Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-50414
www.engineeringscience.rs

publishing

Journal of Applied Engineering Science
Vol. 22, No. 2, 2024
Professional Paper
Paper number: 22(2024)2, 1187, 267-271

3D DOCUMENTATION OF CULTURAL HERITAGE USING TERRESTRIAL LASER SCANNING

Arli Llabani*, Freskida Abazaj

Faculty of Civil Engineering, Polytechnic University of Tirana, Rruga Muhamet Gjollesha, Tirana, Albania
** arli.llabani@fin.edu.al*

This study presents a comprehensive exploration of the application of terrestrial laser scanning (TLS) technology for the 3D documentation of cultural heritage, focusing on the iconic Clock Tower of Tirana as a case study. Terrestrial laser scanning has emerged as a powerful tool in the field of cultural heritage preservation, offering a non-intrusive and highly accurate method for capturing the intricate details of historical structures. The research employs state-of-the-art TLS equipment to create a detailed 3D model of the Clock Tower, a prominent cultural landmark in Tirana, Albania. The methodology involves scanning the exterior of the tower, capturing its architectural features, ornate decorations, and historical elements. The high precision of TLS facilitates the generation of a point cloud, enabling the creation of an accurate digital replica that serves as a valuable resource for conservation, research, and education. The study also explores the challenges and benefits associated with TLS technology in the context of cultural heritage documentation. Issues such as data processing, registration, and integration of multiple scans are addressed, emphasizing the importance of a meticulous approach to ensure the reliability of the 3D model. Additionally, the research highlights the potential of the digital model in supporting conservation efforts, risk assessment, and virtual tourism, promoting accessibility and understanding of cultural heritage for a wider audience. The findings of this study contribute to the growing body of knowledge on 3D documentation techniques for cultural heritage preservation and provide insights into the specific application of terrestrial laser scanning in the context of the Clock Tower of Tirana. The results underscore the significance of leveraging advanced technologies to safeguard and promote the rich cultural heritage embedded in historical structures, fostering a deeper appreciation for the past while ensuring its preservation for future generations

Keywords: 3D documentation, accuracy, terrestrial laser scanning, heritage

1 INTRODUCTION

Cultural heritage, an integral part of our shared human history, stands as a testament to the evolution of societies, civilizations, and artistic achievements. As the custodians of our cultural legacy, it is imperative to employ cutting-edge technologies to document and preserve these irreplaceable artifacts, structures, and landscapes [1,2].

Among the myriad tools available for this purpose, terrestrial laser scanning (TLS) has emerged as a transformative methodology, revolutionizing the way we capture and analyze the intricate details of historical sites [3].

The convergence of heritage preservation and technological innovation has given rise to a new era in archaeological and architectural documentation, where the three-dimensional (3D) representation of cultural heritage plays a pivotal role. Terrestrial laser scanning, a non-contact and non-destructive surveying technique, has proven to be an invaluable asset in capturing highly accurate and detailed spatial information of heritage sites. This technique utilizes laser beams emitted from a scanner to measure the distance to objects, creating a dense point cloud that accurately represents the surfaces and geometry of the scanned environment.

The advantages of terrestrial laser scanning in cultural heritage documentation are manifold. Unlike traditional methods that may be invasive, time-consuming, and prone to errors, TLS allows for rapid and precise data acquisition with minimal impact on the physical integrity of the site. It facilitates the creation of high-resolution 3D models that capture not only the external structures but also intricate details, textures, and architectural nuances that might otherwise be overlooked [4,5].

The utilization of TLS technology extends beyond mere documentation; it opens avenues for advanced research, conservation, public engagement, and educational initiatives. By creating accurate 3D representations of cultural heritage sites, we not only safeguard their physical integrity but also provide a digital platform for researchers, conservators, and enthusiasts to explore and study these treasures in unprecedented detail [6].

In the subsequent sections, this paper will navigate through the methodologies employed in the 3D documentation process, the challenges encountered, and the implications of leveraging TLS in the context of cultural heritage preservation [7,8]. And so on…

1.1 Case study

The area selected for this study is the "Clock Tower" in Tirana, an important historical and architectural object. The Clock Tower is in the center of the city and represents an important symbol of Tirana's identity. The study area includes the tower itself and the buildings around it, where relatively many tall buildings have been built in recent years, as well as in the vicinity of this building located in the center of the city near it.

The clock tower was constructed in the Islamic architecture by the Ottoman Turks, and it only had a bell from Venice that would ring once each hour. The lower floor serves as its square base, and the clock mechanism is located upstairs. There is just one gate leading inside the clock tower. Thick stone walls that supported wooden staircases that led to the tower's summit were constructed in the lower section. Narrow windows let in plenty of light. Remodeled in 1928 to house and safeguard an actual clock's mechanisms, the highest part of the tower bears these changes.

The object's cultural and historical significance makes this area crucial to research, and it's also necessary to evaluate how accurate the laser scanning technique was in producing a comprehensive 3D model of the tower.

The Clock Tower is one of the most popular and attractive objects of Tirana, and its study offers a unique opportunity to compare and analyse the measurement method with Laser Scanner in creating an accurate and detailed 3D model of this the object. The choice of the Clock Tower of Tirana brings an important contribution to the field of geodetic measurements and 3D modelling, since through these detailed measurements with Laser Scanner. Apart from the significance of evaluating the accuracy of this approach, this research will also provide a unique contribution to the conservation of cultural assets.

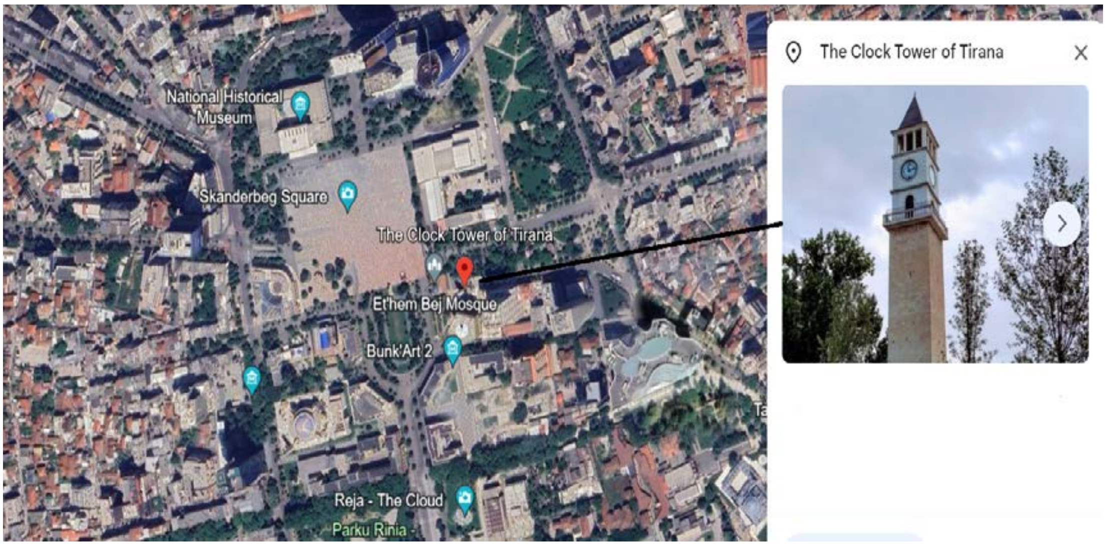

Fig. 1. The clock tower of Tirana location (Google Maps)

2 METHODS

2.1 Laser scanner target markers

RAD (Ringed Automatically Detected) marks are a type of artificial target required for registration scans. Each Mark is unique, this means that when a unique mark is found in two scans, the software registration can tell that the center point of the mark in each scan corresponds diagonally. The size of RAD mark should be done by looking at a certain distance to distinguish the referred brand the resolution we have chosen [9].

During this experiment, RAD marks were also placed on the facades of other buildings.

Fig. 2. RAD mark placed on the façade of the object

2.2 terrestrial laser scanning

Faro M 70 Laser Scanner was used to perform Laser scanning measurements. The FARO Laser Scanner Focus M 70 is a powerful 3D laser scanner specifically designed for both indoor and outdoor applications that require scanning up to 70 meters. FARO Focus M70 With its genuine mobility, user-friendliness, and professional-grade scanning technology combined, the new device provides real-time views of recorded data together with dependability and flexibility. All widely used software programs for industrial manufacturing, forensics, accident reconstruction, and architecture and construction may readily import the 3D scan data [10].

Fig. 3. Laser scanner Faro M 70 [16]

After scanning the control points, the scanning of the object begins using the laser beam. The laser scanning device sends laser beams towards the object and receives the information of the beams that return after reflection from the surface of the object. This is done by scanning the object from different angles to capture points on all sides of the object in order to achieve complete coverage of the object [11,12].

To ensure good coverage of the object in the scan, it is important that the scan points are sufficient and accurately represent the surface of the object. This can be accomplished by using a distance that is appropriate for the subject and the beam you are using, as well as by scanning the subject from different angles to capture as much detail as possible. Also, the technique of "sub observation" can be used, which involves scanning the object in different layers to capture information in hard-to-reach areas [13].

After placing the scanner in the right place for scanning the object with full coverage. We ensure that the device is placed in a stable and precisely leveled position to minimize the possibility of damage.

To achieve high accuracy during the laser scanning process, it is important to configure the correct parameters. Here are some parameters we need to consider achieving a high accuracy:

1) Scan Resolution: Scan resolution determines the distance between scan points. A higher resolution will yield more scan points and result in a higher level of detail in the 3D model. However, a higher resolution requires more time to complete the scan. Determining the resolution of the scan is based on the level of detail we wish to include in the 3D model and on the time, we have available for the scan [14].
2) Laser Beam Intensity: The intensity of the laser beam affects the ability of the device to capture details in the object. In brightly lit environments, it may be necessary to increase the intensity of the laser beam to ensure clear and appropriate results. In dimly lit environments, the intensity of the laser beams can be reduced to avoid the effects of excessive illumination.
3) Unit of Measurement: Define the unit of measurement that will be used to display the scan results. Generally, metric units (such as the meter) are used to display results in coordinate systems.
4) Color Matching: Some laser scanning devices offer the ability to define the level of color matching. Specifying an appropriate level of color matching helps create a 3D model with accurate and clear colors.
5) Scan Distance: In our position, we need to set the right distance for scanning the object of the Clock Tower. The scan distance affects the scan field, which is the cross between the object distance and the point scan. We set the scanning distance according to the size and complexity of the object we are scanning.

Accurate determination of the above parameters will help ensure high accuracy during the laser scanning process and the creation of a complete and detailed 3D model for the Clock Tower in Tirana.

3 RESULTS

3.1 Terrestrial laser scanning data processing

Faro Scene was used for the processing of terrestrial laser scanning data. Faro SCENE is a complete tool for handling and managing detailed 3D point data for professional users. It is intended only for the viewing, organizing, and manipulation of 3D scan data from high-resolution 3D laser scanners, including the FARO Focus Laser Scanner. With a multitude of features and tools, including filtering, automatic object recognition, scan registration, and automatic scanner coloring, SCENE swiftly and simply processes and handles scan data. Once the scan data from SCENE has been processed, you can get right to the evaluation and additional processing. It provides features ranging from straightforward measurements to 3D visualization and the ability to export your scan data in many forms, including CAD formats, for the purpose of adding new points or point clusters.

For the processing of the terrestrial laser scanning data, the connection of the clusters with each other was first performed, identifying the same RAD marks that were found simultaneously in the successive scans. In the Import menu, we entered the scans into the program. Each scan was equipped with its own serial number, which made the process of connecting the scans to each other easier. In the Processing menu, select the two scanners that we will connect to as a start [15].

Fig. 4. TLS Point Cloud generated in Faro Scene

3.2 Accuracy assessment of terrestrial laser scanning

Initially, to determine the accuracy of the terrestrial laser scanning, we measured the markers placed on the facade with a total station, giving them coordinates with high accuracy. The coordinates of these marks were used to calculate the root mean square error and to derive the accuracy of the use of this technique in the selected object.

To evaluate the accuracy of terrestrial laser scanning, the root mean square error (RMSE) was used as a standard measure. The RMSE measures the difference between the marks that were surveyed and the locations of those same points in TLS point cloud.

$$RMSE_X = \sqrt{\frac{1}{n} * \sum_{i=1}^{n}(X_{Li} - X_{Si})^2} = 0.012\ m = 1.2\ cm \quad (1)$$

$$RMSE_Y = \sqrt{\frac{1}{n} * \sum_{i=1}^{n}(Y_{Li} - Y_{Si})^2} = 0.014\ m = 1.4\ cm \quad (2)$$

$$RMSE_H = \sqrt{\frac{1}{n} * \sum_{i=1}^{n}(H_{Li} - H_{Si})^2} = 0.017\ m = 1.7\ cm \quad (3)$$

$$RMSE_H = \sqrt{RMSE_X^2 + RMSE_Y^2 + RMSE_H^2} = 0.0251 = 2.51\ cm \quad (4)$$

Table 1. RMSE values

$RMSE_X$	$RMSE_Y$	$RMSE_H$	RMSE
0.012 m	0.014	0.017	0.025

4 CONCLUSIONS

In conclusion, the use of Terrestrial Laser Scanning-based documentation is an effective method for documenting, monitoring, and analyzing cultural heritage places. Further, the study found that TLS can enhance the efficiency and accuracy of cultural heritage site documentation and can aid in detecting and managing potential risks and threats.

The findings of the study have important implications for future terrestrial laser scanning documentation and preservation efforts, as they demonstrate the potential of laser scanners to enhance cultural heritage preservation efforts.

Based on the presented research and results, the Terrestrial Laser Scanning offers the documentation of cultural heritage areas. The accuracy obtained from Terrestrial Laser scanning method was 2.5 cm.

Terrestrial Laser Scanning has higher positional accuracy than photogrammetry and shows high data acquisition rate in the perpendicular direction.

Terrestrial laser scanning consistently delivers higher spatial accuracy due to direct point measurements. This makes it the preferred choice when precise dimensional information is critical, such as for intricate architectural elements.

Although some accuracy assessments and further studies have been conducted, terrestrial laser scanning seems to be more powerful than UAV photogrammetry for the 3D documentation of the heritage sites.

5 REFERENCES

[1] Akgul M., Yurtseven M., Gulci S., Akay A.E. (2018). Evaluation of UAV and GNSS-Based DEMs for Earthwork Volume. *Arabian Journal for Science and Engineering,* vol. 43, no. 4, pp. 1893-1909, DOI: 10.1007/S13369-017-2811-9

[2] Balázsik V., Tóth Z., Abdurahmanov I. (2021). Analysis of Data Acquisition Accuracy with UAV. *International Journal of Geoinformatics,* vol. 17, no. 1, pp. 1-10, DOI: 10.52939/ijg.v17i1.1697

[3] Erdelyi J., Kopacik A., Kyrinovic P. (2018). Construction control and documentation of facade elements using terrestrial laser scanning. *Applied Geomatics,* vol. 10, no. 2, pp. 113-121, DOI: 10.1007/s12518-018-0208-4

[4] Hassan A.T., Fritsch D. (2019). Integration of Laser Scanning and Photogrammetry in 3D/4D Cultural Heritage Preservation—A Review. *International Journal of Applied Science and Technology,* vol.9, no.4, pp. 9-16, DOI: 10.30845/ijast.v9n4p9

[5] Jaafar H.A., Meng X., Sowter A., Bryan P. (2017). New approach for monitoring historic and heritage buildings: Using terrestrial laser scanning and generalized Procrustes analysis. *Structural Control and Health Monitoring,* Vol. 24, no. 11, DOI: 10.1002/stc.1987

[6] Kwoczynska B., Piech I., Polewany P., Gora K. (2018). Modeling of sacral objects made based on aerial and terrestrial laser scanning. Baltic Geodetic Congress, pp. 275-282. DOI: 10.1109/BGC-Geomatics.2018.00059

[7] Logothetis S., Delinasiou A., Stylianidis E. (2015). Building information modelling for cultural heritage: a review. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. II-5/W3, pp. 177-183, DOI: 10.5194/ISPRSANNALS-II-5-W3-177-2015

[8] Mohammadi M., Rashidi M., Mousavi V., Karami A., Yu Y., Samali B. (2021). Quality evaluation of digital twins generated based on UAV photogrammetry and TLS: bridge case study. *Remote Sensing,* vol.13, no. 17, pp.3499, DOI: 10.3390/rs13173499

[9] Moon D., Chung S., Kwon S., Seo J., Shin J. (2019). Comparison and utilization of point cloud generated from photogrammetry and laser scanning: 3D world model for smart heavy equipment planning. *Automation in Construction,* vol. 98, pp. 322-331, DOI: 10.1016/j.autcon.2018.07.020

[10] Mulakala J. (2015). Measurement Accuracy of the DJI Phantom 4 RTK & Photogrammetry. https://www.gim-international.com/files/23b0ad77f81a0aa56e8c83f8c4300270.pdf (Accessed: 28 October 2023).

[11] Pritchard, D., Sperner, J., Hoepner, S., and Tenschert, R. (2017). Terrestrial laser scanning for heritage conservation: the Cologne Cathedral documentation project. ISPRS Ann. Photogramm. *Remote Sensing.* Spatial Inf. Sci., IV-2/W2, pp. 213–220, DOI: 10.5194/isprs-annals-IV-2-W2-213-2017

[12] Pompejano F. (2020). From national to cultural monuments: an overview of architectural heritage protection in Albania (1912-1992). *Journal of Architectural Conservation,* vol.26, no. 1, pp. 55-70, DOI:10.1080/13556207.2019. 1684021

[13] Remondino F. (2011). Heritage recording and 3D modeling with photogrammetry and 3D scanning. *Remote Sensing,* vol. 3, no. 6, pp. 1104-1138, DOI: 10.3390/rs3061104

[14] Rodríguez-Gonzálvez P., Jiménez Fernández-Palacios B., Muñoz-Nieto Á.L., Arias-Sanchez P., Gonzalez-Aguilera D. (2017). Mobile LiDAR System: New Possibilities for the Documentation and Dissemination of Large Cultural Heritage Sites. *Remote Sensing,* vol. 9, no. 2, pp.189, https://doi.org/10.1016/j.culher.2019.12.013

[15] Wang Y., Chen Q., Zhu L., Liu L., Zheng, L. (2019). Survey of Mobile Laser Scanning Applications and Key Techniques over Urban Areas. *Remote Sensing,* vol. 11, no. 13, pp. 1540, DOI: 10.3390/rs11131540

[16] https://www.g2metric.co.il/product/faro-laser-scanner-focus-m70/, (Accessed: 30 May 2024).

Paper submitted: 10.03.2024.

Paper accepted: 07.06.2024.