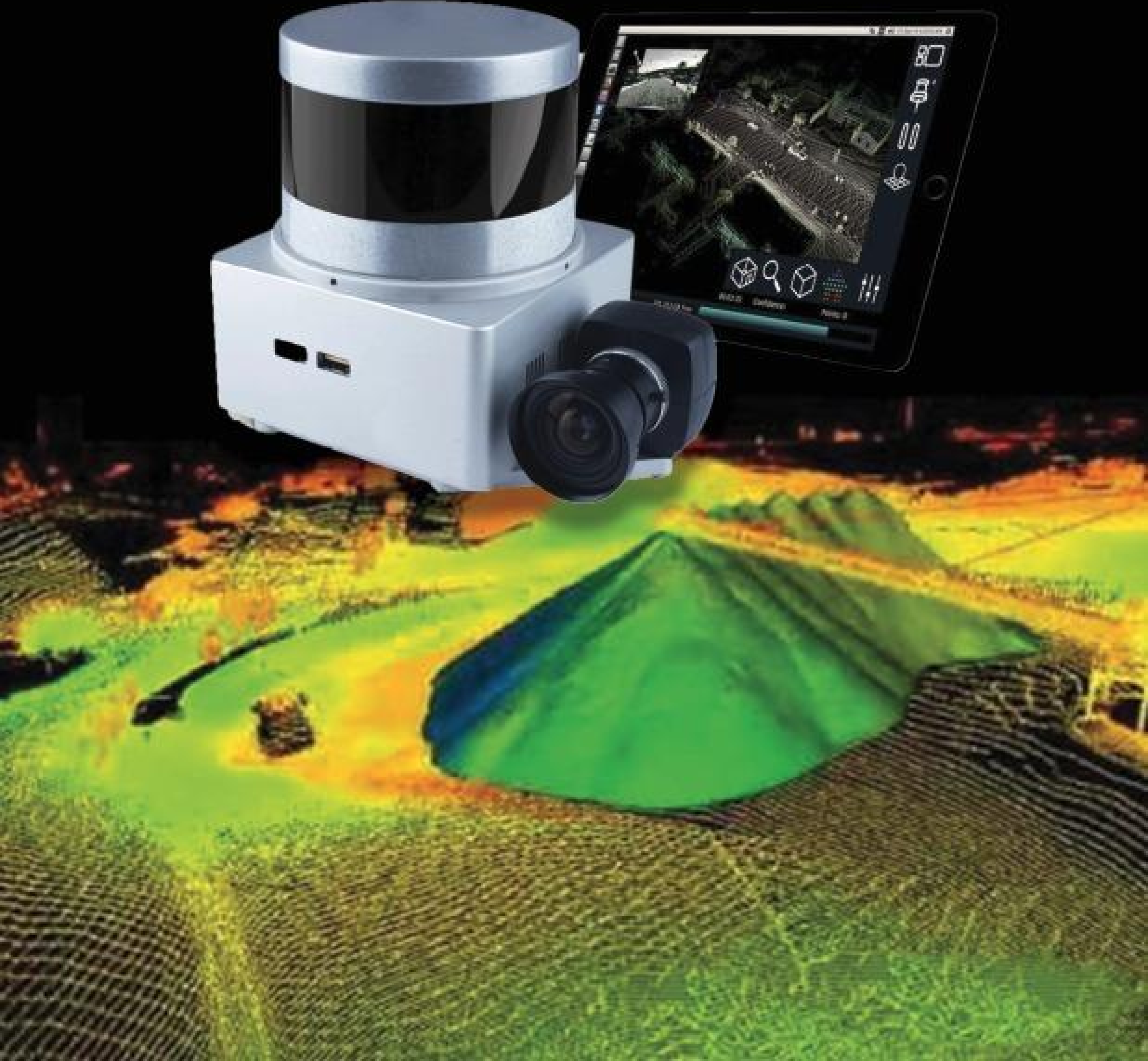

Advanced LiDAR

About Journal

The Advanced LiDAR is a peer-reviewed journal that publishes studies on LiDAR technology development, use, and earth sciences and is scanned in International Indexes and Databases. The journal, LiDAR Systems, and LiDAR Autonom Systems, etc. focuses on the design and applications of LiDAR, including.

Aim & Scope

Turkish Journal of LiDAR,

- To present international developments in the use of terrestrial, wearable, UAV, air, and mobile LiDAR to the information of scientists interested in the fields of Map, Geology, Environment, Mining, Urban Planning, Agriculture, archeology, and architecture.
- To provide an easily accessible and wide-ranging discussion environment that will strengthen and accelerate the sharing of knowledge and experience between scientists, researchers, engineers, and other practitioners who are involved in direct or indirect activities with the following topics.
- To contribute to the initiation and development of inter-institutional cooperation with LiDAR technology, which is of great importance in solving problems related to professional developments that can play a role in technological and economic development in the world and in Turkey.

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- ✓ Augmented Reality and virtual reality (VR) applications with LiDAR,
- ✓ Geographical Information Systems integration with LiDAR data,
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3D Modeling of Mufti Abdullah Sıddık Mosque using Wearable Mobile LiDAR

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Abstract

Mobile LIDAR, which can be attached to any moving vehicle, started to be used after 2000. In recent years, Wearable Mobile LiDAR (WML), which can be carried by wearing it on a person, has started to be used. WML is used for mapping and 3D modeling of interior and narrow places that cannot be reached by any vehicle and only one person can enter. In this study, 3D model and orthophoto of Mufti Abdullah Sıddık Mosque located in Mersin University Çiftlikköy campus were produced. With WML, data were collected in a short time like 13 minutes in the field and the produced orthophoto and 3D models were produced within the error limit. When the system is used fast and based on Ground Control Points (GCP), it gives results within the error limits. This study demonstrates the usability of WML in structure modeling and mapping.

1. Introduction

The world population is constantly increasing. The growing population is generally concentrated in cities. Today, the needs of technologically developing and growing cities are also increasing. For a sustainable development, it is necessary to make earthquake-resistant structures by taking into account the earthquake reality of the buildings and to examine the deformation in the following years. It is thought that it is important in the construction or restoration stages of large buildings or in possible disasters to record cities in 3D. The 3D modeling of the structures made with the WML method also reveals all the details that escape the human eye (Erdoğan et al., 2021;). With the WML method, fast reliable mapping of structures is possible. The number of buildings in our cities is increasing day by day. We think that a 3D model of these structures with their geographical location is necessary in order to be able to recognize, record, respond to their needs, protect people's lives and develop geographic information systems that will help those who govern the city. In this study, the 3D model and orthophoto of Mufti Abdullah Sıddık Mosque located in Mersin University Çiftlikköy Campus were produced using WML.

Point cloud technology is developing day by day (Karataş et al.2022a). Cultural heritage documentation and modelling can be performed with high precision (Karataş et al.2022b). Architectural properties can be defined and determined in a short time (Karataş et al.2022c; Kanun et al., 2021; Kaya et al., 2021; Şenol et al., 2017; Şenol et al., 2020; Ulvi & Yiğit, 2022; Yakar et al., 2009; Yılmaz & Yakar, 2016).

2. Wearable Mobile Lidar (WML)

The method of scanning by a human wearing the Mobile LIDAR platform is called WML. WML is a system in which 3D point cloud data of scenes within a horizontal range of 360o can be viewed and recorded by

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a tablet computer, which is usually loaded by a human being through a backpack.

WML is a compact system that includes a LIDAR sensor, RGB camera and GNSS-IMU, which can work in all light conditions. LiDAR sensors, which can capture full 360° panoramic images, have a range of 100 - 200 m in different brands. A 3D model is created by calculating the distance from the time elapsed until the reflection of the rays hitting the object illuminated by a LIDAR light, and by determining the surfaces over the triangular model consisting of points (NAVVİS, 2021; Lauter, 2020; GEXCEL, 2021; Geoslam 2021).

Since the system is carried on a person's back, it can be easily moved and worked in narrow and complex structures. The system can be easily transported in the trunk of a vehicle. GML is designed to be used in places where people can walk. It is a system designed to be a solution for indoor and outdoor areas, underground mines, tunnels, cultural heritage sites, forests, urban areas, buildings and crime scenes that are difficult to record and complex (NAVVİS, 2021; Lauter, 2020; GEXCEL, 2021; LEICA, 2021). The GEXCEL Heron wearable mobile LIDAR scanner is shown in Figure 1.

Figure 1. GEXCEL Heron GML scanner (GEXCEL, 2021).

Since GNSS does not work in covered areas, other systems are required. Simultaneous localization and mapping “Simultaneous Localization And Mapping” (SLAM) was developed in 2008. The system is mobile, that is, active by movement, while the system is making a map of an unfamiliar environment, it improves the map it produces according to the location it is progressing, and offers an algorithmic approach to solving problems by constantly positioning itself. When mobile robotics travel with SLAM, it positions itself according to the environment by using the distances from LIDAR. It requires LIDAR, GPS, accelerometer, sensors and algorithm data to do this. SLAM technology is a solution against the deterioration of GPS signals in closed areas, forests, inside buildings, tunnels, caves, wells, mines and narrow streets in the city where the sky is not visible at all or completely. SLAM technology has revolutionized mapping in difficult and complex locations. SLAM calculates the instantaneous position of each displacement of the wearable mobile LIDAR by taking the relative and absolute positioning inputs. However, its position calculated in this way cannot be expected to be as precise as a static position (Geoslam, 2021; Thomson, 2020; Thomson, 2021).

2.1. WML Considerations

The points to be considered in the field for the quality of the cartographic data obtained; Filippo, vd., 2018; Stefano, vd., 2021; Chio ve Hou, 2021, Karabacak, 2022; Ulvi et al., 2015; Yakar et al., 2008; Yakar et al., 2010).

- First, a reconnaissance is made in the work area, the walking path is determined, and if there are obstacles on the walking path, they are removed.
- If there is a door that the GML operator will pass through on the walkway, it is made open.
- Take precautions to avoid walking people and moving objects during scanning.
- If you slow your walking pace, you will collect more detailed data.
- Slow down when entering different rooms so that the SLAM algorithm can combine the inside and outside.
- Slow down when transitioning to different light and dark places so that SLAM can combine properly.
- Make the work of the SLAM algorithm easier by placing different objects in uniform spaces. For example, you can place a bicycle or a dustbin in the tunnel.
- Move by drawing an arc on turns.
- If there is another door on the way out than the door you entered, differentiate the scenes by descending from there, or if there is another staircase when going up and down, use it.
- Carry the LIDAR pole upright.
- Finish the route where you started.
- Do not make sudden movements.
- Reduce your walking speed in tasks requiring precision.
- Working by dividing large work areas into small areas will prevent the growth of error amounts.
- Keep the scan time less than 30 minutes.

2.2. Positioning Performance with RT-PPP Method

It is a wearable or handheld mobile laser scanner developed in 2015. It uses SLAM Algorithm. It can be used in all kinds of walkable areas. It can capture 3D point clouds and 5K panoramic images to collect both geometry and color information together. The portable Mobile laser scanner tested in this study is the Heron wearable Lidar device manufactured by Gexcel. Emitting infrared laser beams at a wavelength of 903 nm, a 16-channel Velodyne Puck LITE laser scanner achieves 300,000 points per second within a range of 100 m and with a 360° horizontal view and a 30° (-15 +15) vertical field of view. The laser scanner sensor is combined with an XSens MTI, IMU, whose data is used in system trajectory prediction. While working, the LiDAR head is mounted on a telescopic carbon fiber pole, connected to a battery and a control unit.

Parts of the Gexcel Heron wearable 3D mobile mapping system are shown in Figure 2. The scanner head with the laser sensor is screwed onto a pole. The cable connection from the scanner head connects to the battery for power, data exchange and the tablet for the program. The device is controlled and managed with the Heron live program in the tablet. The instantaneous state of the point cloud made on the tablet screen appears and the mobile LIDAR operator stops the work when there is a possible problem on the screen and returns to the beginning if necessary and repeats the work. The pole holding the LIDAR can be used by placing it in a pocket attached to the belt, or it can be used by holding it vertically by hand (Oruç and Baş, 2021; Oruç and Öztürk, 2021; Alptekin & Yakar, 2021; Alptekin et al., 2022).

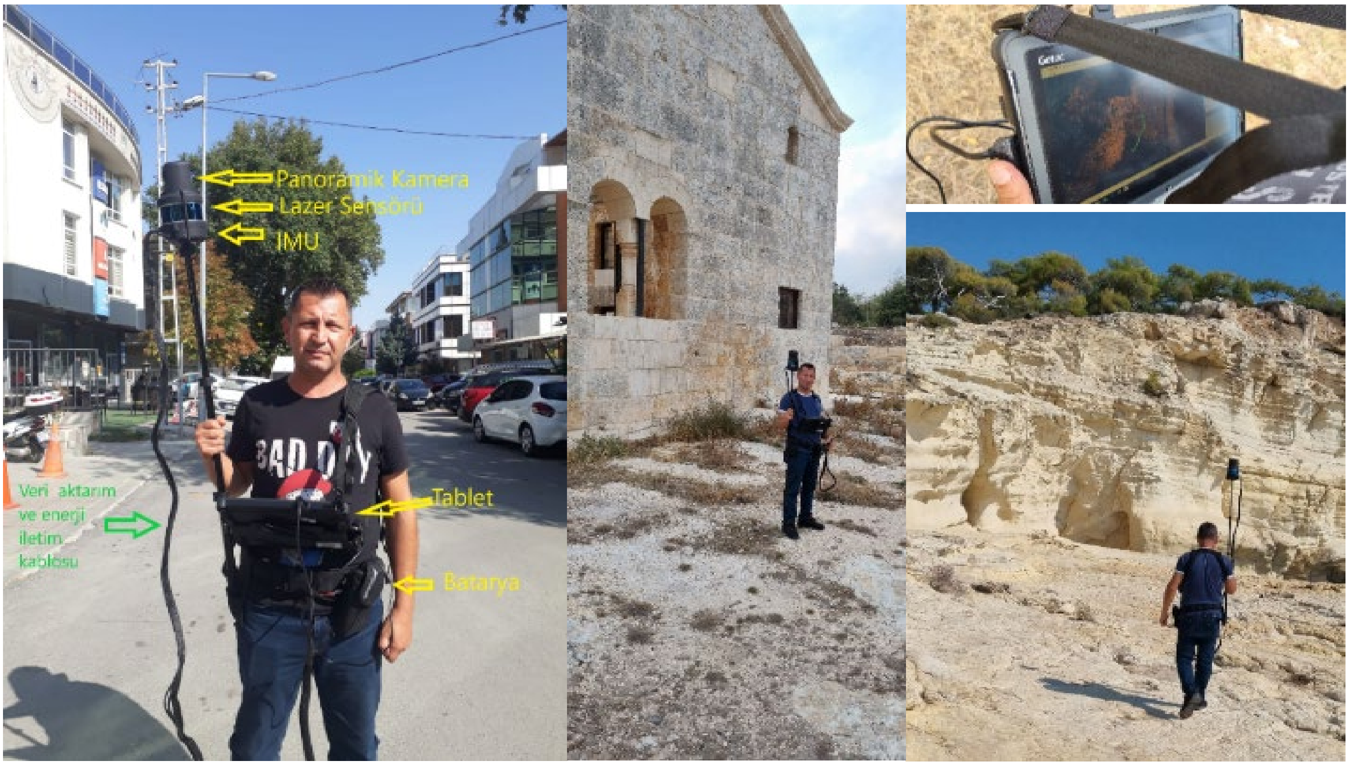


Figure 2. Heron GML

According to the manufacturer's specifications, the system provides a local accuracy of 3 cm and a final global accuracy of 5 cm. The presence of loops and closures, as well as the properties of the scanned environment, may affect the SLAM algorithm and the accuracy may drop to 20-50 cm (Paksoyteknik, 2022, Maset vd., 2021).

Suitable Weather Conditions for Working
- Direct sunlight.
- Wind.
- Dark places
- Operating temperature from -10° C to +45° C.

Unsuitable Weather Conditions for Working
- Rain, snow, heavy rains.
- Very dusty environments.
- Aggressive atmosphere Shaking greater than 500 m/s2, usually lasting 11 ms.
- Strong electromagnetic fields.
- Water coming into the device will destroy the device.

Considerations During Scanning
- Do not shake the sensor.
- Do not splash.
- Avoid sudden movements.
- When scanning and calibrating, make sure that the cables connected to the laser sensor head always face to the right according to your path. The IMU may be affected if the cable direction changes.
- The pole should be kept upright during scanning.

2.3. WML Usage Areas

It can meet the many mapping and modeling in documentation of cultural heritage, forestry and forest mapping studies, indoor modelling, open mine surveys, determination of deformation in structures caused by seismic events, tunnel, cave modeling, renewal of cadastral maps, measurement of energy transmission lines, infrastructure maps and recording of the crime scene. (Filippo vd. 2018, Masiero vd. 2018, Rodríguez-Martín vd. 2022, Carlos Coba vd. 2018, Xu, vd., 2020, Hyyppä, vd., 2020, Ko, vd., 2021, Zhou, 2019, Geoslam, 2021, Otero, vd., 2020, Maset, vd., 2021, Maset, vd., 2022, Vassena ve Clerici, 2018, Sánchez-Aparicio, vd. 2021, Di Stefano, vd., 2021, Chio ve Hou, 2021, Velas, vd., 2019, Ulvi, vd., 2021; Kabadayı, 2021; Kabadayı & Uysal, 2020).

3. 3D Modeling of a Mosque With WML

The 3D model and orthophoto of Mufti Abdullah Sıddık Mosque, located in Mersin University Çiftlikköy campus, were produced. For mosque measurement, ITRF coordinates were obtained by measuring 6 polygons in the field with GNSS and total station. Pictures from field studies for mosque measurement are shown in Figure 3.

Figure 3. Mufti Abdullah Sıddık Mosque field study

3.1. Scanning Inside and Outside of Mosque with Closed Route Using GCP

The route was planned by visiting the inside and outside of the mosque, using 6 GCPs as the closed route, so that the inside and outside of the mosque would be completed in the same purchase. Closed doors were opened and a plan was made according to the obstacles. The route was planned to be closed, but considering that the retaining wall around the mosque with a ladder would disrupt the dimensions, the route that started over the wall was closed by coming to the bottom of the wall from the garden of the mosque. The route was completed in 13 minutes. When we walk on the rough slope, the route is disrupted (Figure 4).

Figure 4. The sloped land around the mosque.

Trying to solve it at different intervals to fix it. Odometering the route and the problematic place on the route are seen in the odometer stage with a red line (Figure 5).

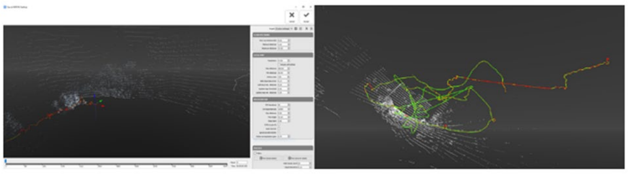


Figure 5. Odometer of the Closed and GCP Route.

The automatically generated ties with the GCP points included are given in Figure 6.

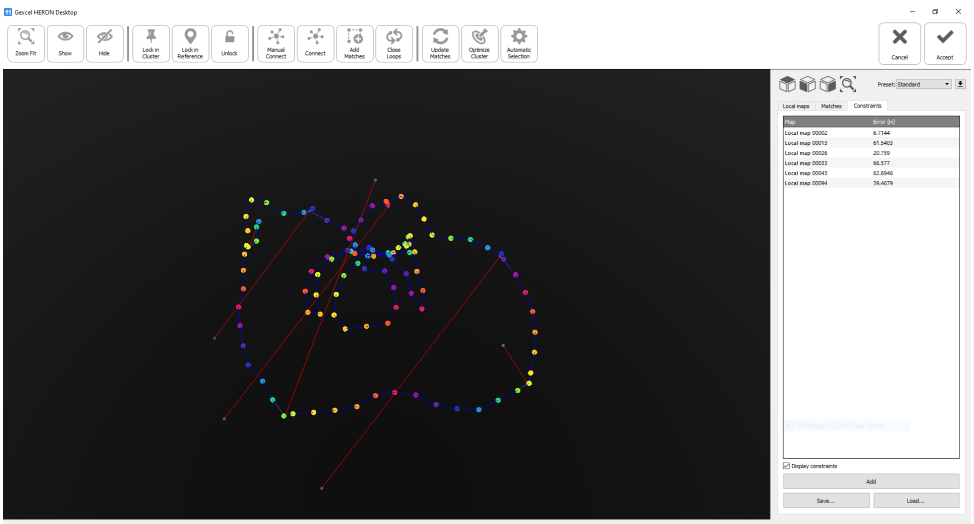


Figure 6. Tie with GCP points included

New ligaments were pulled (Fig. 7).

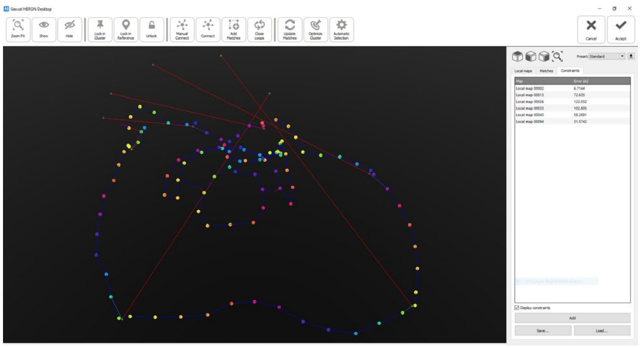


Figure 7. Tie when new links are added

As a result of newly added ligaments and balancing, the error in the RMSD range of 4.1 cm on average 2.5 cm was calculated as 8 cm at most and 3 cm on average (Figure 8).

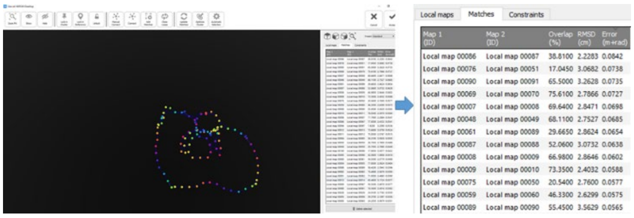


Figure 8. The biggest mistakes in ties as a result of balancing.

As a result of balancing, the error in the control points was 0,1,1,3,4,5 cm. Average output was 2.3 cm (Fig. 9).

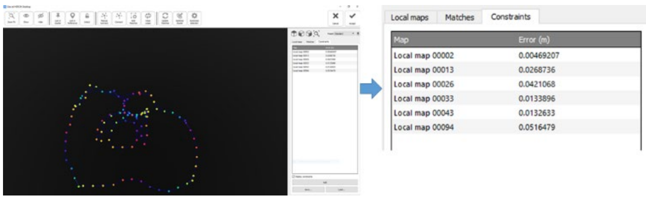


Figure 9. Errors hitting YKN as a result of balancing.

The error rate is higher in the vineyards at the stair exits to the upper floor of the mosque. Therefore, it was tried to reduce the error in the route by creating links between the route on the first floor of the mosque and the ground floor (Figure 10).

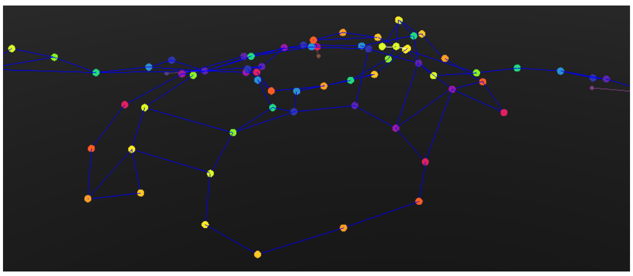


Figure 10. The ties added between the first floor and the ground floor in the mosque.

The representation of the ties together in the 3D model is given in Figure 11.

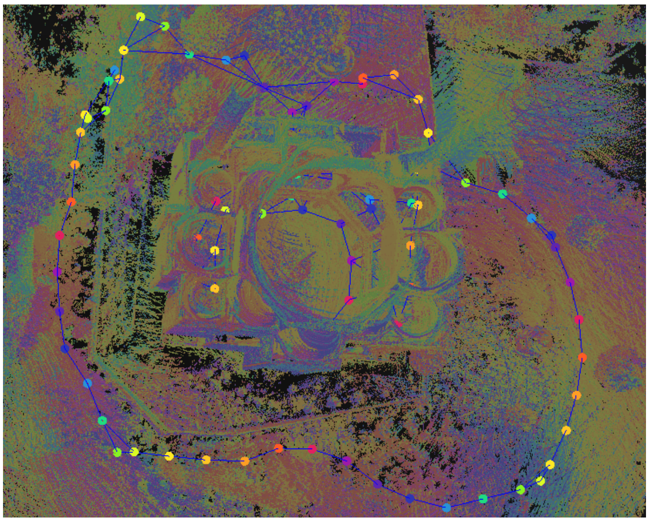


Figure 11. View of the 3D model together with ties.

The work is transferred to the Reconstructor program (Figure 12).

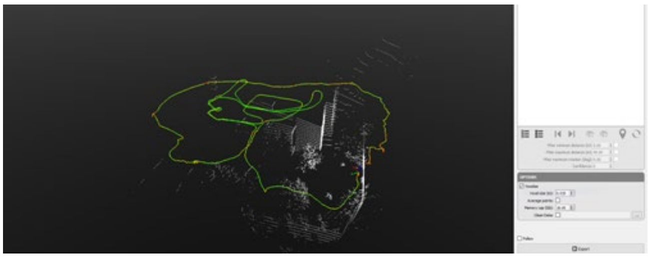


Figure 12. Exported to Go to Reconstruct.

In Reconstructor, the 3D model of the Mosque can be examined from different angles and measured (Figure 13).

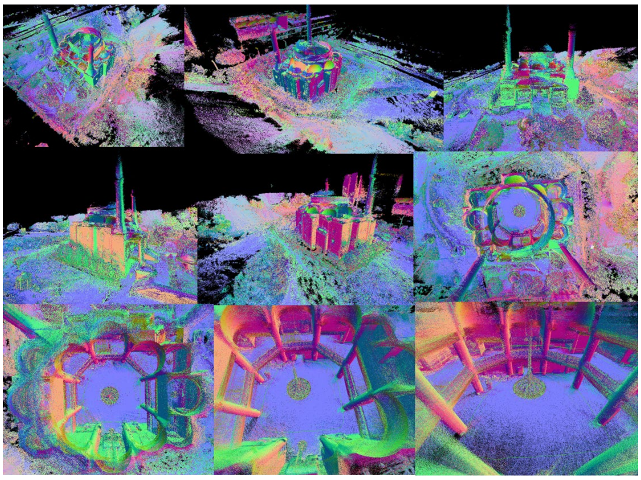


Figure 13. Mosque 3D model from different angles in Reconstructor.

An orthophoto of the structure was produced in Reconstructor (Figure 14). The edges measured on the orthophoto were measured with a steel tape measure as 5.56, 3.33, 5.66, 6.70, 3.77, 5.47, 7.40 m clockwise starting from the northwest in the field. The differences between the measurements were calculated as 4.1, 1.3, 1.2 and 1 cm, respectively, and the average of the differences was 1.9 cm (Table 1), (Figure 15).

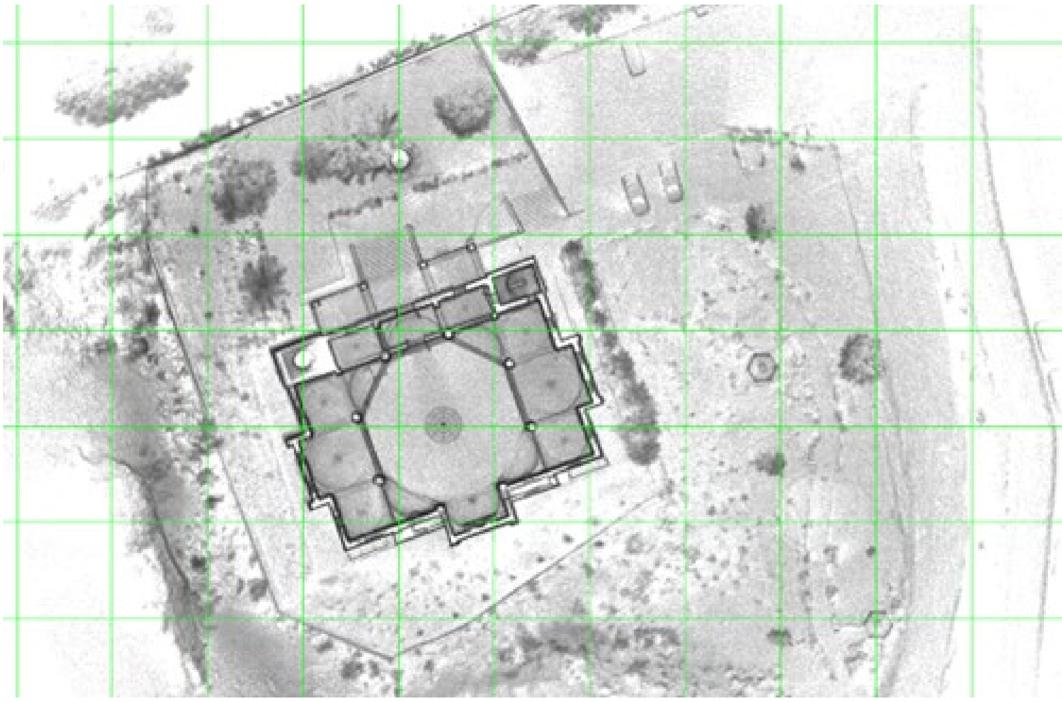


Figure 14. Mosque orthophoto.

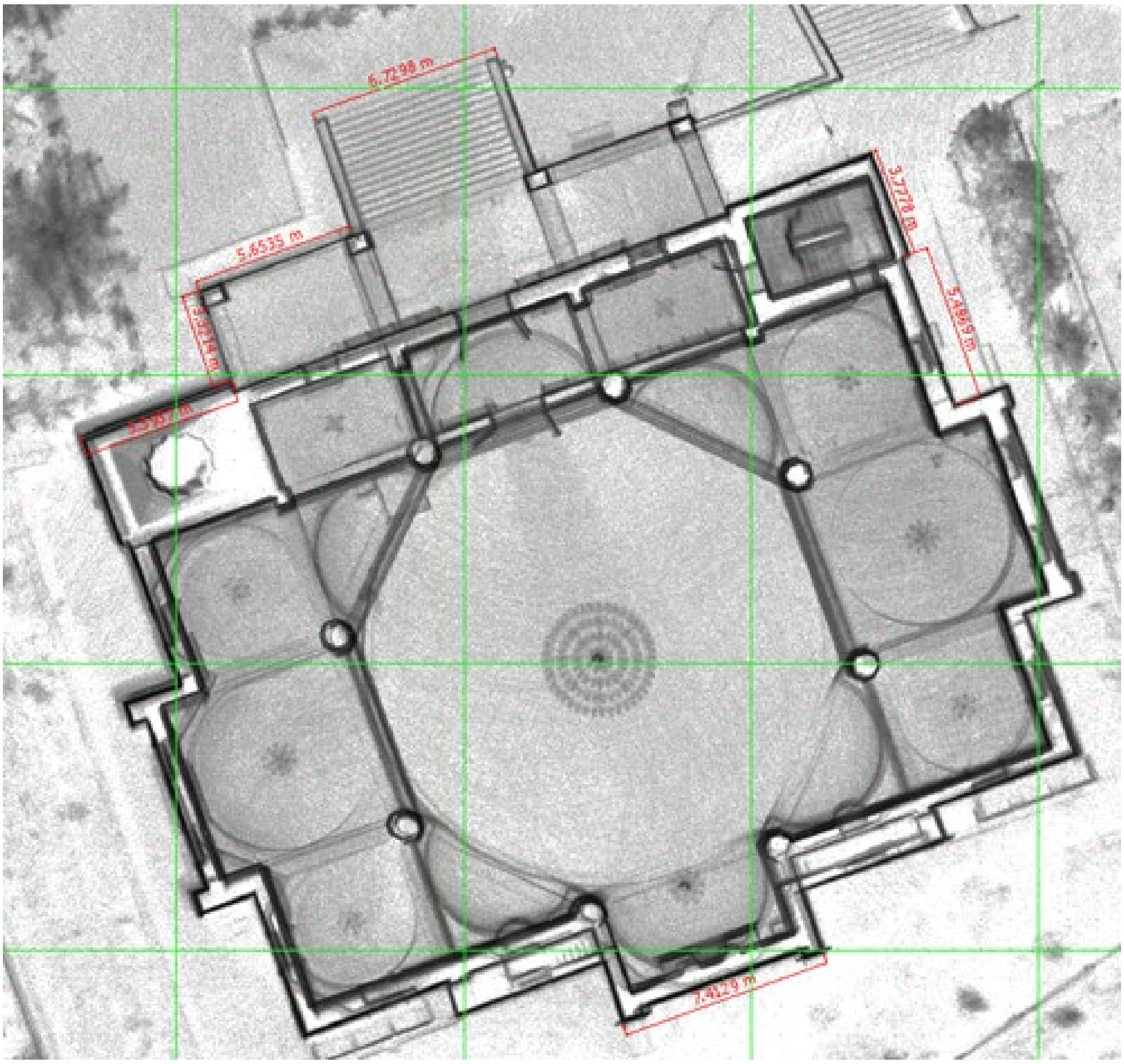


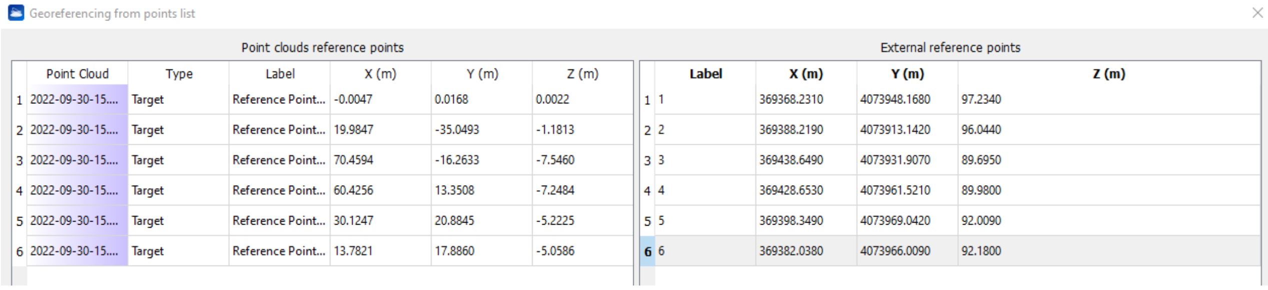
Figure 15. Lengths measured on the mosque orthophoto.

Tablo 1. The lengths of the mosque walls over the land and its orthophoto

	1	2	3	4	5	6	7
Length on land (m)	5.56	3.33	5.66	6.70	3.77	5.47	7.40
Length in orthophoto (m)	5.60	3.32	5.65	6.73	3.78	5.49	7.41
Difference (cm)	4	1	1	3	1	2	1

In the Reconstructor, the location of the GCP points given by GML and the ITRF coordinates given by GNSS and totalstation can be viewed (Figure 16). In the Reconstructor, the errors hitting the YKN and their deviations relative to the coordinate axes can be displayed (Figure 17).

A coordinate transformed 3D point cloud can be displayed in Reconstructor (Figure 18).


Georeferencing from points list

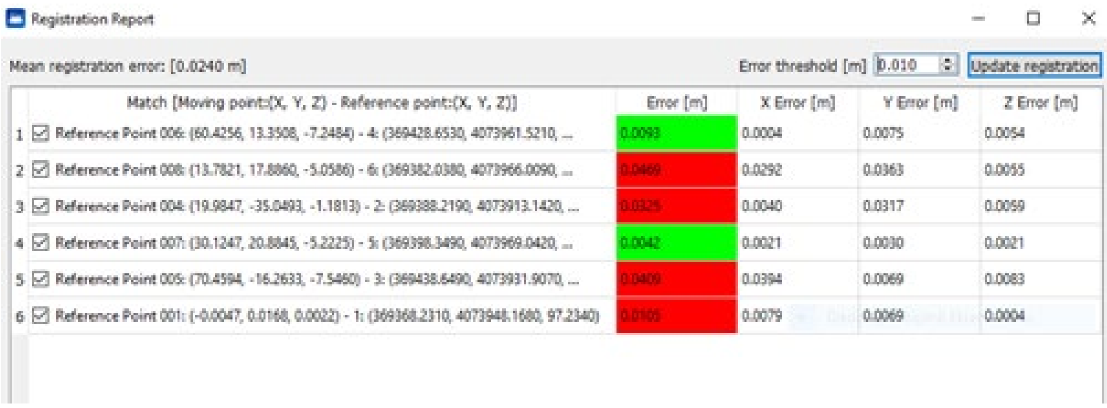
Point clouds reference points

	Point Cloud	Type	Label	X (m)	Y (m)	Z (m)
1	2022-09-30-15....	Target	Reference Point...	-0.0047	0.0168	0.0022
2	2022-09-30-15....	Target	Reference Point...	19.9847	-35.0493	-1.1813
3	2022-09-30-15....	Target	Reference Point...	70.4594	-16.2633	-7.5460
4	2022-09-30-15....	Target	Reference Point...	60.4256	13.3508	-7.2484
5	2022-09-30-15....	Target	Reference Point...	30.1247	20.8845	-5.2225
6	2022-09-30-15....	Target	Reference Point...	13.7821	17.8860	-5.0586

External reference points

	Label	X (m)	Y (m)	Z (m)
1	1	369368.2310	4073948.1680	97.2340
2	2	369388.2190	4073913.1420	96.0440
3	3	369438.6490	4073931.9070	89.6950
4	4	369428.6530	4073961.5210	89.9800
5	5	369398.3490	4073969.0420	92.0090
6	6	369382.0380	4073966.0090	92.1800

Figure 16. GCP position and ITRF coordinates.


Registration Report

Mean registration error: [0.0240 m] Error threshold [m] 0.010 Update registration

	Match [Moving point:(X, Y, Z) - Reference point:(X, Y, Z)]	Error [m]	X Error [m]	Y Error [m]	Z Error [m]
1	Reference Point 006: (60.4256, 13.3508, -7.2484) - 4: (369428.6530, 4073961.5210, ...	0.0093	0.0004	0.0075	0.0054
2	Reference Point 008: (13.7821, 17.8860, -5.0586) - 6: (369382.0380, 4073966.0090, ...	0.0469	0.0292	0.0363	0.0055
3	Reference Point 004: (19.9847, -35.0493, -1.1813) - 2: (369388.2190, 4073913.1420, ...	0.0325	0.0040	0.0317	0.0059
4	Reference Point 007: (30.1247, 20.8845, -5.2225) - 5: (369398.3490, 4073969.0420, ...	0.0042	0.0021	0.0030	0.0021
5	Reference Point 005: (70.4594, -16.2633, -7.5460) - 3: (369438.6490, 4073931.9070, ...	0.0409	0.0394	0.0069	0.0083
6	Reference Point 001: (-0.0047, 0.0168, 0.0022) - 1: (369368.2310, 4073948.1680, 97.2340)	0.0105	0.0079	0.0069	0.0004

Figure 17. GCP hitting errors and their deviations relative to the coordinate axes.

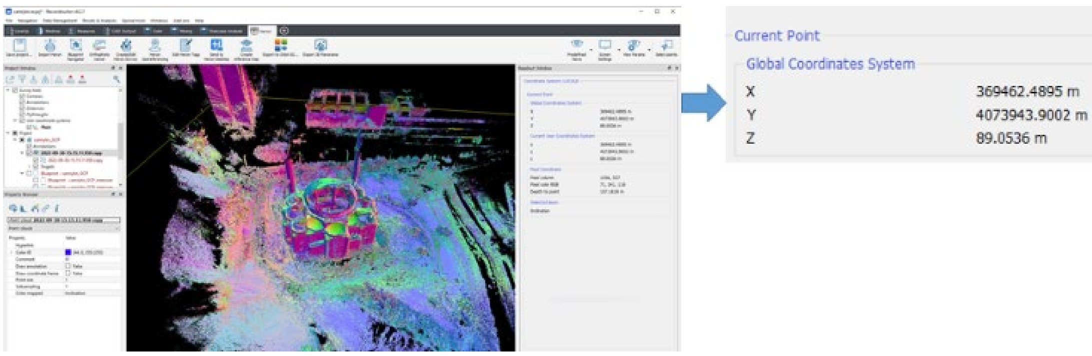


Figure 18. 3D mosque model in ITRF coordinate system

4. Conclusion

With the GML, the exterior and interior of the mosque were completed on the same route in a short time like 13 minutes. Since the walking path in the western direction of the mosque is sloped and stony, mistakes grow in the vineyards where it is difficult to walk. When going up the stairs in the mosque, the error is big in the vineyards on the stairs. In this case, errors were reduced by pulling ties from the first floor of the mosque to the entrance floor of the mosque. Since there is no GNSS support in the GML used in the study, the growth of errors was prevented with YKN and the mosque map and 3D model could be produced in the ITRF coordinate system within the error limits. The weak point of the system is that GCP should be used to give reliable results and this increases the working time in the field. In this study, it is suggested to use GML to produce maps and 3D models of structures.

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Author contributions

Atila Karabacak: Data curation, Writing-Original Draft Preparation, Validation, Data curation, Writing, Visualization, Control and Validation
Murat Yakar: Conceptualization, Methodology, Software, Investigation, Software

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

References

Alptekin, A. & Yakar, M. (2021). Lazer Tarayıcının Jeolojik Olayların Modellenmesinde Kullanımı. *Türkiye Lidar Dergisi,* 3(2), 71-75. DOI: 10.51946/melid.1018197

Alptekin, A., Çelik, M. Ö., Doğan, Y. & Yakar, M. (2022, February). Illustrating of a landslide site with photogrammetric and LIDAR methods. In Research Developments in Geotechnics, Geo-Informatics and Remote Sensing: Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019 (pp. 303-305). Cham: *Springer International Publishing.*

Cabo, C., Del Pozo, S., Rodríguez-Gonzálvez, P., Ordóñez, C. & Gonzalez-Aguilera, D. (2018). Comparing terrestrial laser scanning (TLS) and wearable laser scanning (WLS) for individual tree modeling at plot level. *Remote Sensing*, 10(4), 540.

Carla LAUTER'in 13 Mayıs 2020 tarihli yazısı (Yeni giyilebilir VLX tarayıcıları ile NavVis, mobil haritalamayı ana akım haline getirmeyi hedefliyor) www-geoweeknews-com. (son erişim 01.10.2021)

Chio, S. H. & Hou, K. W. (2021). Application of a Hand-Held LiDAR Scanner for the Urban Cadastral Detail Survey in Digitized Cadastral Area of Taiwan Urban City. *Remote Sensing*, 13(24), 4981.

Di Filippo, A., Sánchez-Aparicio, L. J., Barba, S., Martín-Jiménez, J. A., Mora, R. & González Aguilera, D. (2018). Use of a wearable mobile laser system in seamless indoor 3D mapping of a complex historical site. *Remote Sensing,* 10(12), 1897.

Di Filippo, A., Sánchez-Aparicio, L. J., Barba, S., Martín-Jiménez, J. A., Mora, R. & González Aguilera, D. (2018). Use of a wearable mobile laser system in seamless indoor 3D mapping of a complex historical site. *Remote Sensing*, 10(12), 1897.

Di Stefano, F., Chiappini, S., Gorreja, A., Balestra, M. & Pierdicca, R. (2021). Mobil 3D tarama LiDAR: bir literatür taraması. *Geomatik, Doğal Tehlikeler ve Risk, 12*(1), 2387-2429.

Di Stefano, F., Torresani, A., Farella, E. M., Pierdicca, R., Menna, F. & Remondino, F. (2021). 3D surveying of underground built heritage: Opportunities and challenges of mobile technologies. *Sustainability*, 13(23), 13289.

Erdoğan, A., Kabadayi, A. & Akin, E. S. (2021). Kültürel mirasın fotogrametrik yöntemle 3B modellenmesi: Karabıyık Köprüsü Örneği. *Türkiye İnsansız Hava Araçları Dergisi*, 3(1), 23-27.

Geoslam (2021). https://geoslam.com/

GEXCEL (2021). https://gexcel.it/en/solutions/heron-portable-3d-mapping-system

Hyyppä, E., Kukko, A., Kaijaluoto, R., White, J. C., Wulder, M. A., Pyörälä, J. & Hyyppä, J. (2020). Accurate derivation of stem curve and volume using backpack mobile laser scanning. *ISPRS Journal of Photogrammetry and Remote Sensing*, 161, 246-262.

Kabadayı, A. & Uysal, M. (2020). Çok yüksek çözünürlüklü İHA verilerinden bina tespiti. Türkiye İnsansız Hava Araçları Dergisi, *2*(2), 43-48.

Kabadayı, A. (2021). Unmanned aerial vehicle usage in rough areas and photogrammetric data generation. *Advanced UAV*, 1(1), 8-14.

Kanun, E., Metin, A. & Yakar, M. (2021). Yersel Lazer Tarama Tekniği Kullanarak Ağzıkara Han'ın 3 Boyutlu Nokta Bulutunun Elde Edilmesi. *Türkiye Lidar Dergisi*, 3(2), 58-64. DOI: 10.51946/melid.1025856

Karabacak A. (Kasım 2022) Mobil Haritalama Yöntemlerinin Farkli Yerlerde Uygulamalari ve Karşilaşilan Sorunlar, Mersin Üniversitesi Fen Bilimleri Enstitüsü, Uzaktan Algilama ve Coğrafi Bilgi Sistemleri Anabilim Dalı, Yüksek Lisans Tezi,

Karabacak, A. & Yakar, M. (2022). Giyilebilir Mobil LİDAR Kullanım Alanları ve Cambazlı Kilisesinin 3B Modellemesi. *Türkiye Lidar Dergisi, 4*(2), 37-52. DOI: 10.51946/melid.1146383

Karataş, L., Alptekin, A. & Yakar, M. (2022a). Determination of Stone Material Deteriorations on the Facades with the Combination of Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Historical Burdur Station Premises. *Advanced Geomatics*, 2(2), 65-72.

Karataş, L., Alptekin, A. & Yakar, M. (2022b). Creating Architectural Surveys of Traditional Buildings with the Help of Terrestrial Laser Scanning Method (TLS) and Orthophotos: Historical Diyarbakır Sur Mansion. *Advanced LiDAR*, 2(2), 54-63.

Karataş, L., Alptekin, A. & Yakar, M. (2022c). Analytical Documentation of Stone Material Deteriorations on Facades with Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Şanlıurfa Kışla Mosque. *Advanced LiDAR*, 2(2), 36-47.

Kaya, Y., Yiğit, A. Y., Ulvi, A. & Yakar, M. (2021). Arkeolojik alanların dokümantasyonununda fotogrametrik tekniklerinin doğruluklarının karşılaştırmalı analizi: Konya Yunuslar Örneği. *Harita Dergisi*, 165, 57-72.

Ko, C., Lee, S., Yim, J., Kim, D. & Kang, J. (2021). Comparison of Forest Inventory Methods at Plot-Level between a Backpack Personal Laser Scanning (BPLS) and Conventional Equipment in Jeju Island, South Korea*. Forests*, 12(3), 308.

LEICA (2021). https://leica-geosystems.com/products/mobile-sensor-platforms/capture-platforms/leica-pegasus-backpack

Maset, E., Cucchiaro, S., Cazorzi, F., Crosilla, F., Fusiello, A. & Beinat, A. (2021). Investigating the Performance of a Handheld Mobile Mapping System in Different

Outdoor Scenarios. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 43, B1-2021.

Maset, E., Scalera, L., Beinat, A., Visintini, D. & Gasparetto, A. (2022). Performance Investigation and Repeatability Assessment of a Mobile Robotic System for 3D Mapping. *Robotics*, 11(3), 54.

Masiero, A., Fissore, F., Guarnieri, A., Pirotti, F., Visintini, D. & Vettore, A. (2018). Performance evaluation of two indoor mapping systems: Low-cost UWB-aided photogrammetry and backpack laser scanning. *Applied Sciences*, 8(3), 416.

Oruç, M. E. & Baş, G. (2021). Kompleks Yapı ve Alanlarda Yersel Lazer Tarama Teknolojisinin Kullanımı. *Türkiye Lidar Dergisi*, 3(2), 39-47.

Oruç, M. E. & Öztürk, İ. L. (2021). Usability of Terrestrial Laser Technique in Forest Management Planning. *Türkiye Lidar Dergisi*, 3(1), 17-24.

Otero, R., Lagüela, S., Garrido, I. & Arias, P. (2020). Mobile indoor mapping technologies: A review. *Automation in Construction*, 120, 103399.

Paksoyteknik (2022). https://paksoyteknik.com.tr/index.php/paksoy-topcon/lazer-tarama/gexcel-heron

Rodríguez-Martín, M., Sánchez-Aparicio, L. J., Maté-González, M. Á., Muñoz-Nieto, Á. L. & Gonzalez-Aguilera, D. (2022). Comprehensive Generation of Historical Construction CAD Models from Data Provided by a Wearable Mobile Mapping System: A Case Study of the Church of Adanero (Ávila, Spain). *Sensors,* 22(8), 2922.

Sánchez-Aparicio, L. J., Mora, R., Conde, B., Maté-González, M. Á., Sánchez-Aparicio, M. & González-Aguilera, D. (2021). Integration of a wearable mobile mapping solution and advance numerical simulations for the structural analysis of historical constructions: A case of study in San Pedro Church (Palencia, Spain). *Remote Sensing*, 13(7), 1252.

Şenol, H. I., Erdogan, S., Onal, M., Ulukavak, M., Memduhoglu, A., Mutlu, S. & Yilmaz, M. (2017). 3D Modeling of A Bazaar in Ancient Harran City Using Laser Scanning Technique. International Archives of *The Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42.

Şenol, H. İ., Memduhoglu, A. & Ulukavak, M. (2020). Multi instrumental documentation and 3D modelling of an archaeological site: a case study in Kizilkoyun Necropolis Area. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 11(3), 1241-1250.

Thomson C., (2020), (What is SLAM?) https://info.vercator.com/blog/what-is-slam

Thomson C., (2021), 3 types of terrestrial laser scanners https://info.vercator.com/blog/3-types-of-terrestrial-laser-scanners.

Ulvi A., Yiğit, A. Y., Çelik, M. Ö. & Alptekin, A. (2021). Detection of existing infrastructure lines with wearable laser scanners and making infrastructure map: a case of Mersin University. *Mersin Photogrammetry Journal*, *3*(2), 61-68.

Ulvi, A. & Yiğit, A. Y. (2022). Comparison of the Wearable Mobile Laser Scanner (WMLS) with Other Point Cloud Data Collection Methods in Cultural Heritage: A Case Study of Diokaisareia. *ACM Journal on Computing and Cultural Heritage*, 15(4), 1-19.

Ulvi, A., Yakar, M., Toprak, A. S. & Mutluoglu, O. (2015). Laser Scanning and Photogrammetric Evaluation of Uzuncaburç Monumental Entrance. *International Journal of Applied Mathematics Electronics And Computers, 3*(1), 32-36. DOI: 10.18100/İjamec.41690

Vassena, G. & Clerici, A. (2018). Open pit mine 3D mapping by tls and digital photogrammetry: 3D model update thanks to a slam based approach. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42(2), 1145-1148.

Velas, M., Spanel, M., Sleziak, T., Habrovec, J. & Herout, A. (2019). Indoor and outdoor backpack mapping with calibrated pair of velodyne LiDARs. *Sensors*, 19(18), 3944.

Xu, S., Sun, X., Yun, J. & Wang, H. (2020). A new clustering-based framework to the stem estimation and growth fitting of street trees from mobile laser scanning data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 13, 3240-3250.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2008). Lazer Tarama Teknolojisi ve Fotogrametrik Yöntem ile Hacim Hesabı. *TÜBİTAK*, Proje No: 105M179, 90s.

Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2009). Comparative Evaluation of Excavation Volume by Terrestrial Laser Scanner and Total Topographic Station Based Methods. *Lasers in Engineering*, 19(5), 331.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2010). Comparative evaluation of excavation volume by TLS and total topographic station based methods. *Lasers in Engineering*,19, 331–345

Yılmaz, H. & Yakar, M. (2016). LiDAR (Light Detection and Ranging) Tarama Sistemi. *Yapı Teknolojileri Elektronik Dergisi*, 2 (2), 23-33.

Zhou, S., Kang, F., Li, W., Kan, J., Zheng, Y. & He, G. (2019). Extracting diameter at breast height with a handheld mobile LiDAR system in an outdoor environment. *Sensors*, 19(14), 3212.

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3D Laser Scanning and Photogrammetric Measurements for Documentation of the Facades of Mardin Castle, Türkiye

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Abstract

Mardin Castle is a cultural heritage of approximately 900 years and is located in the 1st Degree Archaeological Site. The castle has an east-west extension and contains Roman-Byzantine artifacts as well as many structures from the Islamic period (Mervani, Akkoyunlu, Artuklu).The entire length of the building is approximately 850 m when viewed from the south side at a right angle. Architectural documentation of the façades of such a gigantic building is a subject that requires a long time and effort with traditional methods and has a high risk of error. The main purpose of this article is to document the ruins of the southern facade of the Mardin castle and the rocky cliffs with architectural drawings. For this purpose, it has combined different analytical and investigation techniques such as terrestrial laser scanning, photogrammetry and observational analysis. In the study findings, facade surveys of the facade of the castle were obtained. The results of the study confirm that methods such as terrestrial laser scanning technology save a great deal of time and effort spent in the process of documenting huge structures such as castles.

1. Introduction

Terrestrial laser scanning technology and technologies for photogrammetric techniques provide great convenience for obtaining architectural drawings of gigantic structures. These techniques save a great deal of time and effort in buildings that are not easy to take architectural measurements and produce architectural drawings in traditional ways. Moreover, these methods are especially important as they minimize the error rate (Balzani et al., 2001).

Especially during natural disasters and wars, it has always been considered important to document such archaeological sites and to preserve all relevant information and details (Alptekin & Yakar, 2021). Today, with the increase in earthquake events in our region, as in many cities in the south, it has become a national duty to protect the heritage (Ay,2018). It is seen that many historical castles, especially Gaziantep Castle and Diyarbakır Castle, have been damaged or destroyed due to the earthquakes experienced in our country in the recent period. In this context, it is an urgent requirement to record and document the architectural features of these historical buildings (Karataş et al., 2023).

Terrestrial 3D laser scanning has become one of the most important methods for high resolution 3D documentation of structures today. But the benefits of laser scanning are still underestimated by professionals. Today, many studies have been carried out on the digital documentation of structures with terrestrial laser technology and it has been determined that positive results have been obtained (Alptekin et al.,2019; Gabriele et al.,2010; Fröhlich & Mettenlaiter, 2010; Georgopoulos et al.,2004; Guldur et al. al.,2005; Grussenmeyer et al.,2008; Oruç & Baş, 2021; Alptekin & Yakar, 2021;). However, it is seen that there are not many studies in the literature on the documentation of huge areas such as castles by terrestrial laser scanning method. One of the few documented studies; Naanouh & Stanislava (2021)

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used a combination of terrestrial laser scanning and photogrammetry to create a three-dimensional model and digital documentation of Beaufort fortress (Arnoun, South Lebanon). The study results demonstrate the potential for the integration of terrestrial laser scanning and photogrammetry to be used in 3D digital documentation and spatial analysis of the Lebanese Citadel and its huge sites (Kabadayı & Erdoğan, 2022; Alptekin et al., 2022). He explained that this combination minimized the time, effort and error rate. Another example is Pane et al. (2020) used advanced laser scanning systems with a combination of different tools to document as accurately as possible the possible damage mechanisms and the complex geometric system of the castle of Pescopagano, which was severely damaged in the 1694 earthquake. In the results, they compared the results of using these techniques together with traditional methods and explained their benefits.

In the literature, there is no study documenting the architectural features of the castle structure in the city of Mardin. The main purpose of this article is to document the ruins of the southern facade of the Mardin castle and the rocky cliffs with architectural drawings. This study is an important study in terms of revealing the architectural facade drawings of Mardin Castle, which is the symbol of the city. The study evaluates the results of the combination of terrestrial laser scanning and photogrammetry to create digital documents of the facades of the Mardin castle. Laser scanning produced point clouds in the vertical direction, while photogrammetry produced planar images. Such tools have proven their effectiveness in scanning huge areas such as castles. Photogrammetry allowed to complement visual data for parts of buildings that were difficult to obtain by laser scanning (Erdoğan et al., 2022). The method presented in the study forces us to consider extending the terrestrial laser scanning method with other tools. This article provides examples of the beneficial use of laser scanning and proposes an extended theory.Mardin Castle; east side 1200 m., west 1180 m. It was built on a flat area on a rocky hill at a height. It is a location built on the upper part of the land on which most of the city rests (Dolapönü ,1961; 1972; Gabriel ,1940; Karataş et al.,2023c; Yakar et al., 2008; Yakar et al., 2009 ; Yılmaz &Yakar, 2016). This area rises from the point where the slope ends, separated by steep cliffs. As far as the topography allows, the castle is entered from the south, from a point almost centered on the area on which the castle is located. This entrance is reached by a steeper ramp and a staircase at the end (Karataş et al., 2023d; 2023e; Oruç & Öztürk, 2021).

2. Method

The study was carried out in two stages. Various field studies were carried out by visiting the building site. Then, the collected data was transformed into data on which architectural drawings can be produced in the office environment.

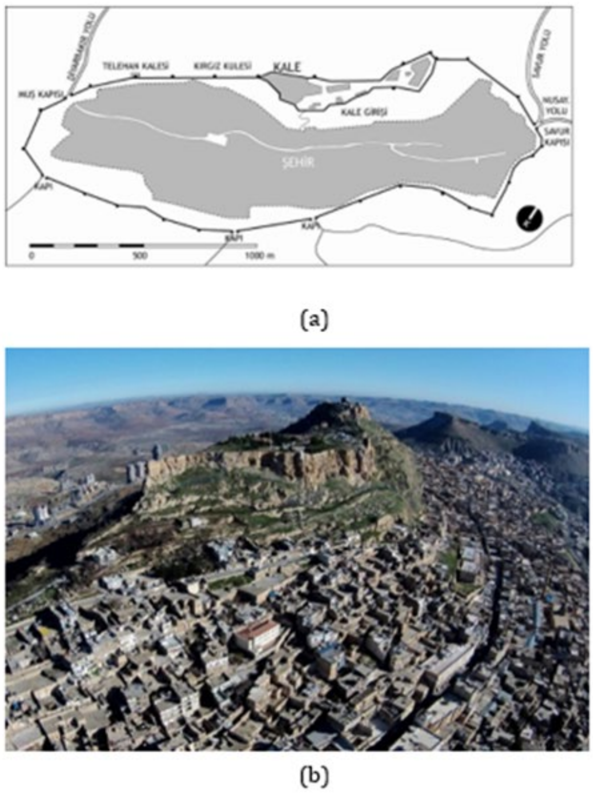


Figure 1. a) Mardin castle site plan sketch b) Aerial view of the castle (Mardin Metropolitan Municipality, 2023)

2.1. Data collection

The fortification wall, which is a cultural heritage of approximately 900 years, and the building remains on it, as well as the rocky formation in the southern cliffs, need to be documented precisely and completely. In this context, it was decided that it would be an effective and correct method to document the cliffs, fortification wall and building remains through the 3D point cloud to be obtained by using the laser scanner (Laser Scanner). The complete scanning of the Mardin Castle's south facade fortification wall remains and the rocky cliffs was carried out in two stages. First, the remains of the city wall and the rocky formation on the southern slope were scanned with a laser scanner and turned into a 3-dimensional point cloud (Figure 2).

In this context; Leica Geosystems brand ScanStation C10 model 3D laser scanner was used for the overall measurement of the building (Figure 3). When the device is examined in terms of general technical features; It can document with wide angle scanning and photography, 360º horizontal X 270º vertical. It also has the features of detailed and precise scanning and photographing of these regions by focusing on the defined partial areas and surfaces. The device can scan 90% reflective surfaces up to a distance of 300m. It is 50k dots/second. The efficient working ambient temperature of the device; It is between 0º C and 40º C. The device cannot operate at temperatures close to, below or above these values. The camera integrated into the device has a resolution of 4 megapixels and has the ability to take up to 260 photos of the scanned area at each station. The photographs taken by the device during scanning were essentially requested to color the scan data and to detail the scanned surface by giving texture. For this purpose, the tool can be used together with the point cloud, but it can also be used externally by transferring it from memory to other computers. Commands and data related to field usage and scanning results of the device can be followed and intervened from the LCD screen on it. There is also the option of connecting the device to an external portable computer during field work. In this way, field scans can be followed simultaneously from the screen on the computer to be connected. There is 80GB of integrated memory space on the device, and the digital data recorded in this memory area in the field is transferred to the Sony Vaio Brand (8GB Ram, Intel i7 processor) portable computer at the end of the day.

Figure 2. Sample photograph of documenting the rocks of the south façade cliff section with a laser scanner (Mardin Metropolitan Municipality, 2023)

Many stations have been set up with laser scanners on the southern slope and upper part of the building. The connection between the stations is provided by introducing at least 2 and 3 common reference points (special manufacturing targets that the device can detect) with the previous station. In this way, a reference network consisting of target points was established throughout the structure. This reference network; Using the Sokkia brand Set 530 RK total station(Figure 3) device, the laser scanner was read simultaneously with the field work, and a coordinate network of the reference points was created. In this way, possible station aggregation or data loss problems in laser scanner data are prevented.

In addition, control and reference measurements regarding certain parts of the building (mosque structure, bastions, certain points of some main pillars, etc.) were taken with the total station device. The limited parts of the building that are too narrow for the laser scanner to work and the references cannot be read were documented using a total station. Remains of buildings, rock formations, caves in the cliff, and fortifications were measured in every situation that allowed measurement. It was tried to enter some sections (dehlis, cistern, etc.) with the help of specially equipped expert mountaineering teams. Detail measurements with rare sections that cannot be read with laser and total station devices; It was measured with a Leica brand, Disto A5 model laser distometer at long distances. Short distances, on the other hand, were measured with a tape measure and recorded on-site and simultaneously. Detailed measurements were taken with tape measure in the architectural elements and the detail drawings were made manually on metric papers in the field. The detail measurements taken were evaluated together with the laser scanner data and the detail drawings of such architectural elements were made in the office environment. Detailed photographic documentation was made in the limited sections where the angle value between the scanner and the surface to be scanned is low. Photographic documentation is used as an aid to supplement laser scanner data.

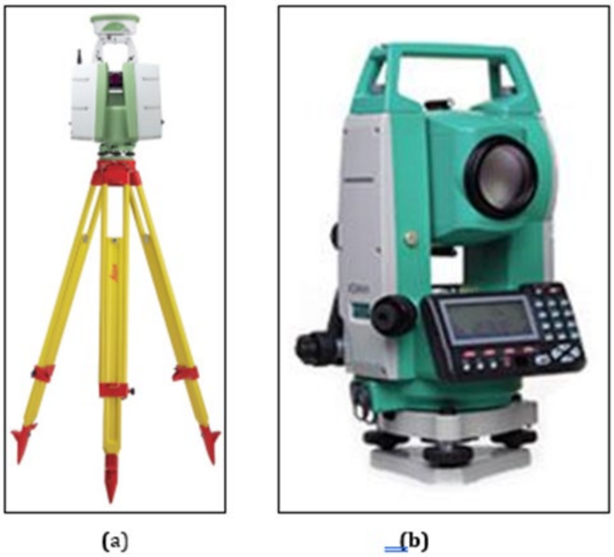


Figure 3. a) Leica ScanStation C10 b) Sokkia Set 530RK

The ruins of the south facade of the Mardin Castle, building remains, the rocky formation on the southern slope, the upper part of the castle and the relations of these ruins with the old city settlement of Mardin and its immediate surroundings were photographed in detail with the method of photographic documentation. During these studies, 2 cameras and tripod legs were used. The first one is Fuji Brand FinePix HS10 model, professional digital camera with 30X optical zoom, panoramic shooting, 10.3 mega pixel resolution. The other is an Olympus SP-550UZ, 7.1 megapixel semi-professional digital camera with 18X optical zoom. Photographs were taken from many different points of view of the building from different angles in order to document all parts of the building in detail and completely. The building components are documented, both in general and in detail.

The entire length of the building is approximately 850 m when viewed from the south side at a right angle. For this reason, it was not possible to fit the building into a single photographic frame. For this reason, panoramic photographs of the building were taken from the old city center of Mardin, and the entire facade was tried to be photographically documented. The photographs obtained from these shots show both the stone elements, joints, etc. on the facade and plan plane of the building. evaluated by using laser scanner data in the documentation of building components. In particular, photographs were taken from the southern façade of the building, from the dominant points of the slope, from the ruins of the castle above the castle, from places such as caves and vaulted galleries. In covered spaces, all the walls, floor and top cover etc. Numerous and detailed photographic documentation has been made from suitable positions to describe its components. In addition, the rock formations on the southern slope were photographed in detail in order to document the rock formations in detail.

In order to use photographs in drawings; Photogrammetric study was carried out by using photo correction method with Photoshop CS4, PhotoPlan 5.0.1.9, and Archicad 6.3 programs. Photogrammetry method and laser scanner data were used together, especially in the drawings of the building sections where the laser scanner data is insufficient and technically impossible to document by the laser scanner. These programs, which are used with the photogrammetry method, can correct the optical deformations caused by the camera as well as the measurement changes caused by the depth (Alptekin et al., 2019; Kabadayı & Uysal, 2019; Karabacak & Yakar, 2022; Karataş et al.,2022; Kaya et al., 2021; Şenol et al., 2017; Şenol et al., 2020; Ulvi & Yiğit, 2022; Ulvi et al., 2015).

2.2. Processing of Data

Major licensed software used with the Leica ScanStation C10 laser scanner; Leica Cyclone 7.1. with Leica Cloudworx 4.1.2. are programs. The laser scanner performed scanning with the Cyclone Scan module integrated in the device. By using the Cyclone ViewerPro module, scanning data could be followed in 3D from the screen on the device or the portable computer screen connected to the device during field work.

Using the Cyclone Model Space module, excess or unnecessary scans (environmental factors that entered the scan outside the main structure) were cleaned from the raw data transferred to the computer to be processed.

By adjusting the coordinates of the drawings, the scan data has been transformed into an easily operable form. The data of different stations, which were made ready to be processed with the Cyclone Model Space module, were automatically combined by the software according to the stations and reference points using the Cyclone Register module. At this stage, the station data, which cannot be combined for any reason, can also be

combined with the total station device, using the coordinate map of the reference points obtained simultaneously with the laser scanner in the field, integrated with the Cyclone Register module. The location, sequence, dates, etc. of the stations that were recorded in the field book during the station combinations. Notes were also used for control and providing purposes.

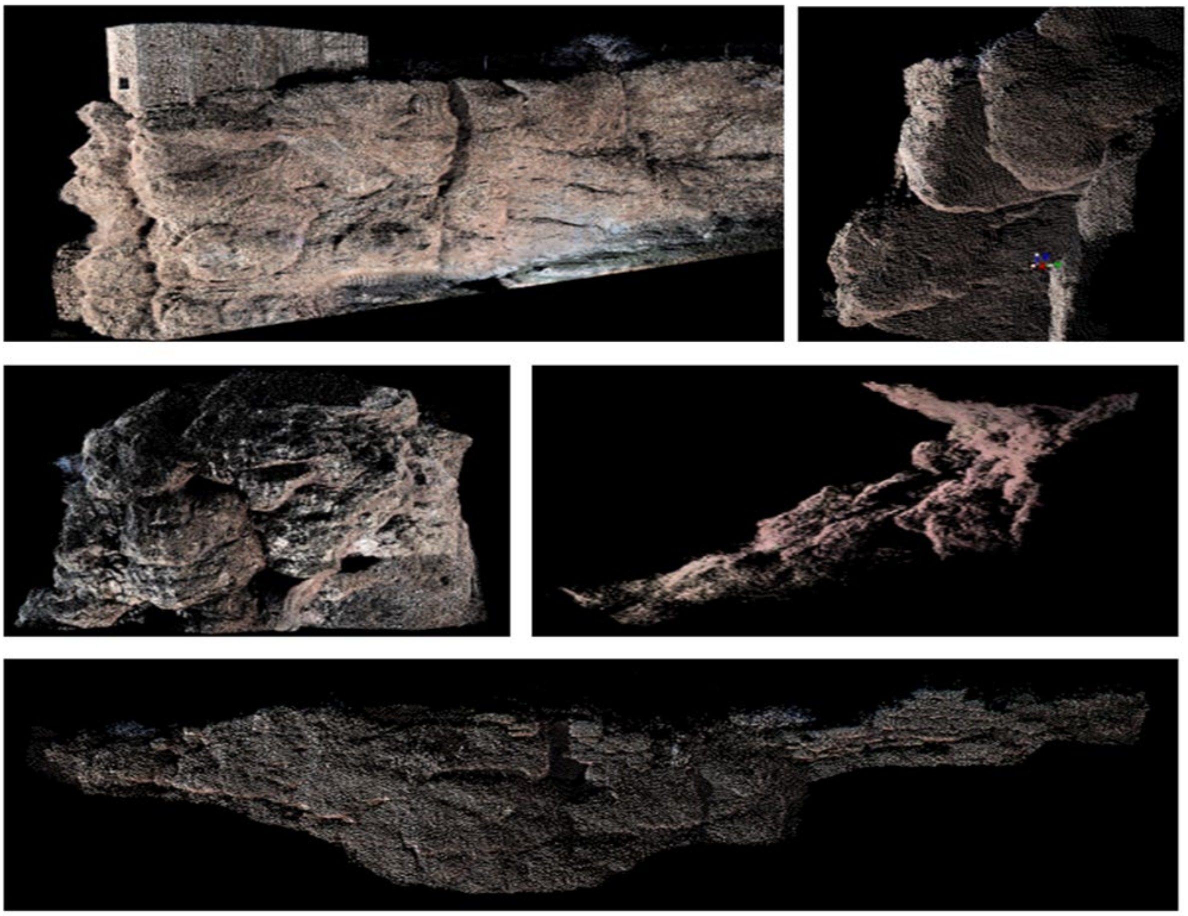


Figure 4. Examples of 3D point cloud images obtained by scanning the castle with a laser scanner (Mardin Metropolitan Municipality, 2023)

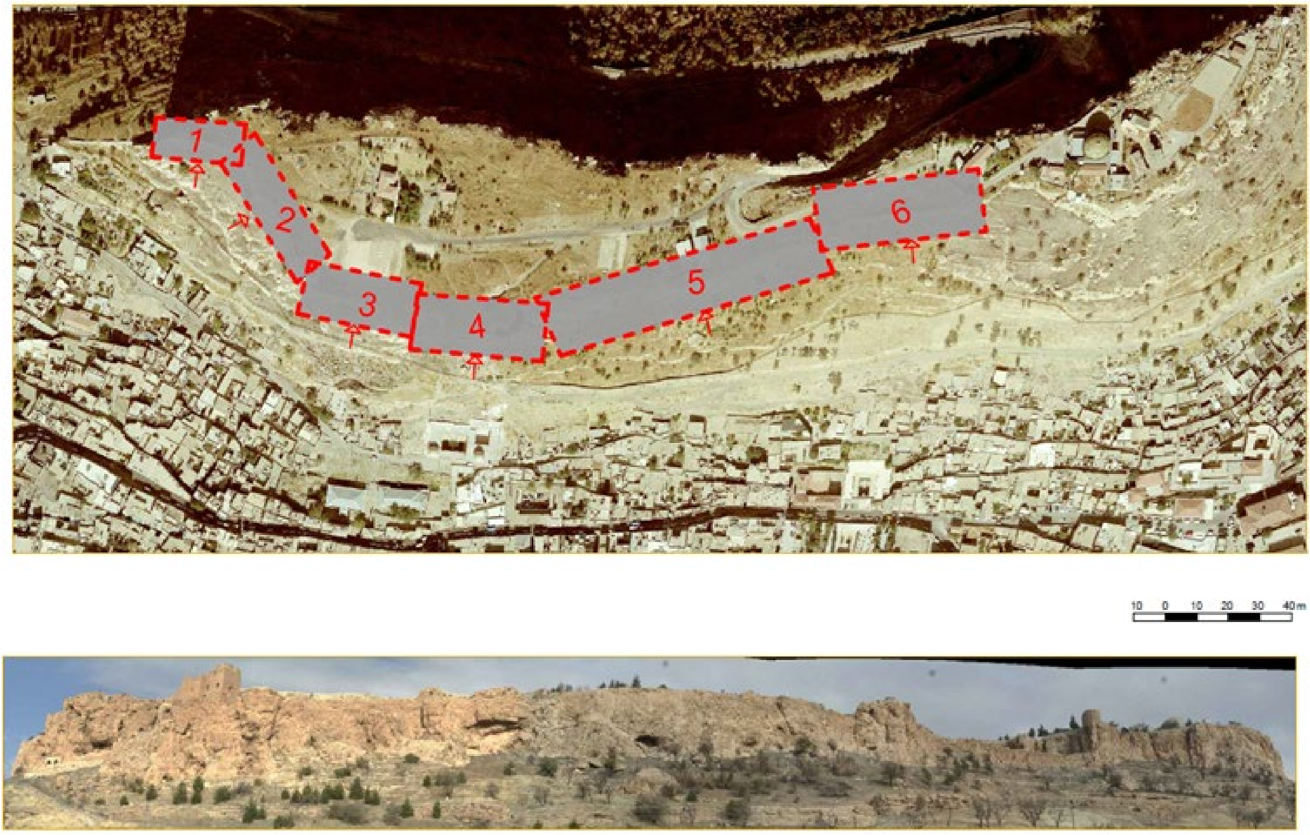


Figure 5. Layout plan (Key Plan) showing the drawing directions of Mardin Castle (Mardin Metropolitan Municipality, 2023)

The scan data prepared with the Cyclone software and its sub-modules are sent to the B.D.T.P. (Computer Aided Design Program) has been made viewable so that drawing can be made on it. At this stage, B.D.T.P. General and detailed drawings of the structure were made through the point clouds of the main structure opened in the environment (Figure 4). By using the 3D point cloud that can be viewed with the Cloudworx software, a facade or detail image can be taken on the desired axis on the building. B.D.T. Facade drawings of the building were made using software programs.

Ortho-images were obtained with Cyclone software, especially for the drawings of the southern cliff rock blocks, masonry texture, profiles, and knitting joints. The detailed drawings of the building and the individual drawings of the rock blocks could be made through the orthographic photographs obtained at a one-to-one scale. Orthographic photographs have the feature o being colorless or in the original colors of the object. The detail drawings of the rock blocks were made using orthographic photographs (in tif format). In order to obtain these ortho-photos used in the drawings, a right angle viewpoint was determined across each rock block and view drawings were obtained with a perpendicular viewpoint. The drawings of the rock blocks were prepared on these ortho-photos and they were made into a map.

In the drawings of the plans and façades, the lower level of the keystone of the arch on the western side of the mass, which consists of two arched structures at the top of the stairs leading to the castle and located near the lower western part of the cliffs, is defined as ±0.00 m elevation in the project. The other levels of the building were calculated with reference to this level and were processed in the drawings. Stone, ornament etc. measured by hand or laser distometer. The detail drawings of the elements were reflected to the drawings with their exact measurements. With the standard coatings, changes and deteriorations are expressed with the scanning command and graphic presentation techniques. For architectural elements, the drawingsmade on paper with a profile comb were scanned with the HP brand Photosmart C3180 scanner, and then the B.D.T. program and adapted to the required scale by drawing on it. The building sections that were measured with the total station were measured with the help of TachyCAD 5.0.0 program on laptop computers connected to the total station device. The rough drawings of the measured sections were created in the field, by controlling the measured points on-site and simultaneously. After the rough drawings were created during the land measurements using the TachyCAD 5.0.0 plugin, the measured drawings were prepared with personal computers using computer aided design programs. The excess lines formed in the rough drawings made in the area were deleted, and the manual measurements and drawings of the architectural elements were added. Drawings are rearranged in a layer system where pen thicknesses are adjusted.

The castle fortification is basically a masonry structure that continues in the east-west direction, with different amounts of remains and directions. In addition, the fortification wall structure creates very different angles in the east-west foundation direction. In this framework, it was not possible to transfer the castle wall structure to the architectural drawing with a single point of view to be determined. For this reason, 6 viewing directions have been determined, where the castle wall can be seen in as large parts as possible with a right angle. With these points of view, the photographs of the castle walls were converted into drawings by looking at them. The remains of the walls, which, although viewed from 6 viewing directions, are perpendicular to these directions of view or at angles that would not be suitable for drawing details, were drawn by looking at the wall remains from the determined cross-section points. Existing in the upper structure of the fortress, the military-purposed interior and its annexes, vehicle roads, paths, helipad, cistern, etc. units were tried to be expressed in the details required by the possible scale on the facades with the site plan and plans (Figure 5).

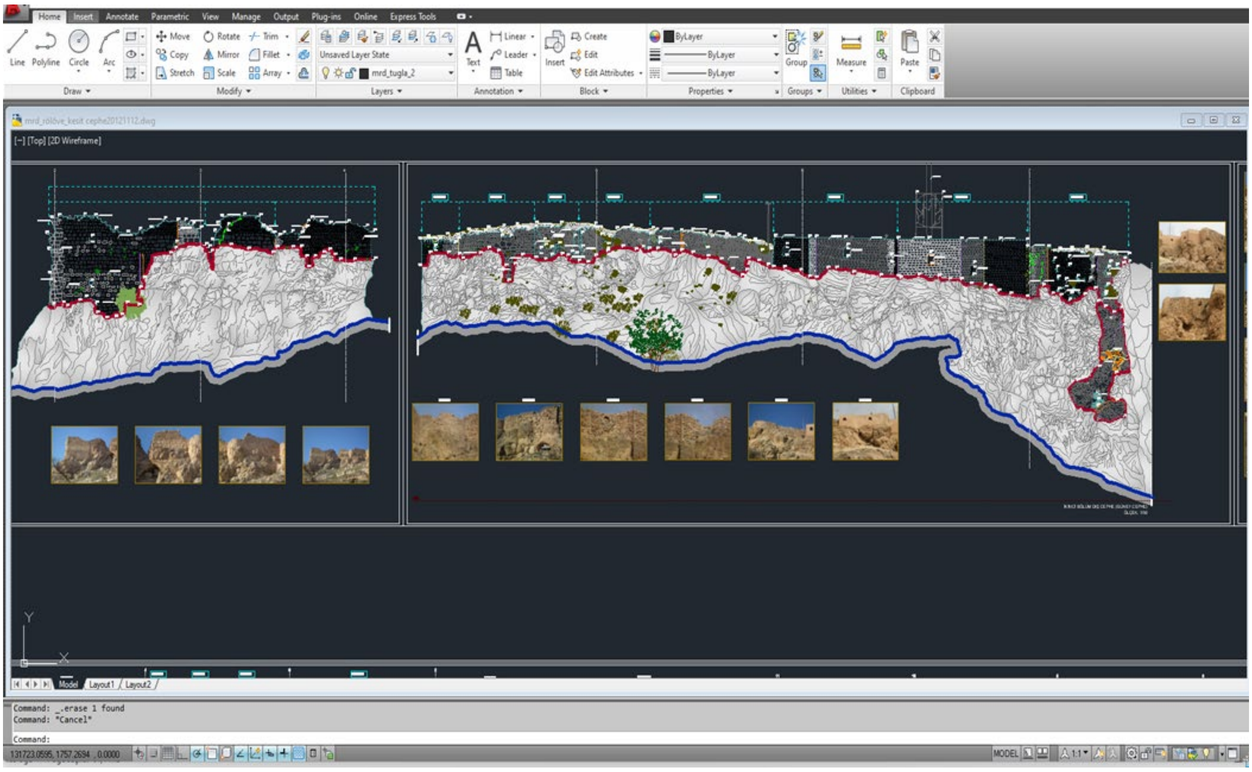


Figure 6. Visual example from photogrammetric documentation made in Autocad (Mardin Metropolitan Municipality, 2023).

3. Findings

Within the scope of the study, 6 points of view from which the castle wall can be seen in as large parts as possible at right angles have been determined, and these aspects have been transformed into architectural drawings. The image given below is a diagram that explains what the colors specified in architectural drawings mean. All architectural drawings are interpreted according to the colors defined in this legend (Figure 6).

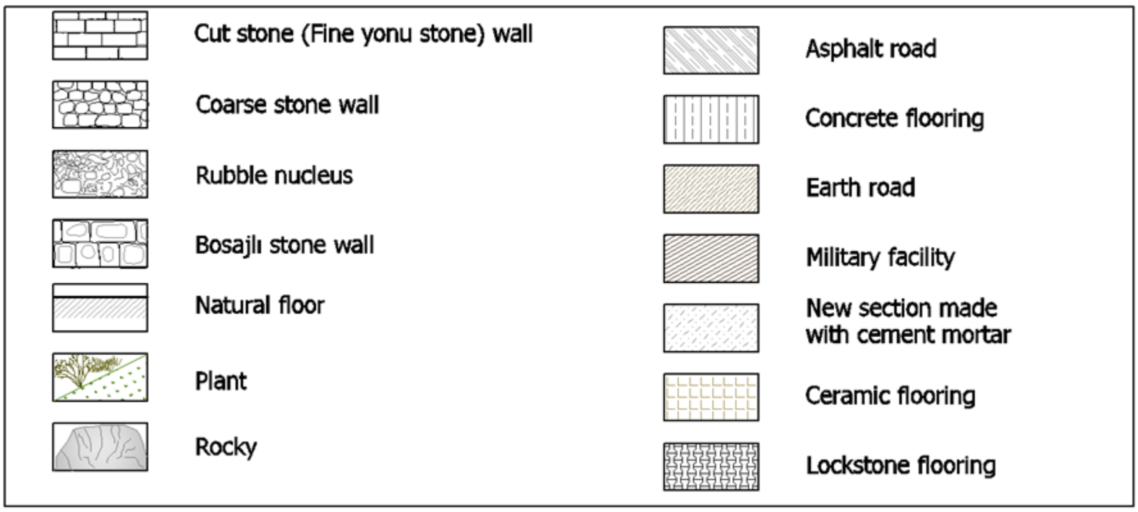


Figure 7. The defined chart of the facade surveys

3.1. First Part Facade

Surveys In the part that corresponds to the first section of the castle, at the western end of the wall line and extending in the south-north direction, the rough cut stone masonry is seen with a bossage at the bottom and five rows on the top. In the continuation of the wall in question extending to the north, breaks are made in accordance with the rock formations. At the bottom, there is a fragment of rough-cut stone masonry, in which regular cut stone blocks are used from time to time. At the top there is a rough-hewn masonry consisting of rows of smaller stones (Figure 8).

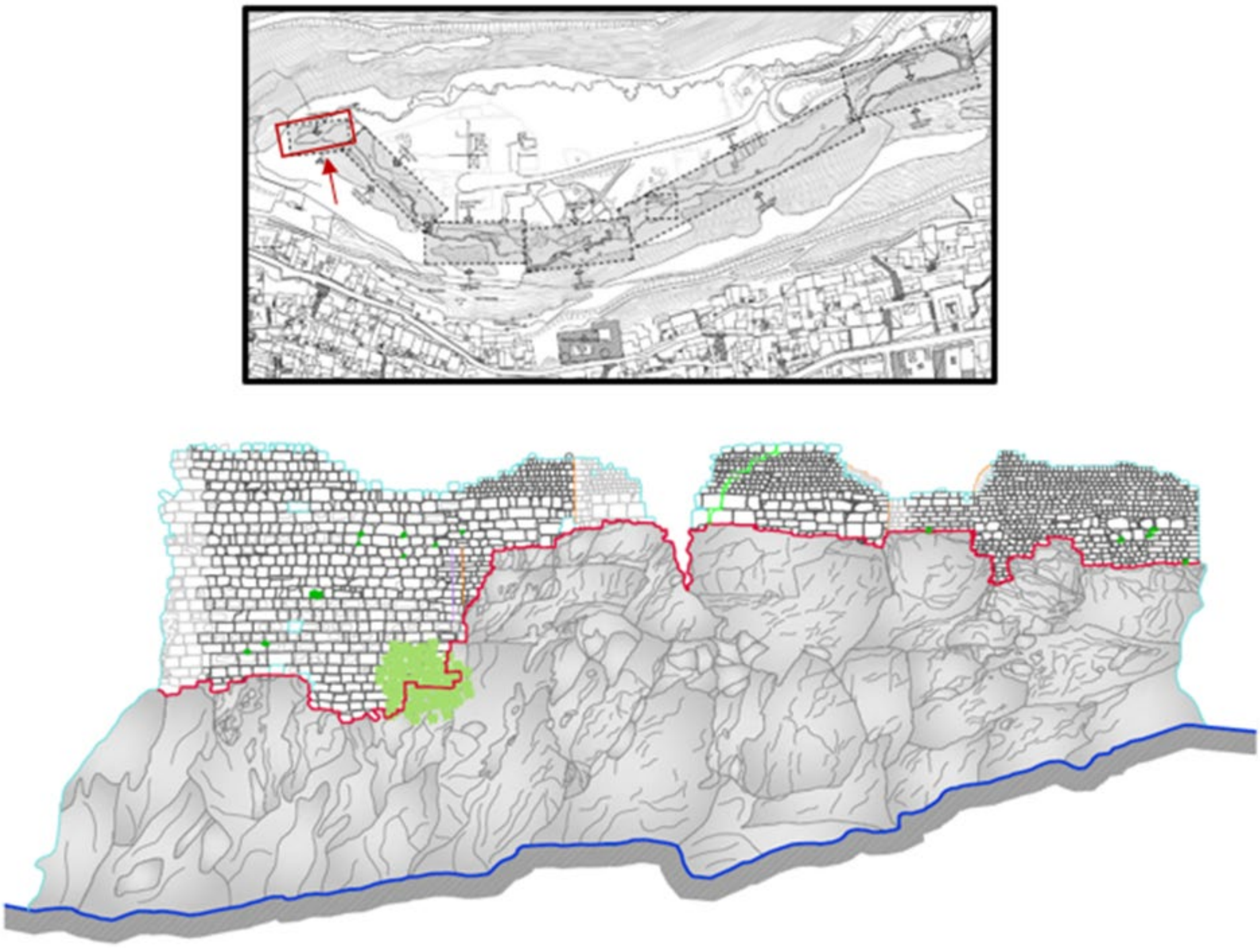


Figure 8. Analytical drawing expressing the south façade view of the first part of the castle (Mardin Metropolitan Municipality, 2023)

3.2. Second Part Facade Surveys

The part of the wall (section 2), which starts from the northern corner and extends to the east with a right-angle break, contains some details that give information about its original condition, although it has been largely destroyed over time. In this context, there is no doubt that the semi-circular shaped ashlar remains in the north corner of the city wall, where it made a right-angle break and which was later added to the wall extending in the south-north direction, belonged to a tower that was once placed in this corner. In the continuation of the wall line extending towards the east, the semi-circular remains of regular cut stone masonry, which apparently were later articulated, on the middle part of the wall resting on the rock formation protruding towards the south, and an in-situ circular slot on the south-facing façade are seen (Figure 9).

3.3. Third section facade surveys

After this point, it can be observed that the wall line extends towards the east by making various breaks in the form of a coarse stone masonry wall following the existing rock formations. However, the upper parts of the wall were raised as a result of major repairs, which were understood to have been made recently, and lost their original state (Figure 10).

3.4. Fourth section facade surveys

Today, it can be said that the building, which is located at the end of the third section and consists of a ruin, served as a bastion with a rectangular plan, protecting the gate no. The part of the wall that extends to the east by passing the İçkale gate from the top, makes a right-angle turn as a wall of neat cut stone, following the rock that extends to the south by making a nose at this point, and breaks again at the point where the rock ends and extends towards the east as a monumental facade design. It is noteworthy that the wall in question turned into a qibla façade of a 14-15th century religious and social structure, also known as the Kale Mosque, located in this part of İçkale (Figure 11).

3.5. Fifth section facade surveys

The part of the wall, which broke to the north following the qibla wall of the Kale Mosque, turned to the east again on the rock formations in this section and extended in various fractures, although it was largely destroyed, with its coarse stone masonry, it is a part of the Artuqid Age (2nd Period). describes the product. Although it is understood that the vertical rectangular window openings with hewn stone frames, which can be seen in the middle sections of the wall in question, are related to the internally articulated structures at this point of the wall, it is not possible to determine their functions today as they are completely underground (Figure 12).

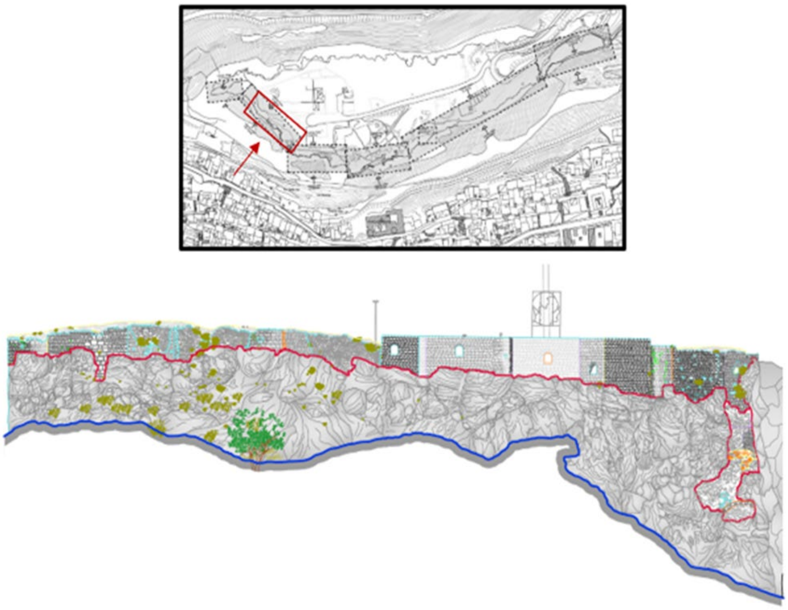


Figure 9. Analytical drawing expressing the south façade view of the second part of the castle (Mardin Metropolitan Municipality, 2023)

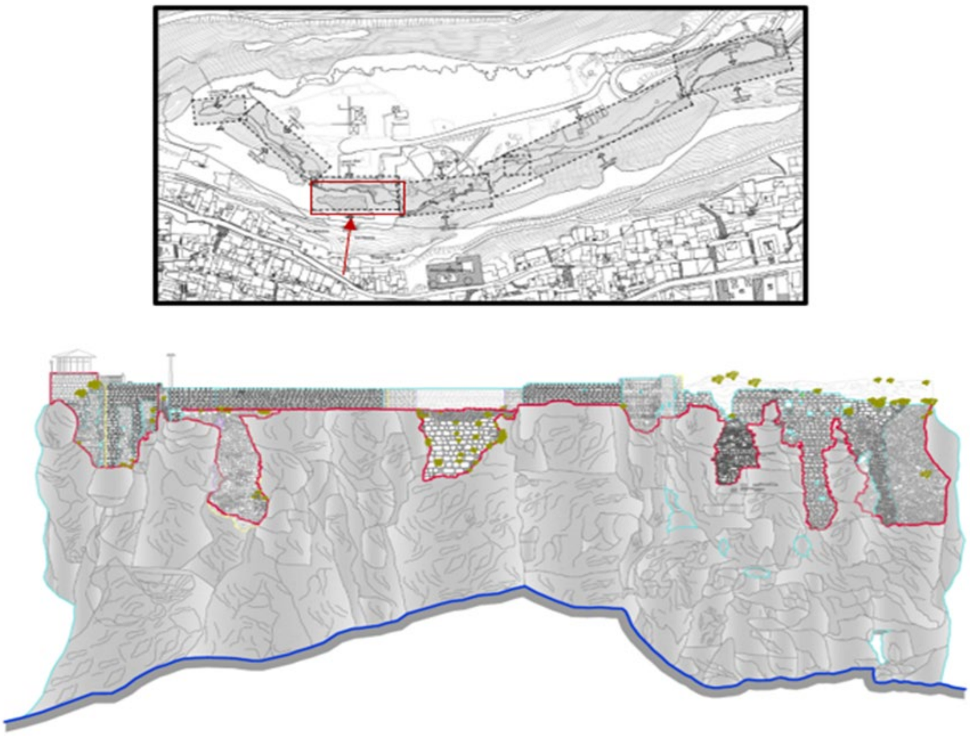


Figure 10. Analytical drawing expressing the southern facade of the third part of the castle (Mardin Metropolitan Municipality, 2023)

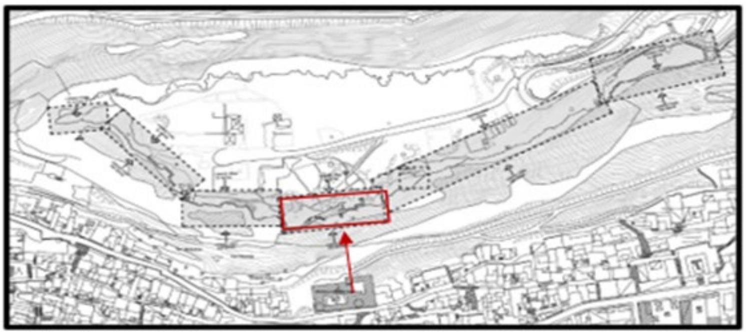
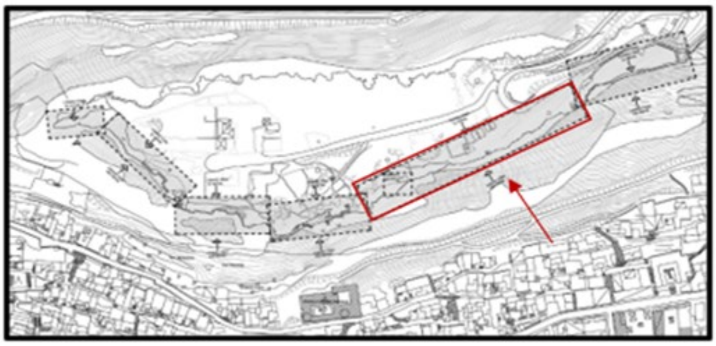


Figure 11. Analytical drawing expressing the southern facade of the fourth section of the castle (Mardin Metropolitan Municipality, 2023)



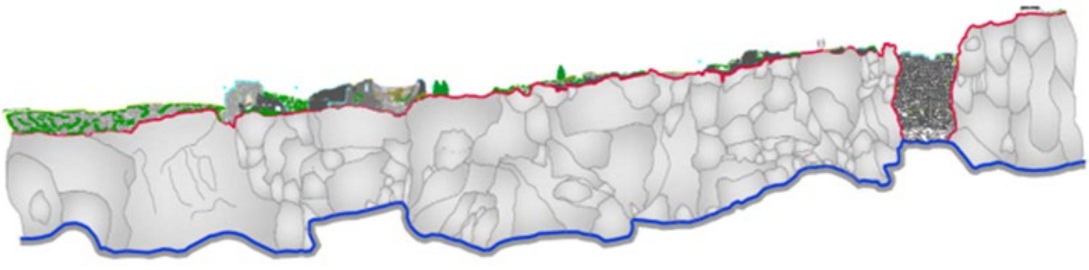


Figure 12. Analytical drawing expressing the southern facade of the fifth section of the castle (Mardin Metropolitan Municipality, 2023)

6. Sixth section facade surveys

The walls forming the next part of the wall have almost completely disappeared and can only be partially traced as foundation walls on the west wing. It can be accepted that the block with smooth cut stone pavement in this section is a product of the Ottoman era in order to reinforce the destroyed places. On the other hand, there are rough-cut stone masonry wall extending in a continuous line between the two ends of the rock formations forming a crescent-shaped recess in this section, and remains at the western end of the wall, possibly belonging to a square bastion. It is understood that the wall behind the wall line and on which imitation dendans were added was added recently (Figure 13).

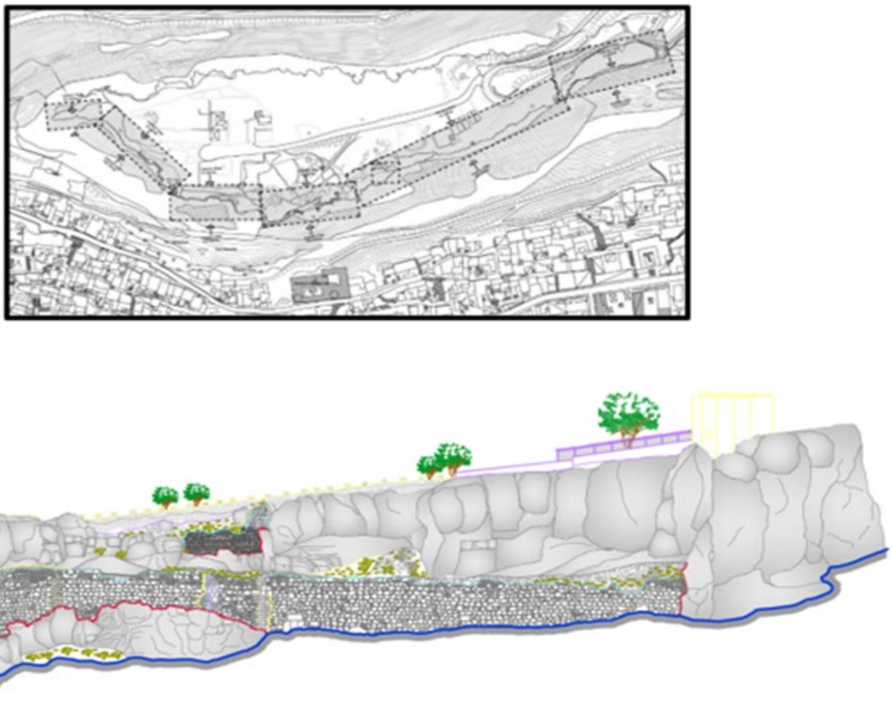


Figure 13. Analytical drawing expressing the southern facade of the sixth section of the castle (Mardin Metropolitan Municipality, 2023)

4. Discussion

The main purpose of this article is to document the ruins of the southern facade of the Mardin castle and the rocky cliffs with architectural drawings. For this purpose, it has combined different analytical and investigation techniques such as terrestrial laser scanning, photogrammetry and observational analysis.

In the study findings, facade surveys of the facade of the castle were obtained. Thanks to the point clouds obtained from laser scanning in the study, the data that will be the base for the facade, plan and section drawings required for the relief plans can be obtained through the images that can be created with various software. In the study, analytical reliefs obtained from the point clouds obtained by the laser scanning method could be easily obtained. et al., 2010;Comert et al.,2012; Gabriele et al., 2010).

In addition, the desired data could be created in a very short time with the presented method. It has been observed that the use of laser scanning method instead of traditional methods in documentation studies reduces the time needed for field studies by 75% and the time needed for drawing operations by 25%. The results of the study confirm the studies in the literature, which argue that methods such as terrestrial laser scanning technology save a great deal of time and effort in the documentation of huge structures such as castles (Alptekin & Yakar; 2021; Jo & Hong,2019; Yakar et al.,2010;2014; Yakar ,2015; Kanun et al.,2021; Larsson et al.,2006; Pane et al.,2020; Schulz & Ingesand,2004; Ulvi & Yakar, 2014; Yakar et al.2015; Yiğit & Uysal,2019;Karataş & Menteşe, 2022; Yilmaz et al. 2008; Yilmaz & Yakar, 2006; Lerones et al., 2010).

5. Conclusion

The preservation and development of ruined castles and fortresses in historical cities represents a great challenge in the field of cultural heritage today. In-depth knowledge of buildings with a multidisciplinary approach constitutes an inevitable task for any harmonious reuse project of this type of property. In the case of Mardin castle, an effective combination of all the most advanced methods for digital research of architecture, such as photogrammetry and laser scanning, was tested. These techniques will express their maximum potential when they intersect with historical analysis, static analysis, and other direct and indirect research methods of the fortress. It is suggested that the historical castle can be included in a continuous maintenance monitoring process in future studies. By using the data we obtained as a base, all 3D data, drawings, historical analyzes etc. Establishing a holistic tracking system for the building by embedding it in the HBIM environment is important for the protection of the building.

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Author contributions

The work has a single author.

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

References

Alptekin, A. & Yakar, M. (2021). 3D model of Üçayak Ruins obtained from point clouds. *Mersin Photogrammetry Journal*, 3 (2), 37-40.

Alptekin, A. & Yakar, M. (2021). Lazer Tarayıcının Jeolojik Olayların Modellenmesinde Kullanımı. *Türkiye Lidar Dergisi, 3*(2), 71-75. DOI: 10.51946/melid.1018197

Alptekin, A., Çelik, M. Ö. & Yakar, M. (2019). Anıtmezarın yersel lazer tarayıcı kullanarak 3B modellenmesi. *Türkiye Lidar Dergisi*, 1(1), 1-4.

Alptekin, A., Çelik, M. Ö., Doğan, Y. & Yakar, M. (2022, February). Illustrating of a landslide site with photogrammetric and LIDAR methods. In Research Developments in Geotechnics, Geo-Informatics and Remote Sensing: Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019 (pp. 303-305). Cham: *Springer International Publishing*.

Alptekin, A., Fidan, Ş., Karabacak, A., Çelik, M. Ö. & Yakar, M. (2019). Üçayak Örenyeri'nin yersel lazer tarayıcı kullanılarak modellenmesi. *Türkiye Lidar Dergisi*, 1(1), 16-20.

Ay, B. Ö. (2018). The effects of ımplementing different ground-motion logic-tree frameworks on seismic risk assessment. *16th European Conference on Earthquake Engineering*.

Balzani, M. A., Pellegrinelli, N., Perfetti, N., Uccelli. (2001). A terrestrial 3D laser scanner: Accuracy tests. *Photogrammetry Remote Sensing*, 18, 445-453.

Comert, R., Avdan, U., Tün, M. & Ersoy, M. (2012). Mimari belgelemede yersel lazer tarama yönteminin uygulanması (Seyitgazi Askerlik Şubesi Örneği). *Harita Teknolojileri Elektronik Dergisi*, 4. 1-18.

Dolapönü, M. H. (1961). Deyr-El-Umur (Mar Gabriel) Tarihi, Mardin.

Dolapönü, M. H. (1972). Tarihte Mardin (Itr-El-Nardin fi Tarih Merdin), İstanbul.

Erdoğan, A., Görken, M. & Kabadayı, A. (2022). Study on the use of unmanned aerial vehicles in open mine sites: A case study of Ordu Province Mine Site. *Advanced UAV*, *2*(2), 35-40.

Fröhlich, C. & Mettenlaiter, M. (2004). Terrestrial Laser Scanning- New Perspectives 3D Surveying, *ISPRS xx. Symposium*, 12-23 July 2004, İstanbul.

Gabriel, A. (1940). Voyages archéologiques dans la Turquie orientale/2 Planches. *Voyages archéologiques dans la Turquie orientale*.

Gabriele, G., Danilo, G. & Marco, B. (2010). The Employment of Terrestrial Laser Scanner in Cultural heritage conservation: The case study of Vallinotto Chapel in Carignano-Italy. *Applied Geomatics*, 2(2), 59-63.

Georgopoulos, A., Tsakiri, M., Ioannidis, C. & Kakli, A. (2004). Large scale orthophotography using DTM from terrestrial laser scanning. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 35.

Grussenmeyer, P., Landes, T., Voegle, T. & Rongle, K. (2008). Comparison methods of terrestrial laser scanning, photogrammetry and tachometry data for recording of cultural heritage buildings. *Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* 37 (B5), 213-218.

Guldur, B., Yan, Y. & Hajjar, J. F. (2015). Condition assessment of bridges using terrestrial laser scanners. *Structures congress 2015- proceedings of the 2015 Structures Congress*, 355-366.

Jo, Y. H. & Hong, S. (2019). Geo-Inf., 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).

Kabaday, A. & Erdoğan, A. (2022). Application of terrestrial photogrammetry method in cultural heritage studies: A case study of Seyfeddin Karasungur. *Mersin Photogrammetry Journal*, *4*(2), 62-67.

Kabadayı, A., & Uysal, M. (2019). İnsansiz Hava Araci ile Elde Edilen Verilerden Binalarin Tespiti. Türkiye *İnsansız Hava Araçları Dergisi,* 1(1), 8-14.

Kanun, E., Metin, A. & Yakar, M. (2021). Yersel Lazer Tarama Tekniği Kullanarak Ağzıkara Han'ın 3 Boyutlu Nokta Bulutunun Elde Edilmesi. *Türkiye Lidar Dergisi,* 3 (2), 58-64.

Karabacak, A. & Yakar, M. (2022). Giyilebilir Mobil LİDAR Kullanım Alanları ve Cambazlı Kilisesinin 3B Modellemesi. Türkiye Lidar Dergisi, 4 (2), 37-52. DOI: 10.51946/melid.1146383

Karataş, L. & Menteşe, D. H. (2022). Dara Antik Kenti (Anastasiopolis) nekropol alanının malzeme sorunlarının fotogrametrik yöntemlerle belgelenmesi. *Türkiye Fotogrametri Dergisi*, 4(2), 41-50

Karataş, L., Alptekin, A. & Yakar, M. (2022). Creating Architectural Surveys of Traditional Buildings with the Help of Terrestrial Laser Scanning Method (TLS) and Orthophotos: Historical Diyarbakır Sur Mansion. *Advanced LiDAR*, 2(2), 54–63.

Karataş, L., Alptekin, A., Yakar, M. & Dal, M. (2023). Assessment of structural problems in Mardin Castle. *Advanced Engineering Days*, 6, 9-13.

Karataş, L., Alptekin, A., Yakar, M. & Dal, M. (2023). Evaluation of conservation and restoration works in protected areas: A case study of Mardin Castle. *Advanced Engineering Days*, 6, 14-17.

Karataş, L., Alptekin, A., Yakar, M. & Dal, M. (2023). Investigation of the historical process of the Mardin Castle. *Advanced Engineering Days*, 6, 1-4.

Karataş, L., Alptekin, A., Yakar, M. & Dal, M. (2023). Mardin Castle building material and construction technique analysis. *Advanced Engineering Days*, 6, 5-8.

Karataş, L., Alptekin, A., Yakar, M. & Dal, M. (2023). Mardin Castle landscaping and landscape interventions proposal. *Advanced Engineering Days*, 6, 18-21.

Karataş, L., Ateş, T., Alptekin, A., Dal, M. & Yakar, M. (2023). A systematic method for post-earthquake damage assessment: Case study of the Antep

Castle, Türkiye. *Advanced Engineering Science*, 3, 62-71

Kaya, Y., Yiğit, A. Y., Ulvi, A., & Yakar, M. (2021). Arkeolojik alanların dokümantasyonununda fotogrametrik tekniklerinin doğruluklarının karşılaştırmalı analizi: Konya Yunuslar Örneği. *Harita Dergisi,* 165, 57-72.

Larsson, S. & Kjellander, R. (2006). Motion control and data capturing for laser scanning with an industrial robot. *Auton Systems*, 54(6), 453-460 (2006).

Lerones, P. M., Fernandez, J. L., Gil, A. M., Gomez-Garcia-Bermejo, Casanova, E. Z. (2010). A practical approach to making accurate 3d layouts of ınteresting cultural heritage sites through digital models, *Journal of Cultural Heritage*, 11(1), 1-9.

Mardin Büyükşehir Belediyesi Kudeb arşivi (2023), Mardin.

Naanouh, Y. & Stanislava, V. (2021). Digital documentation and a 3-d model of beaufort castle via rtk gnss, terrestrial laser scanner and uas-based photogrammetry. *In E3S Web of Conferences*, 310, 05002.

Orhan, O. (2018). Determining potential sinkhole areas using remote sensing and geographic information systems. Doctoral Thesis, Selçuk University, *Institute of Science*, Konya, 182p (in Turkish).

Oruç, M. E. & Baş, G. (2021). Kompleks Yapı ve Alanlarda Yersel Lazer Tarama Teknolojisinin Kullanımı. *Türkiye Lidar Dergisi*, 3(2), 39-47.

Oruç, M. E. & Öztürk, İ. L. (2021). Usability of Terrestrial Laser Technique in Forest Management Planning. *Türkiye Lidar Dergisi*, 3(1), 17-24.

Pane, A., Catuogno, R., Facchini, M., Morano, L. (2020). A fortress between artıfice and nature: the laser scannıng survey of the castle of pescopagano as an ınstrument of knowledge, conservatıon and enhancement. *International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences*, (1), 405-412.

Schulz, T. & Ingesand, H (2004). Terrestrial laser scanning-ınvestigations and applications for high precision scanning. *FIG Working Week*, Athens.

Şenol, H. I., Erdogan, S., Onal, M., Ulukavak, M., Memduhoglu, A., Mutlu, S., ... & Yilmaz, M. (2017). 3D Modeling of A Bazaar in Ancient Harran City Using Laser Scanning Technique. International Archives of The Photogrammetry, *Remote Sensing & Spatial Information Sciences*, 42.

Şenol, H. İ., Memduhoglu, A. & Ulukavak, M. (2020). Multi instrumental documentation and 3D modelling of an archaeological site: a case study in Kizilkoyun Necropolis Area. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 11(3), 1241-1250.

Ulvi, A. & Yakar, M. (2014). Yersel lazer tarama tekniği kullanarak kızkalesi'nin nokta bulutunun elde edilmesi ve lazer tarama noktalarının hassasiyet araştırması. *Harita Teknolojileri Elektronik Dergisi*, 6 (1), 25-36.

Ulvi, A. & Yiğit, A. Y. (2022). Comparison of the Wearable Mobile Laser Scanner (WMLS) with Other Point Cloud Data Collection Methods in Cultural Heritage: A Case Study of Diokaisareia. *ACM Journal on Computing and Cultural Heritage*, 15(4), 1-19.

Ulvi, A., Yakar, M., Toprak, A. S. & Mutluoglu, O. (2015). Laser Scanning and Photogrammetric Evaluation of Uzuncaburç Monumental Entrance. *International Journal of Applied Mathematics Electronics And Computers,* 3 (1), 32-36. DOI: 10.18100/İjamec.41690

Yakar, M. & Omar, M. (2016). Yersel fotogrametrik yöntem ile ibadethanelerin modellenmesi. Selçuk *Teknik Online Dergisi*, 15(), 2-20162.

Yakar, M. (2015). Laser scanning and photogrammetric evaluation of uzuncaburç monumental entrance. *International Journal of Applied Mathematics, Electronics and Computers*. 3.

Yakar, M., Ulvi, A. & Toprak, A. S. (2015). The problems and solution offers, faced during the 3d modeling process of sekiliyurt underground shelters with terrestrial laser scanning method. *International Journal of Environment and Geoinformatics*, 2(2), 39-45.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2008). Lazer Tarama Teknolojisi ve Fotogrametrik Yöntem ile Hacim Hesabı. *TÜBİTAK*, Proje No: 105M179, 90s.

Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2009). Comparative Evaluation of Excavation Volume by Terrestrial Laser Scanner and Total Topographic Station Based Methods. *Lasers in Engineering*, 19(5), 331.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2010). Comparative evaluation of excavation volume by TLS and total topographic station-based methods. *Lasers in Engineering*, 19, 331-345.

Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2014). Performance of photogrammetric and terrestrial laser scanning methods in volume computing of excavtion and filling areas. *Arabian Journal for Science and Engineering*, 39(1), 387-394.

Yiğit, A. & Uysal, M. (2019). Afet yönetiminde uzaktan algilamanin kullanimi. *İdRc 2019 İnternational Disaster & Resilience Congress*, 26-28 June.

Yılmaz, H. & Yakar, M. (2016). LiDAR (Light Detection and Ranging) Tarama Sistemi. *Yapı Teknolojileri Elektronik Dergisi*, 2 (2), 23-33.

Yılmaz, H. M. & Yakar, M. (2006). Yersel Lazer tarama teknolojisi. *Yapı Teknolojileri Elektronik Dergisi*, (2), 43-48

Yilmaz, H. M., Yakar, M. & Yildiz, F. (2008). Digital photogrammetry in obtaining of 3D model data of irregular small objects. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 37, 125-130.

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Analysis of 3D Laser Scanning Data of Farabi Mosque Using Various Softwaren

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Abstract

Three-dimensional laser scanners, which offer an alternative solution to traditional measurement methods, have enabled geomatics engineers to have much higher confidence in the accuracy of their measurements. When high-resolution data used in many different measurement applications, including 2D and 3D drawings, calculations such as area and volume calculations, and topographic measurements are evaluated, it is understood that the resolution and efficiency provided by traditional measurement methods are far inferior. Obtaining data about objects and gaining information about objects by evaluating this data in a computer environment, obtaining 3D images of objects one-to-one is an important issue today. As a result of the development of computer technology and laser scanning systems over time, Terresterial Laser Scanners (TLS) have rapidly begun to be used today. With the TLSs, the 3D geometric and visual information of objects can be obtained accurately, quickly, one-to-one and at low cost. In this study, the 3D model of the exterior of Farabi Mosque located on the Farabi campus of Bülent Ecevit University was obtained and evaluated in different softwares. After a successful merging of the data model, due to the limited functions of Faro Scene 2019 software, area calculation, mesh creation, and volume calculation operations were performed on the cloud data using Autodesk Recap 2020 V6.0, Gexcel Reconstructor 2020 V4.2.0, and Meshlab 2020.07 software, and operations were carried out on cloud data that looks close to reality.

1. Introduction

Terrestrial laser scanning is a new technology developed since the early 2000s (Mirdan, 2018) for precise and accurate distance and angle measurements in geomatics engineering applications. Terrestrial laser scanning (TLS) provides a representation by acquiring millions of three-dimensional data very quickly and integrating it with object images. TLS is achieved with mm accuracy by using laser shots at a distance of hundreds of meters to determine the distance to the object points and the three-dimensional (3D) position of the points (x, y, z). One of the key advantages of the TLS method is that it provides a more realistic representation of objects than other measurment imaging techniques.

Recent developments in terrestrial laser scanners have led to a wide range of applications, and these are increasing day by day (Akarsu an Nazari, 2020). Terrestrial laser scanners have been rapidly evolving as an effective measuring technology for 3D modeling, competing or alternative to existing systems (Yılmaz 2006). The generation of a three-dimensional (3D) model is generally achieved by non-contact systems based on light waves and can be completed on a computer (Yakar, 2010) The capability of the TLS has been extended to the spectral domain with the research-led development of omnidirectional and even hyperspectral lidar instruments (Danson et al. 2014). Increasingly used in a variety of applications by different disciplines, the terrestrial laser scanners are used in geomatics engineering, such as tunnels, mining, deformation

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measurements, urban modeling, restoration and surveying, archaeology, transportation and infrastructure, topography, mining, civil works surveying, architectural and industrial design, medical imaging and monitoring. Laser scanning is especially good for complex surfaces, surface analysis and visualization (Korumaz 2010; Alptekin & Yakar, 2021; Alptekin et al., 2022; Karabacak &Yakar, 2022; Kaya et all., 2021; Şenol et al., 2020) for this reason laser scanning technology is widely used in many professions (Kanun 2021) Obtained 3D data can be a resource for many professional disciplines in order to come up with solutions to problems that may occur in the future. (Şasi 2017; Şenol et al., 2017)

In TLS surveys, it is necessary to learn a lot of technical information in order to determine a strategy. Before scanning, if the object is a building, it is important to position the scanner device according to the technical specifications of the scanner and to place the target marks at the appropriate points in order to obtain best quality 3D data.

2. Method

Technological developments in recent years have brought the use of laser scanning measuring systems more prevalent. Although terrestrial laser scanning has some disadvantages, it has important advantages (Ulvi 2014) These developments have resulted in the development of the current series of Terrestrial Laser Scanners (TLS), which are now widely used, ranging from devices that are installed on an instrument stand and measure from fixed positions to devices that are mounted on vehicle platforms and that perform mobile mode topographic surveying applications (Vosselman and Maas, 2010).

Since the early 2000s, terrestrial laser scanning has evolved from a research and development (R&D) subject to a geo-data technology commercially available from geomatic engineering companies and other service providers around the world.

This technology predecessors were used to quickly obtain three-dimensional (3D) information of various topographic and industrial objects (Scaioni, 2002). Initially, the main use of scanners was to create models of architectural and engineering structures. Since laser scanners can reach all points of a projected object, they can be used in a wide variety of engineering projects. Using 3D information is one of the important techniques in today's digital age. For example, trying to provide an accurate and lifelike image of the surface of an object requires efficient acquisition of large amounts of 3D data. TLS is an important technique that uses laser light to obtain the coordinates of a distant object with only one scan of the object (Fröhlich and Mettenleiter 2004). In addition, emerging terrestrial laser scanner companies continue to develop new scanners, including accuracy, resolution and speed. For example, 2018 model Leica RTC360, one of the latest models, can measure 2 million points per second and is called the TLS with the fastest scanning ever reached, while the longest distance measurement device is the 2019 model VZ-6000 of RIEGL, which scans an object at a distance of 6000 meters (Table 1).

Table 1. Length and accuracy values of some terrestrial laser scanners

Brand	Faro	Riegl	ZOLLER + FRÖHLICH	Leica
Model	FocusS 350	VZ-6000	IMAGER 5016	RTC360
Measuring distance	0.6m-350m	5m-6000m	0.3m-365m	0.5m-130m
Measuring speed	976,000 nokta/saniye	222,000 nok/saniye	1,016,027 nokta/saniye	2,000,000 nokta/saniye
Scan angle	300ºx360º	60ºx360º	310ºx360º	300ºx360º
Distance Accuracy	± 1mm@25m	±15mm	± 1mm@50m	5.3mm@40m
Functional Feature	GPS, GLONASS	remote control , GNSS, Wifi	80Mp kamera	GNSS, 36mp 3kamerali

2.1. Data

After performing the scanning process, the most important step is the scanning data processing step (Chetverikov et al., 2005), and the following issues are important for ideal data analysis and evaluation.

• It should be chosen to provide a wide range of resolutions and accuracy, with varying price, different positional accuracies and scanning distances produced by many companies.

• For ideal scan data, the scan resolution should be chosen according to the application and the detail required, they can be defined based on the minimum feature size visible in the point cloud. Scanning smaller objects requires better accuracy and resolution.

• The selection and location of reference target types before scanning is necessary, which is important for georeferencing and merging point clouds obtained from different scanning centers.

When scanning is complete, the data is saved in the specified project file. Scan functions in TLS vary from one scanner type to another.

TLS can be considered as a combination of photogrammetric and reflectorless Total station compared to traditional 3D modeling methods (Abbas et al., 2014). The scanning process within the field of view is similar to capturing images and producing data with a total station in the 3D coordinate system. Most commercial software packages obtain the X, Y, and Z coordinate values of points in the 3D Cartesian coordinate system, as shown in Figure 1 with TLS, and calculate the r, φ, and θ measurement values (shown in Figure 1) in the 3D polar coordinate system using functional transformation equations (4), (5), and (6) through calculations (Akarsu,2005).

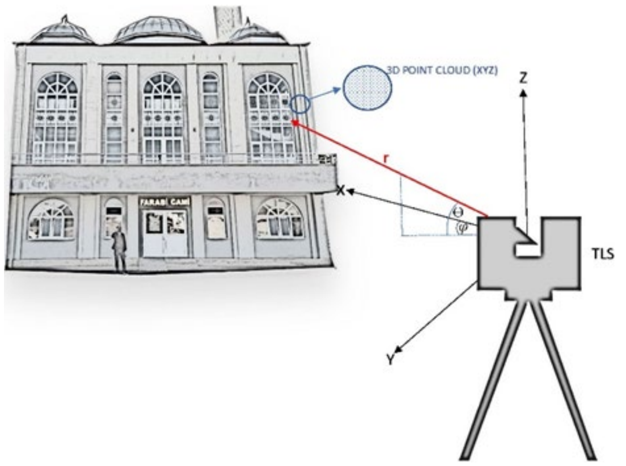

Figure 1. Data acquisition with terrestrial laser scanner

These transformations have an intensity value as an attribute. Therefore, raw dimension values in TLS are for further processing, and 3D data in global coordinates are more useful (Abbas et al., 2014). Thus, transformations from cartesian coordinates to spatial polar coordinates are performed with functions (1), (2) and (3) (Abbas et al., 2014).

$$\text{Range: } r = \sqrt{X^2 + Y^2 + z^2} \quad (1)$$

$$\text{Horizontal angle: } \varphi = \tan^{-1}\left(\frac{X}{Y}\right) \quad (2)$$

$$\text{Vertical angle: } \theta = \tan^{-1}\left(\frac{Z}{\sqrt{X^2 + Y^2}}\right) \quad (3)$$

The transformation from space spherical coordinates to cartesian coordinates is performed with (4), (5) and (6) functions (Abbas et al., 2014).

$$X = r\cos(\varphi)\cos(\Theta) \quad (4)$$

$$Y = r\sin(\varphi)\cos(\Theta) \quad (5)$$

$$Z = r\sin(\Theta) \quad (6)$$

2.2. Point cloud

A point cloud is a representation of an object or environment in three-dimensional space (Brenner, 2007). Often 3D laser scanners are used to create point clouds of real-life objects. A point cloud consists of many points. Each point contains space cartesian or space spherical coordinates, depending on the location coordinates of the point where the TLS is placed (Becerik-Gerber et al. 2011; Ulvi & Yiğit, 2022; Yakar et al., 2008; Yakar et al., 2009; Yılmaz & Yakar, 2016). To achieve a full three-dimensional scan of a room (Fig. 2) or object, several scans are required to avoid missing point clouds due to the restricted line of sight from the scanner. To obtain sufficient point clouds based on several scans, it is necessary to combine the scans (Registation). Merging is the process of combining two or more point clouds into a single cloud (Lindskog et al. 2013). The usage of point clouds can be very heavy for computer hardware, depending on the size of the dataset, often requiring a large amount of RAM, a powerful CPU, and sufficient GPU for smooth processing.

Figure 2. Comparison of high- and low-resolution point cloud (SCENE Workbook 2019)

3. Material and Method

In this study, real-looking, dense 3D data of Farabi Mosque is obtained with terrestrial laser scanning technology and its evaluation in different software is discussed.

The "Faro Laser Scanner Focus X 330" used in the study is a precision measuring instrument that creates 3D images and has the following features (Table 2).

Table 2. Faro Laser Scanner Focus 3D X 330 specifications (Faro Web 2019)

Distance Range	(0.60 – 330) m
Measuring Speed	976000 point/second
Speed distance error	± 2mm
Distance interference	@10m – raw data: 0.3mm @90% reflectance
Laser Class	Laser Class 1
Multi-Sensor	GPS, Compass, Altitude Sensor,
Scanner Control	Touchscreen and WLAN
Weight - Size	5,2 kg - 240 x 200 x 100 mm

Pre-scan measurement design is required and the main steps are as follows:

- **Predetermination of the area to be scanned**: When scanning large areas, the scanner should scan the object or area to be scanned at low resolution, which makes it possible to map the area to be used in other design processes. Large-scale maps can be useful in this regard.
- **Choosing the scanner to use**: A wide variety of scanners are available from many companies, at varying prices, with different positional accuracy and scanning distances. The important thing is to choose the most suitable one for the application to be made.
- **Selection of the most suitable location for scanning points:** It should be chosen to provide the required resolution and accuracy.
- **Selection of target types and pre-determination of targets**: In order to combine point clouds obtained from different scan centers, suitable targets should be selected based on geodetic reference points.
- **Define the expected resolution and accuracy of the point cloud obtained as a result of the scan:** These can be defined depending on the scale of the scan or whether the minimum feature size in the point cloud is visible. Scanning smaller objects requires better accuracy and resolution.
- Last Control**:** Finally, after each of the above-mentioned steps is done, a rough data is obtained by scanning the area or part of the object to be scanned. Considering the time elapsed in this scanning process, the time spent in the entire job can be estimated for the total data to be collected.

Scanning an object using TLS is not just pressing the button and waiting for the results, it is necessary to know all the steps with scanning knowledge (Figure 3).

Figure 3. Process flow chart with TLS

4. Application

In practice, due to the beautiful geometric shape and appearance of the mosque in the Farabi Campus of Bülent Ecevit University in Zonguldak, Türkiye, the Farabi Mosque was scanned and evaluated in Faro Scene 2019 software and various softwares (Figure 4).

The work consists of the following steps and is completed:

- Land Survey
- Positioning of reference spheres
- Scan process
- office work

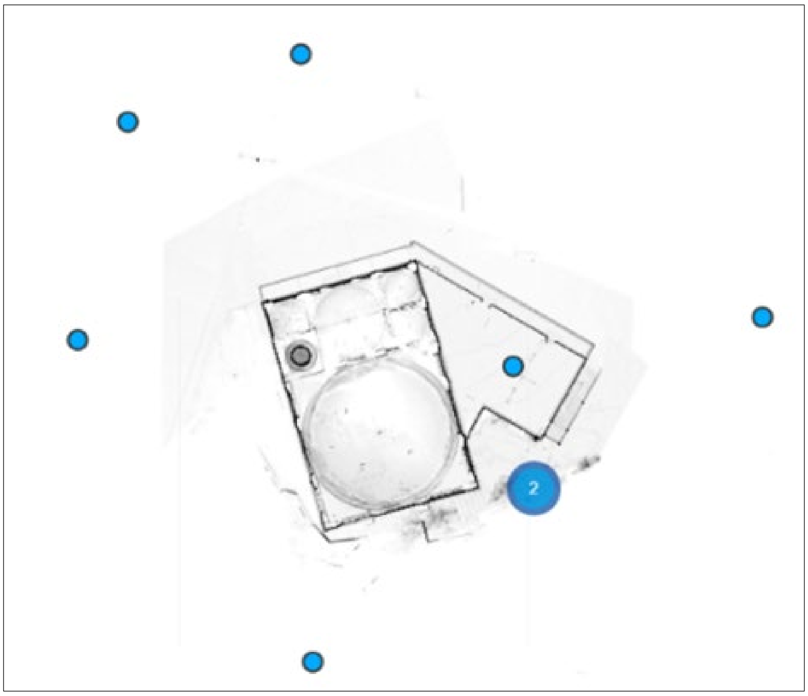

Figure 4. Locations of scanning session stations.

4.1. Registration and model creation

Common features shared by several scans are required for successful alignment of scans. Commonly, software uses special reference targets embedded in the scanned medium. Two common target types are spheres and checkerboards (Becerik-Gerber et al., 2011).

These features ensure accurate targeting and accurate localization of the sphere center point, which is then used as a reference point. The spherical shape allows the target to be scanned from any direction (Lindskog et al. 2013). The checkerboard target consists of two black squares printed on cardboard.

Setting goals requires careful planning to achieve good results (Kedzierski et al. 2009). Not all bonding software requires specific reference targets, instead software that uses a targetless bonding process relies on surfaces and vertices captured in various scans (Fig.5).

Any point cloud generated by a 3D laser scanner is likely to contain invalid data points and reflections. Errors may occur due to disturbances such as reflections or moving objects in the scanned area (Bi and Wang 2010).

Also, missing spatial data from adjacent areas will be included when windows or open doors are present in the scanned area. Faulty spots are eliminated by filtering on parameters such as density and distance. The filtration is then completed by manually deleting the erroneous data points.

In the application, at first, all the data of all sessions scanned with horizontal 360° were combined as they were (Fig.6). However, since they were common point clouds, automatic merging failed, so manual merging was performed.

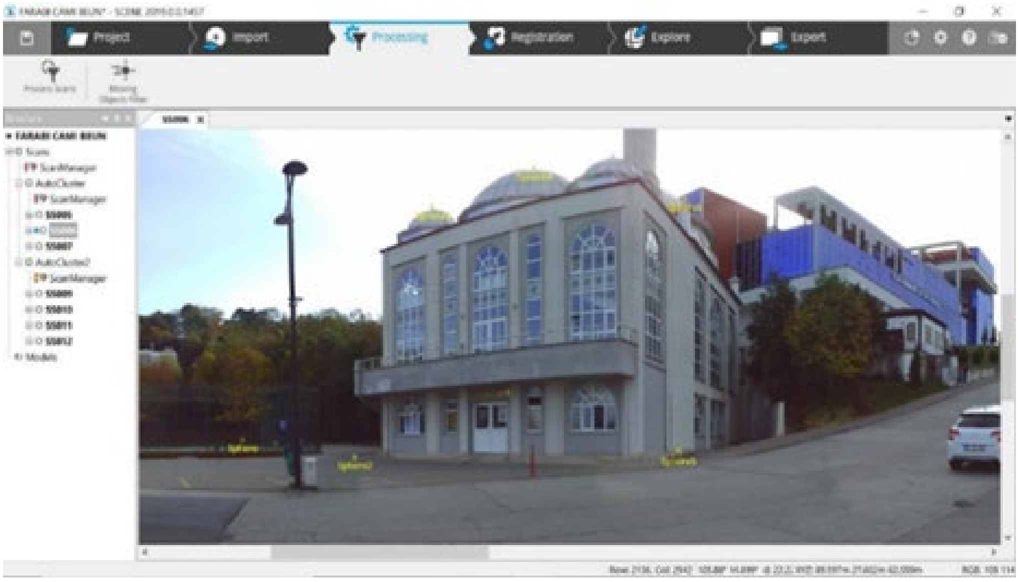

Figure 5. Automatic sphere selection phase of Scene 2019 software.

Figure 6. General view of point cloud obtained by 360° circular scan.

In order to create a 3D digital model of all objects, scans (point clouds) from all stations should be combined in a common (reference) coordinate system (Yildiz and Altuntaş, 2009). Scan points are recorded according to a relative coordinate system of the scanner. The starting point of the scanning coordinate system is the location where the laser meets the mirror. The job of determining the spatial relationship between the scans is called Registration, and the transition step of the scan from the local coordinate system to the general coordinate system is called transformation.

Registration is needed for two purposes (Gümüş, 2010): These are;

1-Merging point clouds from different observation points
2- Placing the object in a specific coordinate system (Geodetic positioning).

Planning and knowing how defragmentation works is essential for successful defragmentation. Some raster projects require only a single scan, while multiple scans are required to create a three-dimensional image. Each scan must be correctly positioned in relation to all other scans.

There are several important concepts associated with consolidation, including; coordinate systems, Common reference objects, sensor data and reference scans.

Connection or control points are required to perform positioning. These points can be a carefully chosen, recognizable point of the object (eg corners) or special targets (high reflective spheres or plates).

Any coordinate system or the coordinate system of one of the scans (usually the first scan) can be selected as a reference (Altuntaş, 2017).

A point cloud measured from a station is a data set in the local coordinate system, consisting of 3D point coordinates. The point cloud of the second dimension, which is superimposed with this dimension, is also in a different local coordinate system.

When the first point cloud (S1) is taken as a reference, the relationship between the first and second point cloud (S2) coordinates of the common points is expressed by the equation (7) (Altuntaş, 2017).

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{S_1} = R_{\omega\varphi\aleph} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{S_2} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \quad (7)$$

The (x, y, z) coordinates in equation (7) are the three-dimensional Cartesian coordinates of the first (S1) and second (S2) point cloud of the same point. Here, Rωφℵ is the 3x3 dimensional rotation matrix formed by the rotation angles between the coordinate systems and [tx ty tz] T is the translation vector between the coordinate systems.

In the application, the scanning consisting of 8 sessions was completed with automatic merging at first, and since the desired 3D image was not obtained, the manual merging phase was started. In the manual assembly phase, the target spheres, the common point between the scans, and the common plane surface were realized with the Targed Based method. In each of the 8 scanning sessions, unnecessary point clouds that do not belong to the target building were cleaned, and then 35 700 815 points (point clouds) were captured and merged. It should be noted that since all sessions were scanned with horizontal 360°, manual merging was not achieved without deleting unnecessary point clouds at first, and the ideal 3D model was not obtained.

Table 3. Results of automatic and manual registration in Faro Scene software

Registration type	Mean point error (±mm)	Maksimum point error (±mm)	Minimum overlap (%)
Auto Merge (Before redundant data cleaning)	12.3	15.7	23.0
Manuel Registration	1.1	8.4	16.5

After removing redundant point clouds, it has been tested with 4 different registration methods to create the ideal 3D model. In Faro Scene 2019 software, these methods are; Cloud to Cloud, Target Based, Topview based and Topview and Cloud to Cloud are merging methods. These methods were carried out within the scope of automatic merging. The ideal 3D model was obtained by completing the manual assembly process with the Targed Based method in order to reduce the post-error average(Fig.7). The error and overlap comparison of the methods is shown in Table 4.

Figure 7. The view angles of 8 sessions after unnecessary points removal for manual registration.

Table 4. Comparison of merging methods made in Faro Scene 2019

Registration method	Maksimum point error (±mm)	Average point error	Registration method
Cloud to Cloud	13.8	5.2	3.5
Target Based	16.8	6.9	5.9
Top View	32.9	13.3	10.9
Topview and Cloud to Cloud	11.6	5.5	10.8
Manually Cloud to Cloud	8.4	4.1	16.5

Table 5. Cartesian coordinates of each session and ellipsoidal coordinates according to WGS-84.

Session no	Converted Local Orthogonal Coordinates			Standard Deviations (Mean Errors)			**Ellipsoidal Coordinates Latitude (φ) Longitude (λ) (°, … …)**	**Orientation Angle** (°,..)
	$x\ (m)$	$y\ (m)$	$z\ (m)$	$\sigma_x(m)$	$\sigma_y(m)$	$\sigma_z(m)$		
1-SS005	75.107258	54.269974	59.553361	-0.0105	0.008	0.9999	41.452391 31.761218	105.42
2-SS006	59.256501	47.95822	59.163336	0.0139	0.0043	0.9999	41.452336 31.761023	51.819
3-SS007	54.614466	27.993533	60.826367	-0.0218	0.009	0.9997	41.452145 31.760969	87.521
4-SS009	117.484677	30.166109	60.051512	-0.0141	-0.003	-1	41.452156 31.761653	149.04
5-SS010	100.338117	15.510721	59.558934	-0.0037	0.0095	-1	41.452152 31.76157	61.247
6-SS011	92.563827	13.16425	60.031081	-0.0334	0.0031	-0.999	41.45204 31.76148	27.834
7-SS012	94.667493	25.649157	63.651876	-0.0042	-0.01	-1	41.452149 31.761461	91.109
8-SS013	76.275529	-1.537738	80.141287	-0.0071	0.0094	-1	41.451946 31.761284	151.27

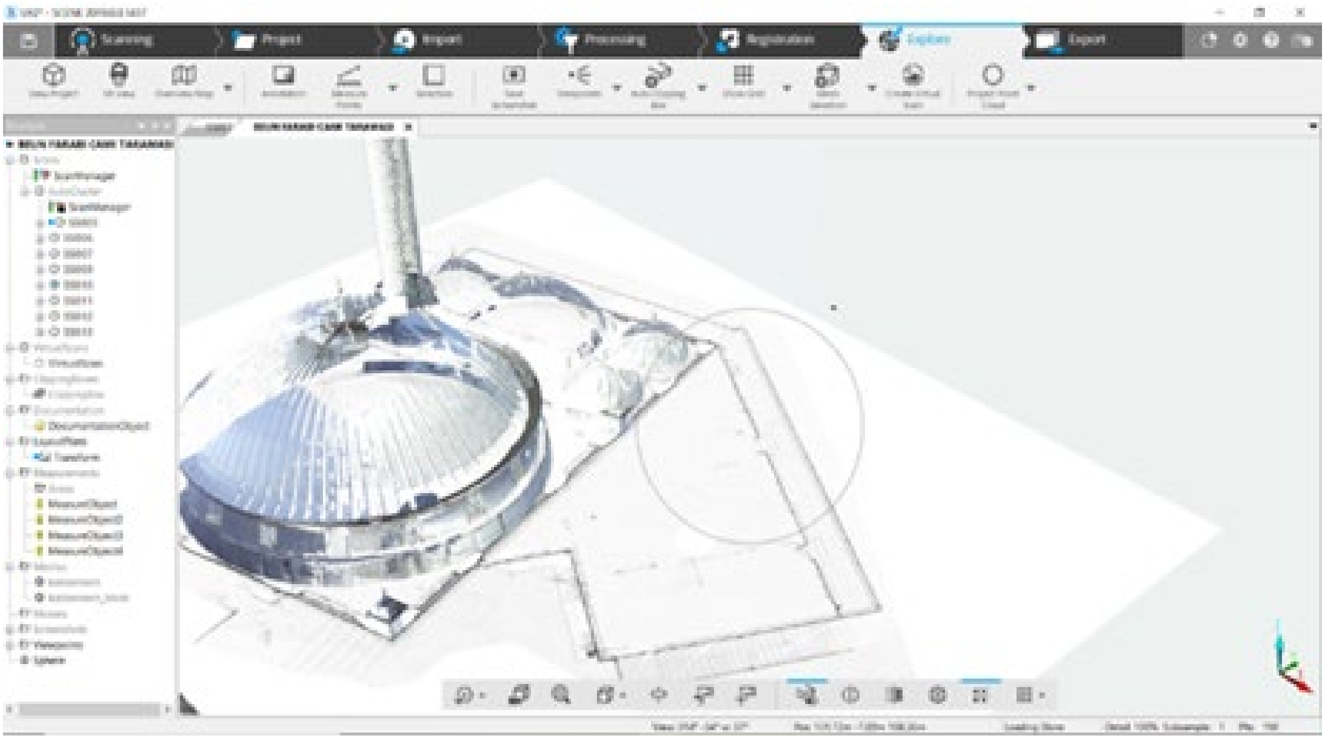

Figure 8. Placement view of the 3D model over the plan in Scene software.

After successful merging, due to the limited functions of the Faro Scene 2019 software, area calculation, mesh generation, and volume calculation operations were performed on the point cloud data using Autodesk Recap 2020 V6.0, Gexcel Reconstructor 2020 V4.2.0, and Meshlab 2020.07 softwares, and operations were carried out on the photorealistic point cloud data (Fig.8, Fig.9)

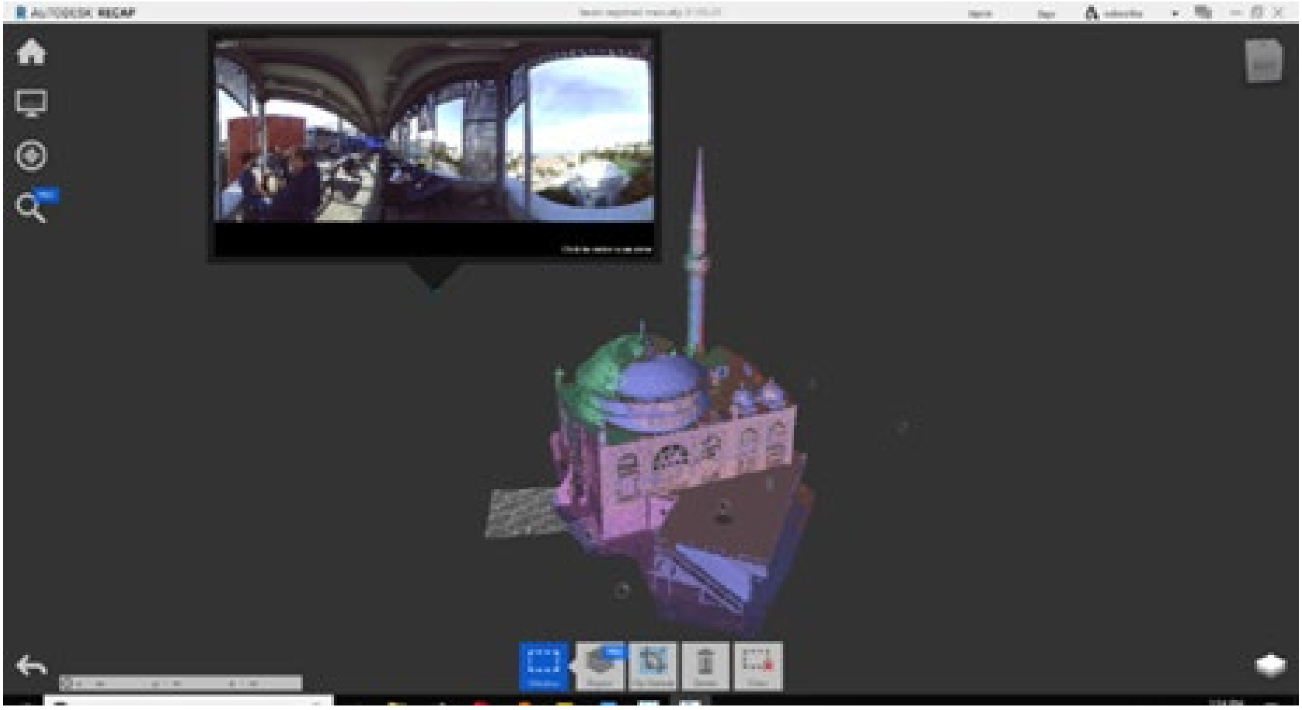

Figure 9. View of the model in Autodesk Recap software with scan locations.

The Focus3D X 330 is a terrestrial laser scanner with an integrated GPS receiver. During each of the 8 sessions, scanning was performed with the automatic GPS sensor feature enabled. The connection of all points in the point cloud was made using the transformation process of the coordinates obtained from the integrated GPS.

The ellipsoidal positional coordinates and Cartesian coordinates, as well as the orientation angles of each session, were converted to GPS WGS-84 ellipsoid and given in Table 5. Automatic and manual registration statistics in Faro Scene software are given in Table 6.

Table 6. Automatic and manual registration statistics in Faro Scene software

Scan No.	Tie	Max.point kta error(±mm)	Average point error (±mm)	Min. Overlap(%)
Manual merging of browsing sessions				
SS009	4	4.6	2.8	20.8
SS012	3	5.7	4.0	16.5
SS010	3	5.7	4.1	28.0
SS005	3	8.4	4.3	18.8
SS011	3	4.5	3.2	16.5
SS006	2	6.6	4.6	51.2
SS007	3	8.4	6.3	18.8
SS013	1	4.0	4.0	45.4
Automatic merging of scanning sessions İstatistikleri				
SS005	2	15.7	11.0	23.0
SS006	2	12.5	9.4	58.2
SS007	2	14.5	13.5	26.4
SS013	1	14.5	14.5	26.4

4.2 Plan, Section and Measurement

After a successful merge, the data is converted to a local or global coordinate system according to the study. Marking any desired point in the data cloud, coordinate information, measurement between points, area calculation and volumetric calculation processes are carried out (Fig.10, Fig.11, Fig.12, Fig.13, Fig14 and Fig,15).

In order for the model created with TLS data to be associated with other spatial data, it must be converted to a geodetic coordinate system. The geodetic coordinate system can be national or global (WGS84 datum parameters) scale. The conversion of measures to the geodetic coordinate system is called geodetic coordinating (georeferencing).

According to Wolf and Dewitt (Wolf et al. 2014), georeferencing (coordinating) can be defined as a technique in which the TLS coordinate system is processed so that the final result is converted to the earth coordinate system. This can be a national or local coordinate system. There are two approaches to implement the georeferencing procedure, either indirect or direct (Abbas et al. 2014).

In this study, direct georeferencing method was used by using GPS data integrated in Faro Focus X330 device in 8 session scans.

Measurement calculationsu made on Figure 12, Figure 13 and Figure 14 models are given in Table 7.

In order to evaluate the 3D data obtained in the Scene 2019 software, it was transferred in different formats. The created 3D models were converted to dxf and different formats. Autodesk Recap in dxf and pts formats, desired plan and measurement processes in Autodesk Autocad and distance measurement, area and volume calculations were made in Reconstructor and Meshlab software (Fig. 11, Fig.12).

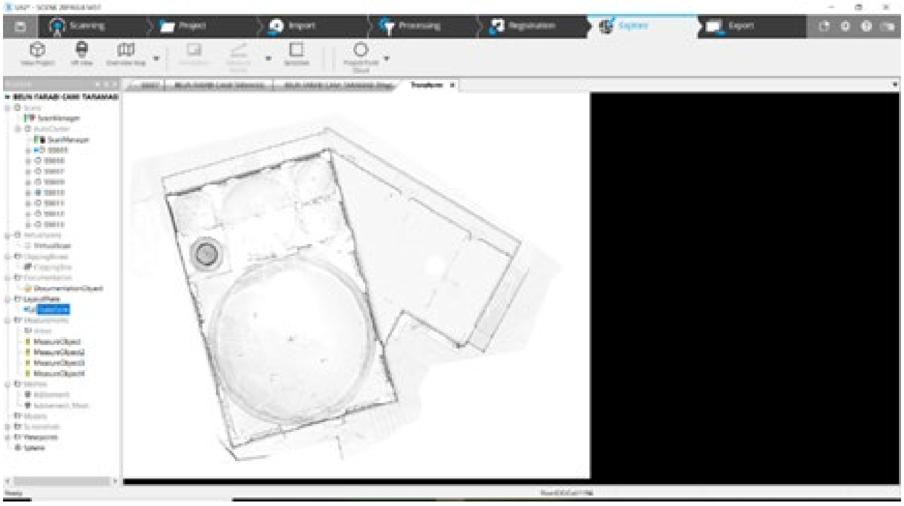

Figure 10. Plan view of the 3D model in Scene 2019 software.

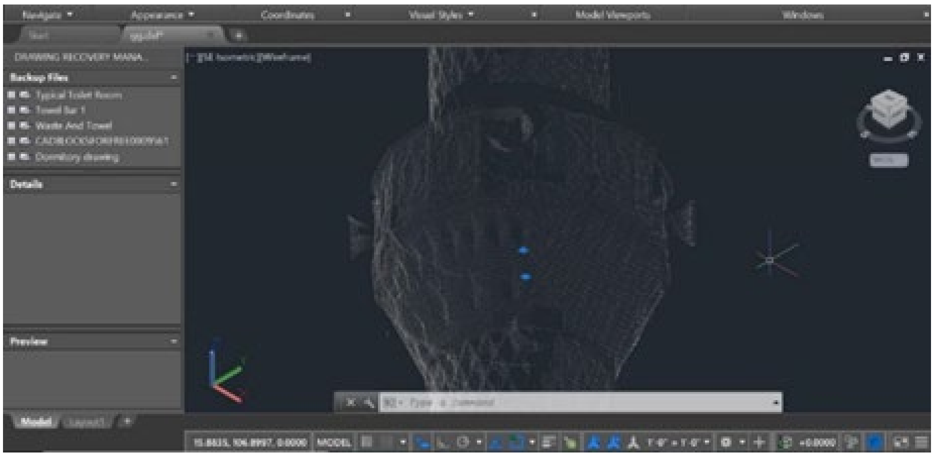

Figure 11. After transfer to Autocad software, 2-point selection image from minaret cloud

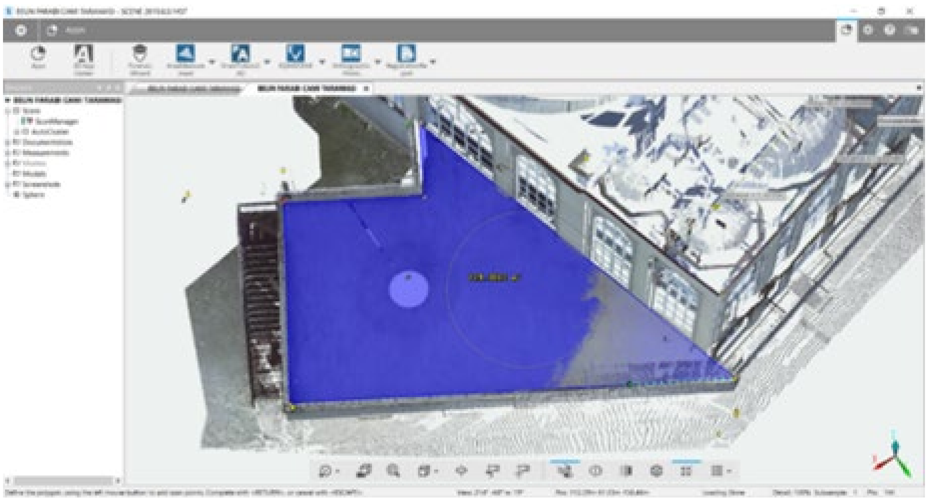

Figure 12. Calculation of terrace area in Scene 2019 software.

Table 7. Some geometric dimensions measured on the Farabi mosque 3D model.

Geometric features	Length (m) / Height (m) Area (m^2) / Volume (m^3)
front length	14.580
facade height	10.450
side length	21.554
minaret height	25.067
Large dome diameter	13.650
Length between two small domes	10.592
front area	148.820
terrace area	139.310
minaret volume: 53.6254	

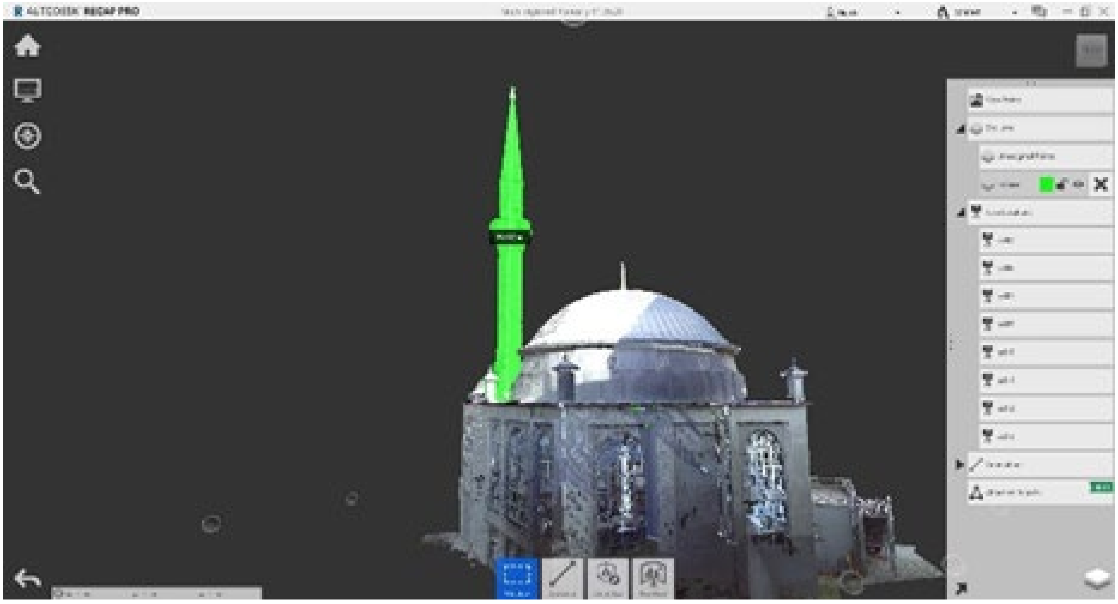

Figure 13. Minaret height measurement in Autodesk Recap 2020 software.

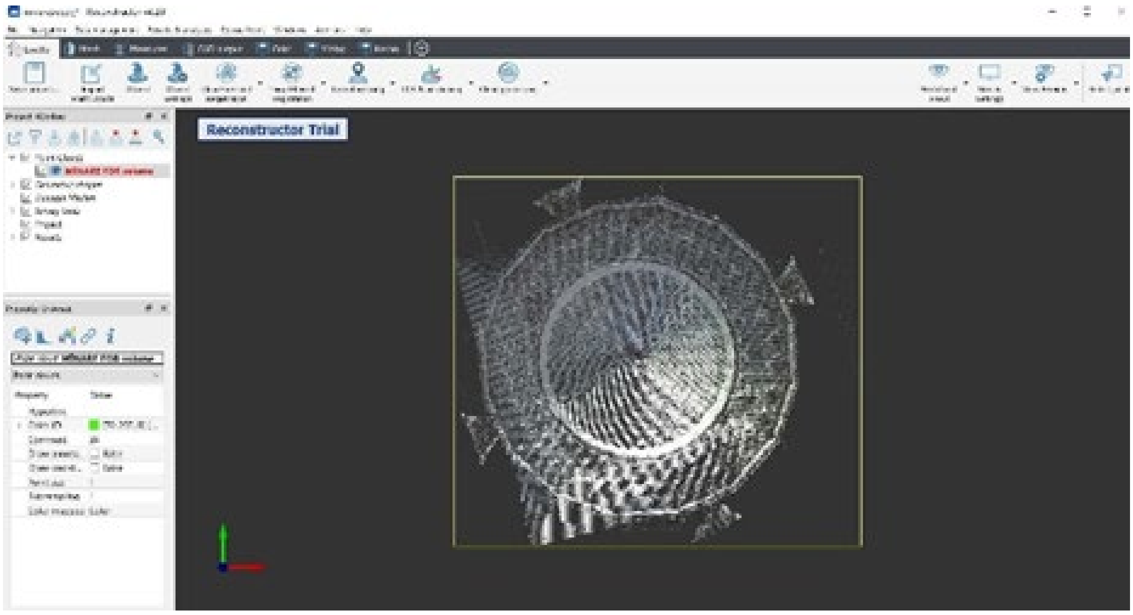

Figure 14. Mesh generation and volume calculation in Reconstructor 2020 software

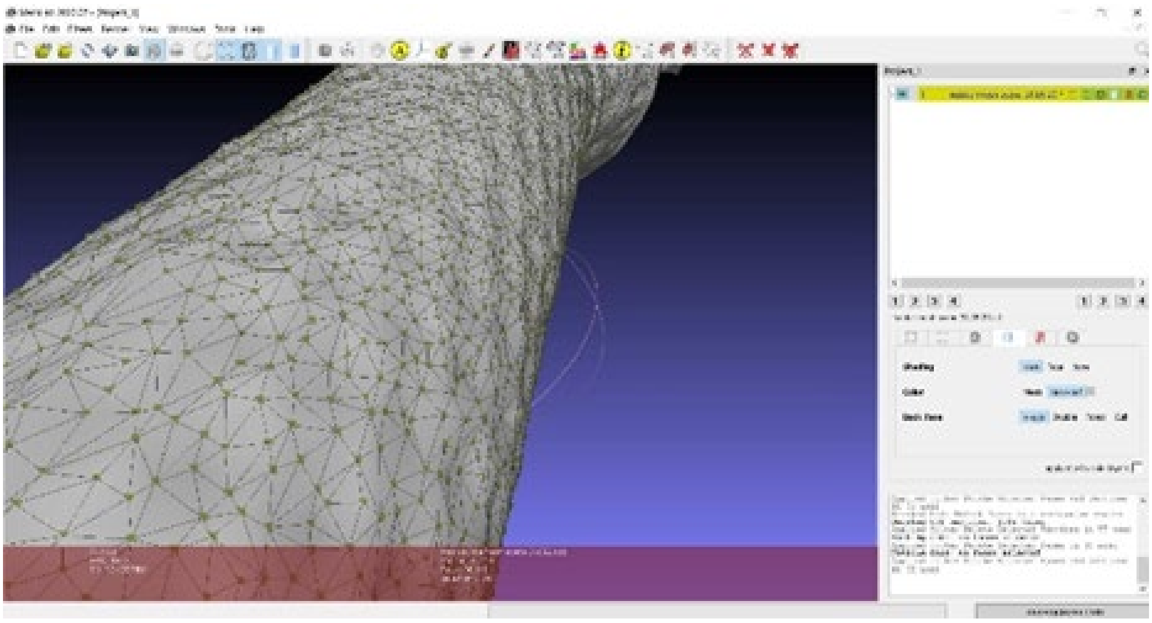

Figure 15. Volume calculation in Meshlab 2020 software

5. Conclusion

In terrestrial laser scanning, it is important to plan and evaluate the object to be scanned before scanning. That is to say, what type of scanning application to be made, which parameters will be given priority, which details of the object to be scanned will be important should be planned before the application. Thus, it will be possible to make evaluations with the accuracy and speed expected in office work. Even a newly released electronic device and evaluation software can always provide much more convenient opportunities in certain aspects than the old ones. In this sense; terrestrial laser scanning tools also follow the current technology, for example, while in old catalogs and old articles, tools with long-range scanning are categorized as having a range of 1000 m, as in the 2019 model Reigl VZ-6000 TLS, which currently has a range of 6000m, technical specifications in recent models, they show several variations.

After the pandemic of the Coronavirus (COVID-19) epidemic, today, which is the age of sensors, the use of thermometer thermal cameras, the use of virtual tourism recorded with TLS and the visits of virtual heritage structures, etc. significant increases in activities.

It is understood that the centers, which are applied by some workplaces that are scanned with TLS and uploaded to the virtual environment, and that offer the opportunity to browse and examine the workplace materials for marketing purposes, will increase after this period.

For example, it is known that the measuring instruments in the space belonging to an antique car dealer or a geomatics engineering tool dealer company can be scanned 3D through the Faro SCENE Webshare Cloud, allowing their customers to examine all the details of antique cars or measuring tools in 3D on the internet. It can be said that in the future, TLS technology will find a wider variety of applications.

In this study, TLS scans were made to obtain the 3D model of the outer surface of the Farabi Campus Mosque of Zonguldak Bülent Ecevit University. Scanning was performed with the Focus 3D X330 TLS instrument, which is Faro's 2013 model, from 8 points. In the office work, after the assembly process, models of other objects around the building and environmental errors are eliminated.

In the study, a real 3D model image was obtained with real color values, whether in color values determined by the scanner according to the structure of the scanned object.

In Scene 2019 software, distance measurement of point clouds can be made between any two points or objects. To calculate the area, Faro Scene required the installation of the free area calculation software Plugin (compatible additional software). Different software was required for volume calculation, so the model was evaluated in Reconstructor and Meshlab software.

The results obtained within the scope of the study reveal that terrestrial laser scanning technology is a very successful method for 3D modeling of objects. Terrestrial Laser Scanning saves time within the scope of the project compared to other measurement methods, and all desired detail measurements can be made on the 3D model obtained.

It should be emphasized that the object that is planned to be scanned with external shooting should be started by adjusting the horizontal and vertical viewing angles before scanning. When this stage is made reasonable, it is suggested that an economic gain will be achieved in the scanning period in the field and the office evaluation period after the scanning (Nazari, 2020). Another important issue at the stage of combining the scan data is that the target marks (target balls or target squares) should be placed in such a way that they can see each other and can be connected.

Author contributions

Shah Wali Nazari; Methodology, data collection, article writing,
Veli Akarsu; contributed to the writing of the article with the idea of the article, article writing,
Murat Yakar: Editing the manuscripthe, article writing.

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

References

Abbasa, M. A.., Luha, L. C., Setana, H., Majida, Z., Chongc, A. K., Aspuria, A., Idrisa, K. M. & Ariffa, M. F. M. (2014). Terrestrial Laser Scanners Pre-Processing: Registration and Georeferencing, *Jurnal Teknologi (Sciences & Engineering)* 71(4).

Akarsu, V. (2005). Geometride Uzay, Düşey ve Yatay Açılar Arasındaki Fonksiyonelİlişki, *Selcuk-Teknik Online Dergi*, 4(3), 134-142.

Akarsu, V., Nazari, S. W. (2020). Yersel Lazer Tarama Teknolojisi İle Heyelanların İzlenmesi, Yerbilimleri Problemlerine Model Yaklaşımlar, Editör: Dr. Fatih Sünbül, 3-36, *İKSAD*, ISBN:978-625-9897-99-0, Ankara, Turkey.

Alptekin, A. & Yakar, M. (2021). Lazer Tarayıcının Jeolojik Olayların Modellenmesinde Kullanımı. *Türkiye Lidar Dergisi*, 3(2), 71-75. DOI: 10.51946/melid.1018197

Alptekin, A., Çelik, M. Ö., Doğan, Y. & Yakar, M. (2022, February). Illustrating of a landslide site with photogrammetric and LIDAR methods. In Research Developments in Geotechnics, Geo-Informatics and Remote Sensing: Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019 (pp. 303-305). Cham: *Springer International Publishing.*

Altuntaş, A. (2017). Yersel Lazer Tarayıcı Nokta Bulutlarının Birleştirilmesi ve Jeodezik Koordinat Sistemine Dönüştürülmesi: Literatür Araştırması, Selçuk-Teknik Dergisi

Becerik-Gerber, B., Jazizadeh, F., Kavulya, G. & Calis, G. (2011). Assessment of target types and layouts in

3D laser scanning for registration accuracy. *Automation in Construction*

Bi, Z. & Wang, L. (2010). Advances in 3D data acquisition and processing for industrial applications. Robotics and Computer-Integrated Manufacturing

Brenner, C. (2007). Interpretation terrestrischer Scandaten. In: Proceedings of "Terrestrisches Laserscanning (TLS 2007), *Beiträge zum* 74. DVW Seminar".

Chetverikov, D., Stepanov, D., Krsek, P. (2005), Robust Euclidean alignment of 3D point sets:the trimmed iterative closest point algorithm, *Image and Vision Computing.*

Danson, F., Gaulton, R., Armitage, R. P., Disney, M. I., Gunawan, O., Lewis, P., Pearson, G. & Ramirez, A. F.. (2014). Developing a dual-wavelength full- laser scanner to characterize forest canopy structure. *Agric For Meteorol* 198.

Fröhlich, C. & Mettenleiter, M. (2004). Terrestrial laser scanning-new perspectives in 3D surveying, Germany.

Gümüş, M. (2010). YL Tez, Yersel Lazer Tarayıcıların Deformasyon Ölçmelerinde Kullanılabilirliği Üzerine bir Çalişma, *Selçuk Üniversitesi, Jedodezi ve Fotogrametri Mühendisliği.*

Kanun, E., Metin, A. & Yakar, M. (2021). Yersel Lazer Tarama Tekniği Kullanarak Ağzıkara Han'ın 3 Boyutlu Nokta Bulutunun Elde Edilmesi. *Türkiye Lidar Dergisi*, 3(2), 58-64.

Karabacak, A. & Yakar, M. (2022). Giyilebilir Mobil LİDAR Kullanım Alanları ve Cambazlı Kilisesinin 3B Modellemesi. *Türkiye Lidar Dergisi*, 4(2), 37-52. DOI: 10.51946/melid.1146383

Karataş, L., Alptekin, A. & Yakar, M. (2022). Analytical Documentation of Stone Material Deteriorations on Facades with Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Şanlıurfa Kışla Mosque. *Advanced LiDAR*, 2(2), 36-47.

Karataş, L., Alptekin, A. & Yakar, M. (2022). Creating Architectural Surveys of Traditional Buildings with the Help of Terrestrial Laser Scanning Method (TLS) and Orthophotos: Historical Diyarbakır Sur Mansion. *Advanced LiDAR*, 2(2), 54-63.

Kaya, Y., Yiğit, A. Y. Ulvi, A. & Yakar, M. (2021). Arkeolojik alanların dokümantasyonununda fotogrametrik tekniklerinin doğruluklarının karşılaştırmalı analizi: Konya Yunuslar Örneği. *Harita Dergisi,* 165, 57-72.

Kedzierski, M., Walczykowski, P. & Fryskowska, A. (2009), Application Of Terrestrıal Laser Scannıng In Assessment Of Hydrotechnıc Objects Condıtıon, *Asprs 2009 Annual Conference Baltimore*, Maryland

Korumaz, A. G., Korumaz, M., Dulgerlera, O. N., Karasaka, L., Yıldız, F. & Yakar, M. (2010). Evaluation of laser scanner performance in documentation of historical and architectural ruins, a case study in Konya. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 38(5), 361-366.

Lindskog, E., Berglund, J., Vallhagen, J. & Johansson, B. (2013). Visualization support for virtual redesign of manufacturing systems*. In Procedia CIRP* 7; 29-31 May, 2013

Mırdan, O. F. (2018). İç ve Dış Mekanların Nokta Bulutlarının Birleştirilmesi, Yüksek Lisans Tezi, *Selçuk Üniversitesi, Harita Mühendisliği Anabilim Dalı.*

Nazari, S. W. (2020). Yersel Lazer Tarayıcılar: Geomatik Mühendisliğinde Uygulama Örneği, ZBEÜ, *Fen Bilimleri Enstitüsü Geomatik Mühendisliği Anabilim Dalı*, Yüksek Lisans Tezi, s.111, Zonguldak, Turkey.

Şasi, A. & Yakar, M. (2017). Photogrammetric modelling of sakahane masjid using an unmanned aerial vehicle. *Turkish Journal of Engineering,* 1(2), 82-87.

Scaioni, M. (2002). Independent model triangulation of terrestrial laser scanner data, The ISPRS International Archives of Photogrammetry, *Remote Sensing and Spatial Information Sciences*

Scene, (2019). FARO Focus Laser Scanners, Training Workbook, Version 2019.

Şenol, H. I., Erdogan, S., Onal, M., Ulukavak, M., Memduhoglu, A., Mutlu, S. & Yilmaz, M. (2017). 3D Modeling of A Bazaar in Ancient Harran City Using Laser Scanning Technique*. International Archives of The Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42.

Şenol, H. İ., Memduhoglu, A., & Ulukavak, M. (2020). Multi instrumental documentation and 3D modelling of an archaeological site: a case study in Kizilkoyun Necropolis Area. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 11(3), 1241-1250.

Ulvi, A., & Yiğit, A. Y. (2022). Comparison of the Wearable Mobile Laser Scanner (WMLS) with Other Point Cloud Data Collection Methods in Cultural Heritage: A Case Study of Diokaisareia. *ACM Journal on Computing and Cultural Heritage,* 15(4), 1-19.

Ulvi, A., Yakar, M., Toprak, A. S. & Mutluoglu, O. (2014). Laser scanning and photogrammetric evaluation of Uzuncaburç Monumental Entrance. International *Journal of Applied Mathematics Electronics and Computers*, 3(1), 32-36.

Vosselman, G., Maas, H.-G. (Eds.). (2010). Airborne and Terrestrial Laser Scanning, first ed. CRC Press. *Boca Raton*, FL.

Wolf, P., DeWitt, B. & Wilkinson, B. (2014). Elements of Photogrammetry with Applications in GIS, 4th ed. *McGrawHill Education*.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2008). Lazer Tarama Teknolojisi ve Fotogrametrik Yöntem ile Hacim Hesabı. *TÜBİTAK*, Proje No: 105M179, 90s.

Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2009). Comparative Evaluation of Excavation Volume by Terrestrial Laser Scanner and Total Topographic Station Based Methods*. Lasers in Engineering*, 19(5), 331.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2010). Comparative evaluation of excavation volume by TLS and total topographic station-based methods. *Lasers in Eng*,19, 331-345

Yildiz, F. & Altuntaş, F. (2009). YL Tez, Yersel Lazer Tarayıcı Nokta Bulutlarının Jeodezik Koordinat Sistemine Dönüştürülmesi, *Selçuk Üniversitesi, Jedodezi ve Fotogrametri Mühendisliği Bölümü*, 42075 Selçuklu

Yılmaz, H. & Yakar, M. (2016). LiDAR (Light Detection and Ranging) Tarama Sistemi. *Yapı Teknolojileri Elektronik Dergisi*, 2(2), 23-33.

Yılmaz, H. M. & Yakar, M. (2006). Yersel lazer tarama Teknolojisi. *Yapı teknolojileri Elektronik dergisi*, 2(2), 43-48.

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Application of Terrestrial Laser Scanning (TLS) Technology for Documentation of Cultural Heritage Buildings and Structures: A Case Study Sarı İsmail Sultan Tomb

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Abstract

One of the most fundamental duties in the management of cultural heritage artifacts in the field of conservation strategy is creating geometric documentation. For conservation or restoration work on historical objects and sites, 3D documentation is a requirement. At every stage of the conservation effort, the creation of particular documentation such as high-resolution 3D models is required. Türkiye is a very rich country in terms of historical artifacts. It is extremely important to document these artifacts in order to preserve them and transfer them to future generations. In documentation studies, the Terrestrial Laser Scanning (TLS) method has started to be preferred with the developing and advancing technology. In this study, the usability of the data obtained by the TLS technique in the documentation of cultural heritage was investigated. The study area, Sarı İsmail Sultan Tomb, was scanned with a terrestrial laser scanner using the TLS technique, the scan data were combined in commercial software and a 3D model of the cultural heritage was created.

1. Introduction

Cultural heritage is the reflection of important events, traditions, lifestyles, beliefs, works of art, architecture, and other cultural elements in human history. This heritage reconciles the past with the present and contains important information to be passed on to future generations (Guarnieri et al., 2006; Çelik et al., 2020; Yakar et al., 2005; Yakar et al., 2020). Documenting, protecting, and transferring cultural heritage to future generations is very important for preserving our cultural values. Documentation of cultural heritage includes the creation of digital copies of historical buildings, archaeological sites, works of art and other cultural objects (Yiğit and Yakar, 2023; Erdoğan et al., 2021). These copies allow cultural heritage to be preserved and passed on to future generations. In addition, these copies allow for better understanding and examination of cultural heritage (Fryskowska et al., 2015; Markiewicz et al., 2015; Ulvi and Yiğit, 2022; Pulat et al., 2022; Kabadayı, 2022).

Terrestrial Laser Scanning (TLS) technique has started to be preferred frequently in the studies of epigraphical examination of cultural heritage assets bearing the traces of past civilizations and their geography and containing writings and details that shed light on history, and in the creation of documentation in this context (Oruç and, Baş, 2021; Fidan et al., 2022; Uzun et al., 2022; Kabadayı & Erdoğan, 2022). This technique is included in the LIDAR (Light Detection and Ranging) system. In this method, a three-dimensional (3D) point cloud (point data set) of the scanned object can be obtained sensitively and quickly. A 3D model of the cultural heritage can be created from the obtained point cloud (Kaçarlar and Hamal, 2021; Yakar et al., 2021). This model serves as a base for determining the indoor and outdoor architectural features of the heritage, determining the lengths of the facades, making two-dimensional (2D) drawings, and restoration works in

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case the heritage is damaged (Capolupo, 2021; Oruç and Öztürk, 2021; Grenzdörffer et al., 2015; Alptekin & Yakar, 2021; Alptekin et al., 2022; Kanun et al., 2021; Karabacak Yakar, 2022; Karataş et al., 2022; Kaya et al., 2021). In this context, the frequency of the point cloud to be produced and the metric accuracy are extremely important. As a result of the features described above, the use of TLS method in the documentation of cultural heritage has started to increase (Varol et al., 2021; Yiğit and Uysal, 2021; Şenol et al., 2017; Şenol et al., 2020; Ulvi et al., 2015 ;Yakar et al., 2008).

The aim of the study is to investigate the usability of my TLS method and the data obtained as a result of this method in the documentation of cultural heritage. Within the scope of the documentation of the cultural heritage of Sarı İsmail Sultan Tomb in Kütahya as the study area, scanning was carried out at 10 station points with the Faro FocusS 350 terrestrial laser scanner, which uses TLS technique. As a result of the scans, a point cloud of the artifact was obtained, and a 3D model was created.

2. Materials and Methods

Terrestrial laser scanning systems are used effectively in many disciplines today and their use is increasing. Many results can be obtained with this technique, which is used in related studies. The terrestrial laser scanner used in the application phase is given in Figure 1 and its technical specifications are given in Table 1.

Laser scanners can produce 3D models directly, precisely and automatically, without any contact with the object. It stands out from other methods, as there is no need for any data other than spatial data and the data processing is done automatically in principle (Sarı et al., 2020; Alkadri et al., 2022; Yakar et al., 2010; Yakar et all., 2009; Yılmaz & Yakar, 2016). In addition, LIDAR technologies can provide digital data immediately after measurement. All these conveniences have increased the use of LIDAR technologies in different fields (Masaharu and Hasegawa 2000; Hamal et al., 2020).

Figure 1. Faro Focus S350 terrestrial laser scanner (Faro, 2023).

It performs its measurements according to the TLS phase difference method used in practice (Sánchez-Aparicio et al., 2018). In this operating principle, the scanner's sensor continuously emits a periodic signal of medium intensity. After this emitted signal is reflected from the surface of the object, it is detected by the sensor, then the phase values of the outgoing and incoming signal are compared (Chatzistamatis et al., 2018; Shao et al., 2019). Distances are calculated by analyzing this phase difference. Such scanners provide a wide field of view, high number of points, high range and high scanning speeds. These scanners generally use visible wavelengths (Faro, 2023).

Table 1. Technical specifications of terrestrial laser scanner (Faro, 2023).

Feature	Value
Weight	4,2 kg
Range	0,6- 50 m
Ranging error	±1 mm
Field of view (vertical, horizontal)	300° ,360°
Multi-Sensor	GPS, Compass, Height Sensor, Dual Axis Compensator
Measurement Speed	up to 976,000 points/second
Laser Class	Laser class 1
High Dynamic Range (HDR) Photo Recording	2x/3x/5x

3. Application

3.1. Study Area

The Sarı İsmail Sultan Tomb, which was determined as the study area, is in the Dedeler village of Tavşanlı district of Kütahya province (Figure 2). Inside the tomb, the tomb on the right belongs to Sarı İsmail Sultan, the tomb in the middle belongs to Dölek Ana, and the tomb on the far left belongs to Ataullah Efendi. Sarı İsmail is one of the pirs whose name is mentioned the most in Bektashi and Alevi literature. It is recorded in the records that he came to Anatolia in the 13th century and that he came to Hacı Bektaş together with Karaca Ahmet. He is known as one of the closest colleagues of Hacı Bektaşı Veli (URL-1).

Before the study, the field work was completed by scanning at 10 different stations (stop) determined around the work. The number and location of the stop points were determined to see one or more sides of the work to be scanned, and attention was paid to create less noise.

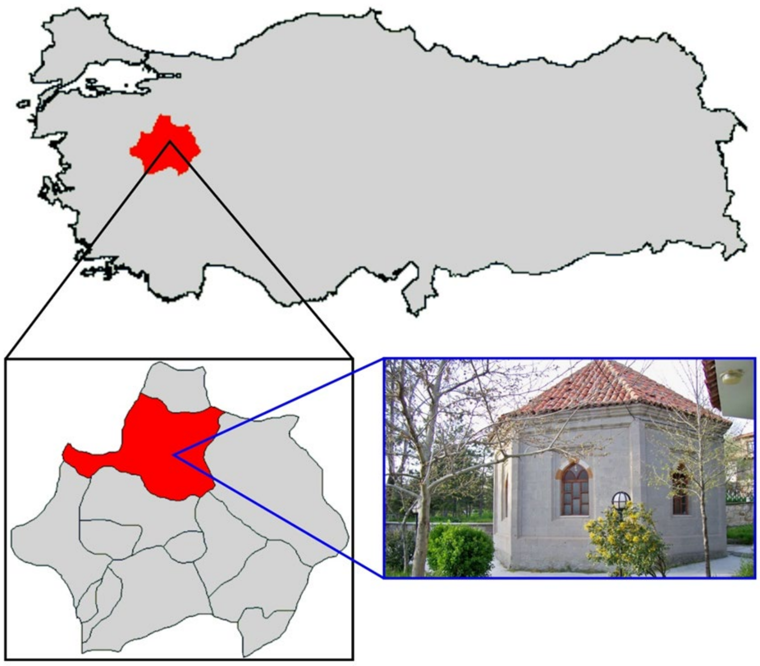

Figure 2. Study area.

3.2. Data Processing

Survey data of the study area were obtained by studywork. After this stage, the scans were combined in Faro Scene software, which is a commercial software, and a point cloud related to the work was produced. Then, a 3D model of the work was created from the point cloud. Thus, the usability of the data obtained by TLS method in the documentation of cultural heritage was investigated. Faro Scene software has been developed for all Faro Focus and other laser scanners capable of 3D scanning (Faro, 2023). With the technical features of this software such as real-time scanning, automatic object recognition, scanning record creation and positioning, scanning data can be processed and managed effectively and simply (Guarnieri et al., 2017). The data obtained because of the scans were transferred to the software and then the data processing stage was started. Scans were combined with the Cloud-to-cloud technique with an error of 0.4 mm. Point cloud data contains a lot of messy and redundant data other than the job being scanned. This irrelevant data has been cleared. This process, which is done to create a healthier and higher quality 3D model of the work, is expressed as noise removal (Tucci, 2019; Saponaro et al., 2020). After this step, a point cloud was generated (Figure 3), followed by a mesh model (Figure 4).

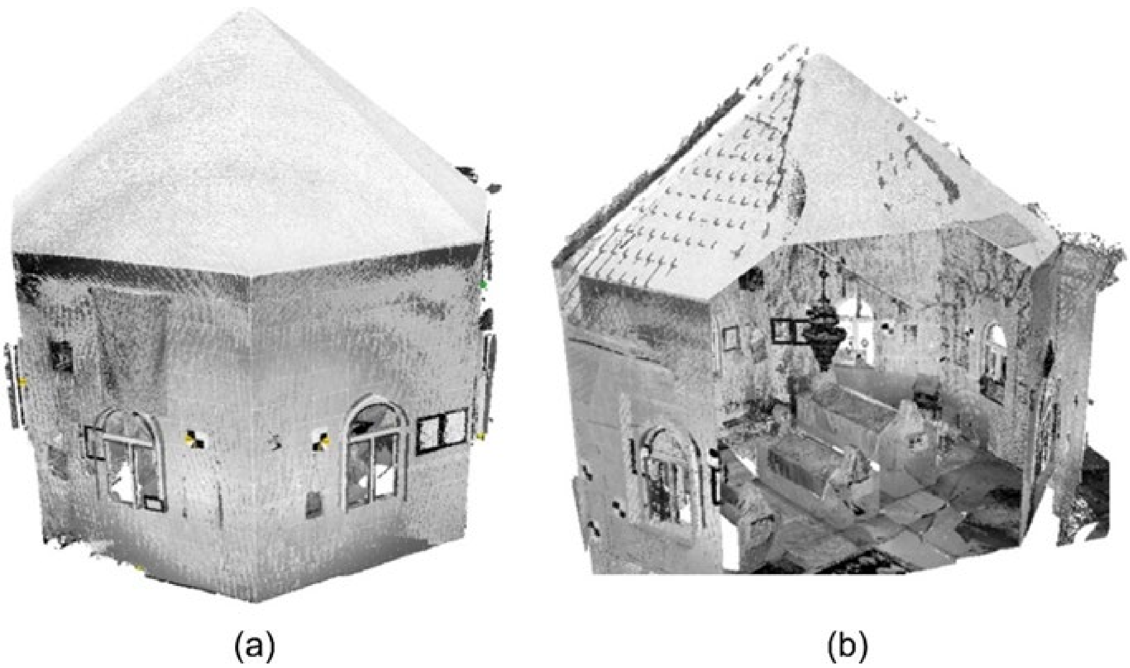

Figure 3. 3D point cloud of the tomb (outdoor) (a), indoor (b)

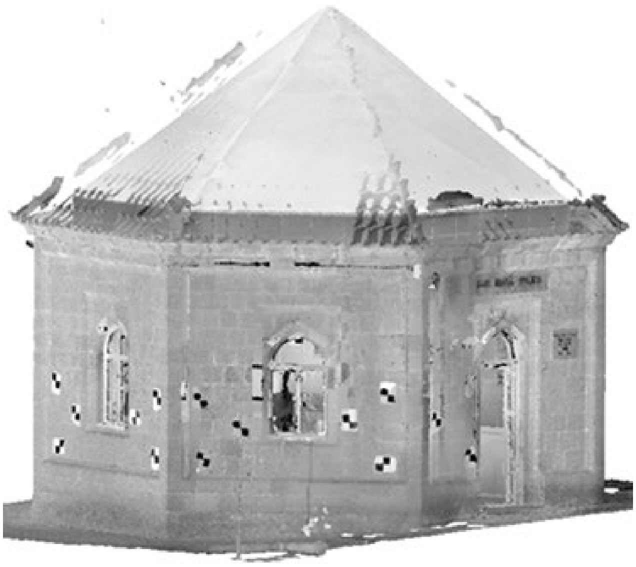

Figure 4. 3D mesh model of the tomb

4. Discussion and Conclusions

Documentation studies are carried out with different methods and tools in order to shed light on the architectural features of cultural heritages, to shed light on the past, to carry the traces of history to the future and to protect them in this context. In these studies, it takes time to carry out measurement processes with classical terrestrial measurement techniques. With the development of technology, TLS has become a standard method that is frequently preferred for these studies. In this method, a point cloud can be obtained by reflecting back the laser beam sent to the object. As a result, a realistic 3D model of the desired structure can be produced. Through the created model, the position, shape, and architectural features of the object can be observed. In TLS technique, data with high accuracy and sensitivity can be obtained in a much shorter time compared to classical terrestrial measurement techniques. In addition, architectural drawings to be made in the documentation of cultural heritage can be made by taking sections from the data obtained from the TLS method. This more multidisciplinary work has not only saved engineers time, but also saved time for experts in other fields.

TLS has some advantages as well as some disadvantages. The location of the station points is important in the scanning process to be performed with the terrestrial laser scanner, which is a part of this system. If the height of the device is less than the object and/or the device is positioned to not see the entire object, then reliable data about the object will not be obtained. In particular, the point cloud of the apex of the scanned structure will not be created, and as a result, the 3D model will not be as desired. In order to avoid such problems in applications, the device should be positioned in line with the object or at a high point. However, this condition cannot always be met due to factors such as different terrain conditions and the large size of the object to be scanned. The use of the Unmanned Aerial Vehicle (UAV) system is among the strong alternative options in order to prevent this negative situation and to create the model to be produced in a complete and healthy way. However, high resolution scans result in dense datasets (point clouds). Depending on the size of the study area, it is highly likely that the processing of these data will be a problem. In addition, the point cloud produced can be colored if a photograph is taken when the documentation is done using the TLS method. In this way, the real color information of the work is obtained. Data obtained from scanning in this study; The workstation with a powerful processor and high-performance graphics card has been processed on a computer. Thus, the data processing process was completed in approximately 3 hours. It is recommended that researchers who will do various studies in different fields with TLS method should pay attention to this point.

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Author contributions

Sena Köse; Methodology, data collection, article writing, Editing the manuscripthe.
Hazal Us; contributed to the writing of the article with the idea of the article, article writing, article writing.

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

References

Alkadri, M. F., Alam, S., Santosa, H., Yudono, A. & Beselly, S. M. (2022). Investigating surface fractures and materials behavior of cultural heritage buildings based on the attribute information of point clouds stored in the TLS dataset. *Remote Sensing*, 14(2), 410.

Alptekin, A. & Yakar, M. (2021). Lazer Tarayıcının Jeolojik Olayların Modellenmesinde Kullanımı. *Türkiye Lidar Dergisi*, 3(2), 71-75. DOI: 10.51946/melid.1018197

Alptekin, A., Çelik, M. Ö., Doğan, Y. & Yakar, M. (2022, February). Illustrating of a landslide site with photogrammetric and LIDAR methods. In Research Developments in Geotechnics, Geo-Informatics and Remote Sensing: Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019 (pp. 303-305). Cham: *Springer International Publishing.*

Capolupo, A. (2021). Accuracy assessment of cultural heritage models extracting 3D point cloud geometric features with RPAS SfM-MVS and TLS techniques. *Drones*, 5(4), 145.

Çelik, M. Ö., Hamal, S. N. G. & Yakar, İ. (2020). Yersel lazer tarama (YLT) yönteminin kültürel mirasın dokümantasyonunda kullanımı: Alman Çeşmesi örneği. *Türkiye Lidar Dergisi*, 2(1), 15-22.

Chatzistamatis, S., Kalaitzis, P., Chaidas, K., Chatzitheodorou, C., Papadopoulou, E. E., Tataris, G. & Soulakellis, N. (2018). Fusion of TLS and UAV photogrammetry data for post-earthquake 3D modeling of a cultural heritage Church. Int. Arch. Photogramm. *Remote Sens*. Spat. Inf. Sci, 143-150.

Erdoğan, A., Kabadayı, A. & Akın, E. S. (2021). Kültürel mirasın fotogrametrik yöntemle 3B modellenmesi: Karabıyık Köprüsü Örneği. *Türkiye İnsansız Hava Araçları Dergisi*, *3*(1), 23-27.

Faro, (2023). https://www.faro.com/trtr/urunler/constructi on-bim-cim/faro-focus/features/, 01.02.2023.

Fidan, D., Oruç, M. E., Hamal, S. N. G. & Fidan, Ş. (2022). Tersine Mühendislik Uygulamalarında Yersel Lazer Tarayıcıların Kullanım Olanaklarının Araştırılması; Klasik Otomobiller Örneği. *Türkiye Lidar Dergisi*, 4(1), 1-10.

Fryskowska, A., Walczykowski, P., Delis, P. & Wojtkowska, M. (2015). ALS and TLS data fusion in cultural heritage documentation and modeling. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* 40(5), 147.

Grenzdörffer, G. J., Naumann, M., Niemeyer, F. & Frank, A. (2015). Symbiosis of UAS photogrammetry and TLS for surveying and 3D modeling of cultural heritage monuments-a case study about the cathedral of St. Nicholas in the city of Greifswald. Int. Arch. Photogramm. *Remote Sens*. Spat. Inf. Sci, 40, 91.

Guarnieri, A., Fissore, F., Masiero, A. & Vettore, A. (2017). From TLS survey to 3D solid modeling for documentation of built heritage: The case study of Porta Savonarola in Padua. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 303-308.

Guarnieri, A., Remondino, F. & Vettore, A. (2006). Digital photogrammetry and TLS data fusion applied to Cultural Heritage 3D modeling. Int. Arch. Photogramm. *Remote Sens*. Spat. Inf. Sci, 36, 1-6.

Hamal, S. N. G., Saı, B. & Ulvi, A. (2020). Using of hybrid data acquisition techniques for cultural heritage a case study of pompeiopolis. *Türkiye İnsansız Hava Araçları Dergisi*, 2(2), 55-60.

Kabadayı, A. & Erdoğan, A. İHA Fotogrametrisi Kullanarak Kadastroda Binaların Konum Doğruluğunun İncelenmesi. *Türkiye Fotogrametri Dergisi*, *4*(2), 65-71.

Kabadayı, A. (2022). Maden Sahasının İnsansız Hava Aracı Yardımıyla Fotogrametrik Yöntemle Haritalanması. *Türkiye İnsansız Hava Araçları Dergisi*, *4*(1), 19-23.

Kaçarlar, Z. & Hamal, S. N. G. (2021). Küçük Objelerin Üç Boyutlu (3B) Modellenmesinde Yersel Lazer Tarama (YLT) Tekniği. *Türkiye Lidar Dergisi*, 3(2), 65-70.

Kanun, E., Metin, A. & Yakar, M. (2021). Yersel Lazer Tarama Tekniği Kullanarak Ağzıkara Han'ın 3 Boyutlu Nokta Bulutunun Elde Edilmesi. *Türkiye Lidar Dergisi*, 3 (2), 58-64. DOI: 10.51946/melid.1025856

Karabacak, A. & Yakar, M. (2022). Giyilebilir Mobil LİDAR Kullanım Alanları ve Cambazlı Kilisesinin 3B Modellemesi. *Türkiye Lidar Dergisi*, 4 (2), 37-52. DOI: 10.51946/melid.1146383

Karataş, L., Alptekin, A. & Yakar, M. (2022). Creating Architectural Surveys of Traditional Buildings with the Help of Terrestrial Laser Scanning Method (TLS) and Orthophotos: Historical Diyarbakır Sur Mansion. *Advanced LiDAR*, 2(2), 54–63.

Kaya, Y., Yiğit, A. Y. Ulvi, A., & Yakar, M. (2021). Arkeolojik alanların dokümantasyonununda fotogrametrik tekniklerinin doğruluklarının karşılaştırmalı analizi: Konya Yunuslar Örneği. *Harita Dergisi,* 165, 57-72.

Markiewicz, J. S., Podlasiak, P. & Zawieska, D. (2015). A new approach to the generation of orthoimages of cultural heritage objects—integrating TLS and image data. *Remote Sensing*, 7(12), 16963-16985.

Masaharu, H. & Hasegawa, H. (2000). Three-dimensional city modeling from laser scanner data by extracting building polygons using region segmentation method. *International Archives of Photogrammetry and Remote Sensing*, 33(B3/1; PART 3), 556-562.

Oruç, M. E. & Baş, G. (2021). Kompleks Yapı ve Alanlarda Yersel Lazer Tarama Teknolojisinin Kullanımı. *Türkiye Lidar Dergisi*, 3(2), 39-47.

Oruç, M. E. & Öztürk, İ. L. (2021). Usability of Terrestrial Laser Technique in Forest Management Planning. *Türkiye Lidar Dergisi*, 3(1), 17-24.

Pulat, F., Yakar, M. & Ulvi, A. (2022). Comparison of photogrammetric software using the terrestrial photogrammetric method: The case of Hüsrev Paşa Mosque. *Intercontinental Geoinformation Days*, 4, 192-195.

Sánchez-Aparicio, L. J., Del Pozo, S., Ramos, L. F., Arce, A. & Fernandes, F. M. (2018). Heritage site preservation with combined radiometric and geometric analysis of TLS data. *Automation in Construction,* 85, 24-39.

Saponaro, M., Capolupo, A., Turso, A. & Tarantino, E. (2020, August). Cloud-to-cloud assessment of UAV and TLS 3D reconstructions of cultural heritage monuments: the case of Torre Zozzoli. *In Eighth International Conference on Remote Sensing and Geoinformation of the Environment* (RSCy2020) (Vol. 11524, pp. 60-71). SPIE.

Sarı B, Hamal, S. N. G. & Ulvi, A. (2020). Documentation of complex structure using Unmanned Aerial Vehicle (UAV) photogrammetry method and Terrestrial Laser Scanner (TLS*). Türkiye Lidar Dergisi*, 2(2), 48-54.

Şenol, H. I., Erdogan, S., Onal, M., Ulukavak, M., Memduhoglu, A., Mutlu, S. & Yilmaz, M. (2017). 3D Modeling of A Bazaar in Ancient Harran City Using Laser Scanning Technique*. International Archives of The Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42.

Şenol, H. İ., Memduhoglu, A., & Ulukavak, M. (2020). Multi instrumental documentation and 3D modelling of an archaeological site: a case study in Kizilkoyun Necropolis Area. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 11(3), 1241-1250.

Shao, J., Zhang, W., Mellado, N., Grussenmeyer, P., Li, R., Chen, Y. & Cai, S. (2019). Automated markerless registration of point clouds from TLS and structured light scanner for heritage documentation. *Journal of Cultural Heritage*, 35, 16-24.

Tucci, G., Rihal, S., Betti, M., Conti, A., Fiorini, L., Kovacevic, V. C. & Bartoli, G. (2019). Ground Based 3d Modellıng (Photogrammetry and Tls)-Survey, Documentatıon And Structural Assessment Of Xx Century Cultural Herıtage In Indıa–A Case Study Of The Masonry Vaults In Dehradun. International Archives of the Photogrammetry, *Remote Sensing & Spatial Information Sciences*.

Ulvi, A. & Yiğit, A. Y. (2022). Comparison of the Wearable Mobile Laser Scanner (WMLS) with Other Point Cloud Data Collection Methods in Cultural Heritage: A Case Study of Diokaisareia. *ACM Journal on Computing and Cultural Heritage*, 15(4), 1-19.

Ulvi, A., Yakar, M., Toprak, A. S. & Mutluoglu, O. (2015). Laser Scanning and Photogrammetric Evaluation of Uzuncaburç Monumental Entrance. *International Journal of Applied Mathematics Electronics And Computers,* 3 (1), 32-36. DOI: 10.18100/İjamec.41690

Ulvi, A., Yakar, M., Yiğit, A. Y. & Kaya, Y. (2020). İHA ve yersel fotogrametrik teknikler kullanarak Aksaray Kızıl Kilise'nin 3 Boyutlu nokta bulutu ve modelinin üretilmesi. *Geomatik Dergisi,* 5(1), 22-30.

URL 1: https://mericulukus.tv/sari-ismail-sultan-ve-turbesi/

Uzun, S. D., Hamal, S. N. G. & Fidan, Ş. (2022). Elde Taşınabilir Lazer Tarayıcılar ile İnsan Yüzünün Modellenerek Güzellik ve Bakım Sektöründe Kullanımının Değerlendirilmesi. *Türkiye Lidar Dergisi,* 4(1), 17-20.

Varol, F., Yiğit, A. Y. & Ulvi, A. (2021). Kültürel Mirasın Dijital Ortamda 3 Boyutlu Arşivlenmesi: Maghoki-Attar Camii Sanal Model Örneği. *Turizm Akademik Dergisi,* 8(1), 181-191.

Yakar, İ., Çelik, M. Ö., Hamal, S. N. G. & Bilgi, S. (2021). Kültürel mirasın dokümantasyonu çalışmalarında farklı yazılımların karşılaştırılması: Dikilitaş (Theodosius Obeliski) Örneği. *Geomatik*, 6(3), 217-226.

Yakar, M., Yıldız, F. & Yılmaz, H. M. (2005). Tarihi ve Kültürel Miraslarin Belgelenmesinde Jeodezi Fotogrametri Mühendislerinin Rolü. *TMMOB Harita ve Kadastro Mühendisleri Odası*, 10.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2008). Lazer Tarama Teknolojisi ve Fotogrametrik Yöntem ile Hacim Hesabı. *TÜBİTAK*, Proje No: 105M179, 90s.

Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2009). Comparative Evaluation of Excavation Volume by Terrestrial Laser Scanner and Total Topographic Station Based Methods*. Lasers in Engineering*, 19(5), 331.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2010). Comparative evaluation of excavation volume by TLS and total topographic station based methods. Lasers in Engineering, 19, 331–345

Yiğit, A. Y. & Uysal, M. (2021). Tarihi Eserlerin 3B Modellenmesi ve Artırılmış Gerçeklik ile Görselleştirilmesi. *Bilecik Şeyh Edebali Üniversitesi Fen Bilimleri Dergisi*, 8(2), 1032-1043.

Yiğit, A. Y. & Yakar, M. (2023). Modeling of the historical monument with mobile phone-based photogrammetry method. *Advanced Engineering Days (AED),* 6, 97-99.

Yılmaz, H. & Yakar, M. (2016). LiDAR (Light Detection and Ranging) Tarama Sistemi. *Yapı Teknolojileri Elektronik Dergisi*, 2 (2), 23-33.