Cultural Heritage and Science
https://dergipark.org.tr/en/pub/cuhes
e-ISSN 2757-9050

The Use of Terrestrial Laser Scanning Technology in the Documentation of Cultural Heritage

Murat Yakar[1] **& Hacı Murat Yılmaz**[*2]

[1]*Mersin Üniversitesi, Mühendislik Fakültesi, Harita Mühendisliği Bölümü, Mersin, Türkiye, myakar@mersin.edu.tr*
[2]*Aksaray Üniversitesi, Mühendislik Fakültesi, Harita Mühendisliği Bölümü, Aksaray, Türkiye, hmyilmaz@aksaray.edu.tr*

Cite this study: Yakar, M., Yılmaz, H.M., (2025). The Use of Terrestrial Laser Scanning Technology in the Documentation of Cultural Heritage. Cultural Heritage and Science, 6(2), 138-148.

https://doi.org/10.58598/cuhes.1801497

Keywords
3D Modelling
Point cloud
Cultural Heritage
Documentation
Terrestrial Laser Scanning (TLS)

Research Article
Received:11.10.2025
Revised: 22.10.2025
Accepted:31.10.2025
Published:22.12.2025

Abstract

The documentation and preservation of cultural heritage sites are of paramount importance for ensuring the transmission of historical, architectural, and archaeological values to future generations. In the face of environmental degradation, urban development, and natural disasters, the need for accurate and reliable documentation methods has become increasingly vital. This study focuses on the use of Terrestrial Laser Scanning (TLS)—also referred to as Yersel Lazer Tarama (YLT)—as a modern and highly effective tool in the three-dimensional documentation and analysis of cultural heritage assets. TLS technology captures millions of spatial data points to generate dense, high-accuracy point clouds that represent the geometry and surface characteristics of structures with millimetric precision. This capability allows for the detailed measurement of structural features, detection of deformations, cracks, and material deterioration, and the creation of accurate 3D models for both conservation and educational purposes. The paper presents a comprehensive review of the principles of TLS, including the methods used for data acquisition, point cloud processing, and surface modeling. It also investigates a range of case studies involving historical buildings, archaeological sites, and stone monuments, demonstrating the practical applications of TLS in various cultural heritage contexts. Additionally, the integration of TLS data with other technologies such as photogrammetry and UAV (drone) imaging is discussed, highlighting the potential for creating enriched, visually realistic, and geometrically accurate digital reconstructions.

In conclusion, this study underlines the critical role of terrestrial laser scanning in restoration planning, structural monitoring, and digital archiving, positioning it as a foundational technology for the preservation and sustainable management of cultural heritage in the digital age.

1. Introduction

The documentation, preservation, and management of cultural heritage have become increasingly important topics in recent years. Accurate and detailed measurements of historical buildings, monuments, and archaeological sites are critically important for both restoration and scientific research. In this context, photogrammetry and terrestrial laser scanning (TLS) technologies have become essential tools for the high-accuracy 3D modeling of cultural heritage [1-4].

Photogrammetry is a technique that enables measurements to be obtained from photographs of an object or structure and is particularly effective in 3D modeling of irregular or small-scale objects [2,3,7-9]. The effectiveness of digital photogrammetric methods in measuring the roughness of discontinuity surfaces was evaluated and their accuracies compared. Such studies enable the creation of more comprehensive and detailed digital models when integrated with laser scanning data [10-14].

Terrestrial laser scanning collects point cloud data of surrounding objects or structures using laser beams. This method offers high-precision measurements and allows detailed data collection in a short time [1,15]. LiDAR systems are especially preferred for historical structures and archaeological sites with complex geometries [16-18]. For instance, Yılmaz and Yakar

(2006) conducted a detailed examination of the potential uses of terrestrial laser scanning technology in the fields of construction and engineering [1].

In recent years, integrated photogrammetry and laser scanning systems using unmanned aerial vehicles (UAVs) have provided significant advantages in documenting large-scale areas and hard-to-reach structures [19-21]. In their 2022 study, Villi and Yakar examined the application areas of different UAV sensor types in detail and discussed their effectiveness in cultural heritage studies [20].

The 3D models obtained in the preservation of cultural heritage provide critical data not only for restoration and analysis but also for virtual exhibition and educational purposes. In a study on the Mezgit Kale Monumental Tomb in Silifke, Mersin, [8] performed high-detail survey and 3D modeling by integrating terrestrial laser scanning and photogrammetric data [8]. Recently, wearable LiDAR systems have also begun to be used in the creation of 3D models for cultural heritage preservation [2,3,22-24]. This study provides not only a technological overview of terrestrial laser scanning (TLS) but also introduces an applied methodological framework demonstrated through selected case studies. The research highlights how TLS can be systematically applied for precise documentation and comparative evaluation of diverse cultural heritage sites

2. Terrestrial Laser Scanning Technology

Terrestrial laser scanning (TLS) is a critical tool in cultural heritage studies, a technology used to obtain geometric measurements and surface details of objects with millimeter precision. These systems emit a laser beam and measure the time or phase difference of the reflected beam to create a point cloud [1,7]. These points represent the 3D geometry of a structure or object with high accuracy.

2.1 Scanner Types and Operating Principles

Terrestrial Laser Scanning (TLS) systems are primarily based on two methods: Time-of-Flight (ToF) and Phase Shift (PS) [7]. Both methods are based on the principle of emitting a laser beam toward a target surface and measuring the return signal; however, they differ in terms of measurement principles and practical advantages.

2.1.1 Time-of-flight (ToF) method

In the Time-of-Flight method, a laser beam is emitted toward a target, and the time it takes for the beam to return is measured with extreme precision, down to a tiny fraction of a millisecond. This measured time is then used to calculate distance based on the speed of light. ToF systems are generally preferred for long-range scanning and can accurately measure distances of up to several kilometers [7,25].

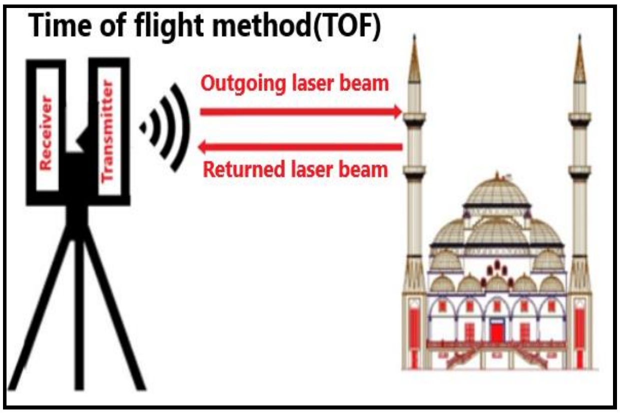

Figure 1. Time of flight

Advantages of These Systems:

Provide high accuracy in long-range measurements.

Have fast data collection capacity for large-area scans.

Deliver reliable results even in low light intensity or variable environmental conditions.

Disadvantages:

May be limited in measuring small details that require high resolution.

Scanning time is generally longer compared to phase shift systems

2.1.2 Phase shift (PS) method

In the phase shift method, the distance is determined by measuring the phase difference between the emitted and the reflected laser signals. This method is used for short-range and high-resolution detailed scanning [7,25]. Phase shift scanners can provide millimeter-level accuracy and are advantageous for generating dense point clouds.

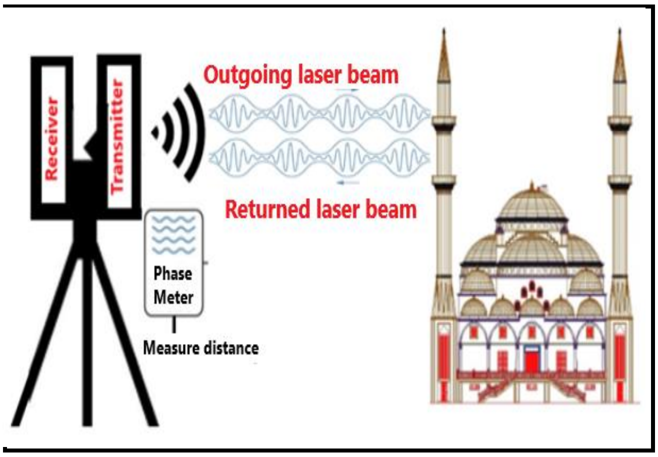

Figure 2. Phase difference

Advantages:

Allows high-accuracy measurement of small details.

Due to high point density, it is effective in detecting surface deformations and deteriorations.Can perform fast scanning in short-range applications.

Disadvantages:

Measurement range is more limited compared to ToF systems; it is more suitable for short- and medium-range measurements.

Ambient light and surface reflectivity can affect measurement accuracy.

2.1.3 Circular and linear scanning modes

Laser scanners can operate in circular (rotary) and linear modes depending on their mechanical scanning movements.

Circular Scanning: The scanner rotates 360° around its own axis to scan the entire surrounding area. This mode is suitable for the rapid scanning of large-scale open areas or building facades. In rotary scanning, the scanning angle and rotation speed can be adjusted to optimize the desired point density and data resolution. Circular scanning is especially preferred for the documentation of archaeological sites, city squares, and large monuments [1,25].

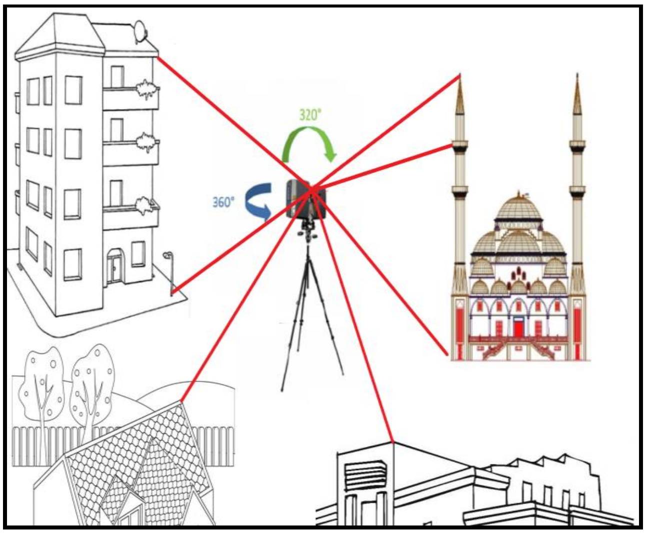

Figure 3. Circular scanning

Linear Scanning: The scanning movement is performed along a specific plane or line. This mode is ideal for detailed surface analysis and for applications requiring precise measurements, such as interior space documentation or the examination of stone surface deformations. The data density obtained through linear scanning is generally higher than that of rotary scanning, offering an advantage in applications that require high resolution.

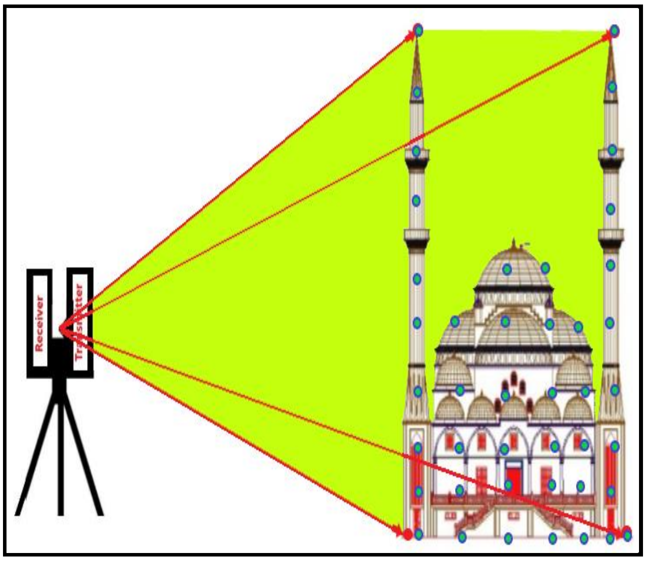

Figure 4. Lineer scanning

2.1.4 Scanner selection criteria

The selection of a TLS (Terrestrial Laser Scanning) device depends on factors such as the scale of the application area, the required measurement accuracy, data collection time, and environmental conditions (Table 1). For example:

Large structures and outdoor environments: Long-range ToF scanners and rotary scanning are preferred.

Small objects and fine details: Phase shift scanners and linear scanning are used.

Complex areas: Optimized data can be obtained by integrating both methods and combining scanning modes [1,7,25].

Table1. Selection of scanners

Application Area	**Recommended Scanner Type**	**Technical Specifications**
Wide open areas, topographic surveys	ToF-based, long-range rotary scanner	300–1000 m range, low point density, IP54 protection
Documentation of historical structures and cultural heritage	Phase shift scanner	50–200 m range, high density, low margin of error
Industrial facilities and pipelines	Phase shift scanner	10–50 m range, high accuracy (±1–2 mm)
Archaeological excavation sites	Portable ToF systems or integrated TLS-UAV systems	Medium range, multi-station capability
Tunnels and underground structures	ToF systems	Operates in low light, high range resolution

2.2 Scanning Planning and Position Selection – Detailed Explanation

In Terrestrial Laser Scanning (TLS) projects, scanning planning and position selection—that is, choosing the points where the instrument will be set up—are critically important for data quality and measurement accuracy. Proper scanning planning increases field efficiency and facilitates the data processing workflow [1,25].

Importance of Scanning Planning Scanning planning involves determining the locations and angles where the scanner will be positioned in advance. Each scanning position has a specific field of view and range. Insufficient position selection can lead to data gaps and missing surface information. There must be sufficient overlap between scans taken from different points. This overlap ensures accurate registration (alignment) of point clouds and improves coordinate accuracy [5,7,26]. Closer positions are preferred in areas with dense surface details. For example, stone surface cracks or embossed details should be scanned from closer scanner positions [25]. Criteria for Selecting Scanning Positions;

Geometric Features of the Structure: The height, width, and indoor-outdoor relationships of the structure determine scanner positions. For example, for interior ceiling details, tripod height and scanner angle should be carefully planned [1,25].

Accessibility Conditions: Physical access to the scanning area, equipment size, and safety considerations are taken into account. In hard-to-reach areas, mobile scanners or long-range systems may be preferred [20,27,28].

Scanning Angle and Perspective: The scanning angle is important for accurately representing surfaces. Surfaces that are irregular or inclined should be scanned from multiple angles. This is a critical factor especially in detecting cracks and deterioration in stone materials [5,25].

Environmental Conditions: Environmental factors such as lighting, reflection, dust, humidity, and temperature affect scanning quality. For instance, laser intensity and scanning angle should be optimized for shiny or reflective surfaces (Figure 5)[7].

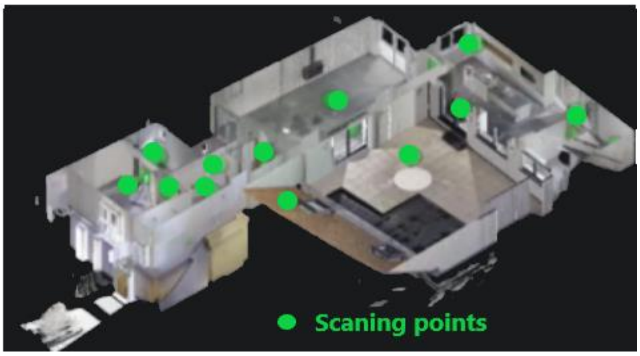

Figure 5. Scanning point positions

Number of Scanning Points and Scanning Strategies

Minimum Scanning: The smallest number of scanning points that provides sufficient overlap and data coverage is preferred. This reduces field time and data processing workload.

Dense Scanning: In areas requiring high detail and accuracy, the number of positions is increased. For example, more frequent scans are taken for embossed stone surfaces or delicate architectural details [1,25].

Hybrid Scanning: Different strategies can be combined for large areas and detailed sections. Wide-angle scans can be used for exterior facades, while dense positions are employed for interior details [20,27].

Scanning Planning Tools and Software Modern TLS projects use software and simulation tools for scan planning:

Image Simulations: The field of view and range in the scanning area are analyzed beforehand using 3D modeling.

Point Cloud Preview: The expected point cloud density for planned scanning positions is estimated.

Optimization Algorithms: The number of scanning points is optimized to be minimal while ensuring maximum data coverage [1,25].

Results of Scanning Planning Well-planned scanning points:

Minimize data gaps and missing areas.

Facilitate point cloud registration processes.

Increase measurement accuracy and ensure data quality. Optimize field time and cost [5,20].

2.3 Point Cloud Processing and Surface Modeling

The raw data obtained from Terrestrial Laser Scanning (TLS) consists of point clouds containing millions of points. These data are not suitable for direct analysis; they must be processed, verified, and converted into a meaningful three-dimensional model [1,7,20]. Point cloud processing and surface modeling are critically important in cultural heritage projects to ensure the geometric accuracy of the structure and to perform detailed analyses.

2.3.1 Point cloud and data density

The scanning method and scanner type directly affect the density and accuracy of the generated point cloud. High point density is crucial for detecting surface deformations and material deterioration. For cultural heritage studies, point clouds with millimeter-level accuracy are preferred (Figure 6). Each point in the point cloud includes X, Y, and Z coordinate information as well as additional data such as reflection intensity, which provides a significant advantage for surface characterization and material analysis [1,7,25].

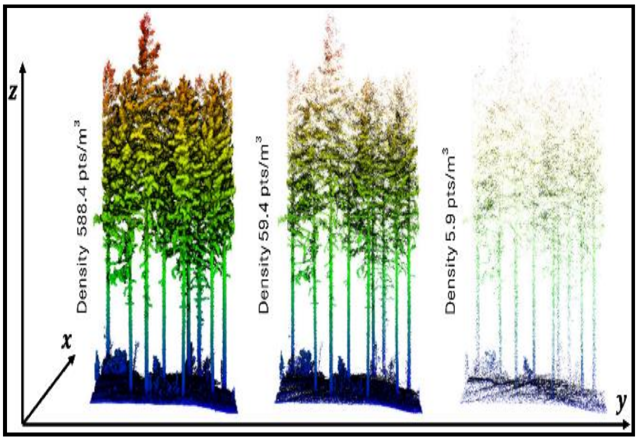

Figure 6. Point density [3]

Raw point clouds contain noise due to measurement errors, sensor deviations, or environmental factors. This noise can reduce modeling and analysis accuracy. Cleaning steps include:

Outlier Removal: Extreme values appearing as measurement errors in a single scan are removed.

Density-Based Filtering: Points with low density or isolated points are removed from the dataset.

Surface Smoothing: Unnecessary small details are reduced while preserving the main geometric features of the structure [5,25].

Data from multiple scanning positions are merged using common reference points or targets. Technical details of this step include:

Target-Based Methods: Prisms or markers placed in the field ensure accuracy between scans.

Cloud-Based Methods (Cloud-to-Cloud Registration): Automatic algorithms, such as ICP (Iterative Closest Point), are used to align point clouds [1,20].

This step is critically important for modeling large or hard-to-access structures.

Data from different scanning points must be transformed into a common coordinate system:

Terrestrial Coordinate System: The model is aligned with map or project coordinates.

Scale Control: Measurement accuracy is verified, and systematic deviations are minimized [25,27].

2.3.2 Surface modeling

Processed point clouds can be converted into 3D surface models for analysis and visualization. The points are connected using a triangular mesh. The mesh density is adjusted according to the complexity of the surface; denser triangles are used in detailed areas. This model accurately represents both interior and exterior geometries [1,7].

Material loss can be calculated for restoration planning. Cracks, breaks, and wear can be quantitatively identified. Structural changes can be monitored by comparing data collected at different times [5,25].

Photographic or color data can be integrated into the point cloud and mesh models. Colored and textured models provide understandable presentations for both scientific analysis and for the public and decision-makers [20,27].

Commonly used software for point cloud processing and surface modeling includes:
FARO Scene: Data filtering, registration, and modeling.
CloudCompare: Open-source software for cloud-based registration and analysis.
Autodesk ReCap / Geomagic: Mesh creation, visualization, and CAD integration [1,25,27].

2.3.3 Data collection and point cloud generation

TLS data is collected by sensors that detect the return of laser beams, creating sets of 3D coordinates known as point clouds [1,25,29]. These point clouds are then processed in software environments for 3D modeling, surface analysis, and metric measurements. In their study on the Uzuncaburç Monumental Entrance Gate, [30] compared TLS data with photogrammetry and demonstrated that TLS provides high accuracy [19].

2.3.4 Precision and accuracy

TLS systems can achieve millimeter-level accuracy and detect surface roughness, cracks, and deformations [4,19]. Noted that compared to digital photogrammetry, laser scanning offers advantages especially on steep and difficult-to-access surfaces.

The reliability and validity of data obtained in TLS projects are directly related to measurement accuracy and data quality. This step is critical for the precise documentation and restoration planning of cultural heritage structures Quality and accuracy analyses involve checks performed during and after the scanning process. Under typical scanning conditions, measurement deviations due to atmospheric refraction and surface reflectivity range between ±2–5 mm. Variations increase at larger incidence angles (>60°) or longer scanning distances exceeding 100 m. [1,7,25].

2.4 Advantages and Disadvantages of Terrestrial Laser Scanning

Advantages:
High accuracy and resolution,
Ability to scan complex geometries in detail,
Fast data acquisition,
Possibility of integration with multiple data sources [4,12].

Disadvantages:
High cost equipment,
Data processing and storage requirements,
Sensitivity to line-of-sight obstructions,
Performance variations depending on weather conditions [1,7].

3. Application Areas in Cultural Heritage

The preservation and documentation of cultural heritage are critically important for both scientific research and restoration projects. Terrestrial Laser Scanning (TLS) technology is widely preferred in this context due to its high accuracy, rapid data acquisition, and capability for detailed analysis. TLS data enables the creation of three-dimensional models of architectural structures, monuments, sculptures, and archaeological sites [1,15,18,31].

3.1 Documentation of Architectural Structures

Terrestrial laser scanning is ideal for detailed surveying of historic buildings and monuments. For example, conducted a study on the Mezgit Castle Monumental Tomb in Silifke, Mersin, where they produced high-resolution surveys and 3D models using TLS data [15]. Similarly, [32] documented stone material degradations on the facade of Şanlıurfa Kışla Mosque by integrating TLS and photogrammetry, resulting in an analytical report [25]. These studies ensure the accurate recording of the current state of the structures and support restoration plans with scientific data (Figure 7).

TLS is especially advantageous for structures with complex geometries. Point clouds can detect cracks, deformations, and material degradations at millimeter-level precision [1,25,19,33]. This data can be used both for visual presentation and metric analysis.

Figure 7. Architectural building documentation

3.2 Modeling of Archaeological Sites

In archaeological sites, terrestrial laser scanning is used to accurately record the topography of the area and the locations of remains. Combined UAV and TLS data at the Kanlıdivane archaeological site to create detailed 3D models, enabling the digital documentation of the area [21,34]. Such models are indispensable for excavation planning, analysis, and archaeological data sharing.

In [35], TLS was used alongside close-range photogrammetry to document the reliefs on stone surfaces in detail [25]. This approach allowed both measurements and visual analyses to be conducted with high accuracy.

Figure 8. Archeological documentation

Table 2. Comparative summary of TLS performance in different cultural heritage sites.

Site	Material Type	Average Point Density (pts/m²)	Mean Accuracy (mm)	Remarks
Mezgit Kale	Limestone	250	±3.0	Fine details visible
Uzuncaburç	Marble	300	±2.5	Smooth surfaces
Kanlıdivane	Rough stone	220	±4.0	Lower reflectivity

3.3 Detection of Stone Material Deterioration

Monitoring material deterioration is critical in the preservation of cultural heritage [32] documented stone material deterioration at Mersin Sarısih Han using UAV photogrammetry integrated with TLS analysis [5]. This approach enabled the identification of both deterioration types and mechanisms.

Data obtained from TLS especially highlights cracks and wear on stone and brick surfaces in 3D. Color mapping applied over the point cloud allows visualization of the extent of material degradation [25].

3.4 Digital Archiving and Educational Use

TLS data plays an important role not only in restoration and scientific research but also in digital archiving and educational applications. In [36] digitally archived 3D models of historic caravanserais and demonstrated the usability of this data for educational purposes [25].

Similarly, created 3D models of Roman-era artifacts in the Silifke-Mersin region, making them available for animation and virtual exhibitions [20,37]. Such digital models serve as effective tools to increase public access and contribute to the conservation of cultural heritage.

3.5 Methodological Approaches

Different methodological approaches are used in TLS-based cultural heritage documentation. The multi-scan registration method is generally preferred, involving scanning the structure from various angles and merging the resulting point clouds. This minimizes data loss in shaded or inaccessible areas [1,15,25].

Data processing steps, including filtering, alignment, and 3D model generation of point clouds, are critically important. Integrated TLS and photogrammetry data to create a high-resolution 3D model of the Uzuncaburç Monumental Gate [18].

3.6 Digital Archiving and Virtual Restoration

3D models obtained through TLS provide reliable data for digital archiving and virtual restoration studies. These serve as references in case of damage or destruction of the structures [18,20]. Additionally, they can be used in virtual reality applications to enhance public access.

4. Analysis of Data Obtained by Terrestrial Laser Scanning and Application Examples

Terrestrial Laser Scanning (TLS) technology stands out as a method providing high accuracy, detail, and measurement reliability in the documentation and analysis of cultural heritage sites [1,4,16].

4.1 Analysis of Terrestrial Laser Scanning Data

Once TLS data is acquired, it is evaluated using various analysis techniques. The analysis process typically involves the following steps:

Geometric Analysis: Measurement of structural elements, surface slope, volume calculations, and crack detection based on scan data [18].

Material Deterioration and Surface Deformation Analysis: TLS data is used to determine the degree of deterioration in stone, brick, and other building materials. For example, produced deterioration maps of stone surfaces in the Mersin Sarisih Han study, identifying both erosion and cracks [25,27].

Topographic and Positional Analysis: Elevation differences, slopes, and topographic changes on the terrain can be measured with high precision using TLS data. Combined TLS data with Sentinel-2 satellite data to perform a detailed geographic analysis of the Hersek Lagoon coastline [20,38].

4.2. Example Studies

Uzuncaburç Monumental Gate: Combined TLS and photogrammetry data to create a detailed 3D model of the monumental gate. The geometric features and material deterioration of the structure were analyzed with millimeter precision [18].

Mersin Silifke Mezgit Castle: Modeled the castle mausoleum using TLS data and identified surface deterioration and cracks. This model served as a reference for restoration and conservation efforts [15].

MKanlıdivane Archaeological Site: Nerged TLS and UAV photogrammetry data to produce a high-accuracy 3D model of the site, providing essential data for structural analysis and archaeological inventory [21,34].

Qobustan Rock Art: Scanned small-scale rock art objects using TLS and digitally archived them. This approach is critically important for the digital preservation of cultural heritage [25,35].

5. Integration of Terrestrial Laser Scanning and Photogrammetry

TLS and photogrammetry are complementary technologies widely used in cultural heritage documentation. While TLS produces highly accurate point clouds by measuring laser reflections [1,7], photogrammetry generates 3D models from image-based methods [6,19]. Combining these two techniques compensates for each method’s limitations, enhancing both geometric and visual accuracy [18,21].

Integration of TLS and photogrammetry data can be achieved through various methods:

Coordinate System Alignment: TLS data is transformed into the same coordinate system as photogrammetric models for accurate overlay and improved measurement accuracy [18].

Merging Point Clouds and Photographic Layers: Combining TLS data with photogrammetric images results in models containing both geometric and visual information, advantageous for detailed deterioration analyses, especially on stone surfaces [25].

Detail Enhancement and Resolution Optimization: High-resolution photogrammetric images are projected onto TLS point clouds, enriching details while maintaining measurement accuracy and photographic realism [15,18]. For TLS–photogrammetry integration, the ICP (Iterative Closest Point) algorithm was used in CloudCompare for point cloud alignment. Further model optimization was conducted in Autodesk ReCap, and texture mapping was performed using Agisoft Metashape

5.1 Advantages of Integration in Cultural Heritage Documentation

The integration of TLS and photogrammetry offers several benefits in cultural heritage projects:
High Precision and Detail: TLS provides geometric accuracy, while photogrammetry adds color and texture information. Together, they document both the shape and surface features of structures in detail [18,25,43].
Time and Labor Efficiency: Photogrammetry allows rapid scanning of large areas, while TLS delivers detailed data with precise measurements. Their combination reduces fieldwork effort and optimizes data collection time [21].
Restoration and Conservation Planning: Integrated models provide more reliable data for analyzing deterioration and deformation, which are crucial for restoration projects [25].

6. Measurement Accuracy and Data Quality in Terrestrial Laser Scanning

6.1 Concept of Measurement Accuracy

In Terrestrial Laser Scanning (TLS) systems, measurement accuracy refers to how closely the acquired point clouds correspond to real-world coordinates [1,7]. Accuracy includes the reliability of both 3D coordinates and distance measurements. In cultural heritage documentation, high accuracy directly influences the reliability of restoration and analytical processes [16,25].
The main factors affecting accuracy include:
Type and resolution of the scanner sensor,
Scanning distance and angle,
Environmental conditions (light, temperature, humidity)
Point cloud processing methods [1,18].

6.2 Point Cloud Density and Distribution

Point cloud density determines the level of detail in scanning results. In cultural heritage documentation, sufficient density enables the detection of fine details and surface deterioration [18,25]. Density may vary depending on scanner parameters, scanning distance, and angle.
Methods to increase density include:
Optimizing scanning positions,
Increasing scanning resolution,
Supporting the scan with repeated measurements [7,39].

6.3 Impact of Scanning Parameters on Data Quality

TLS data quality is directly related to scanning parameters. Key parameters include:
Scanning Angle: Low angles can increase shadowing and missing data on surfaces [1].
Scanning Distance: Greater distances can increase measurement errors and reduce point density [7,16].
Scanning Speed: Rapid scans may introduce noise and reduce accuracy [18].
Optimizing these parameters enhances data quality and reduces processing time [25].

6.4 Methods for Improving Data Quality

TLS data quality can be improved during the processing stage through several techniques:
Noise Filtering: Removing random errors and environmental noise from the point cloud enhances analysis accuracy [1,18].
Geometric Correction and Registration: Merging data from multiple scanning positions into a common coordinate system ensures complete and accurate models [7,25].
Calibration: Periodic calibration of scanners maintains long-term measurement accuracy [16,39].

6.5 Case Studies

Mezgit Kale Mausoleum: Analyzed the effects of different scanning parameters and optimized data accuracy in their study [15].
Uzuncaburç Monumental Gate: Achieved a highly accurate 3D model by optimizing scanning parameters and point cloud density [18].
Ağzıkara Caravanserai: processed TLS data to enhance point cloud accuracy, enabling detailed restoration analysis [34,40].

7. Conclusions and Recommendations

Terrestrial Laser Scanning (TLS) technology stands out as a critical tool in cultural heritage documentation due to its high precision and capacity to acquire extensive datasets. TLS enables the collection of detailed geometric data of heritage structures with high accuracy, providing a reliable foundation for restoration, conservation, and maintenance planning.
Compared to traditional measurement methods, TLS allows for the rapid collection of large datasets and offers significant savings in time and labor during fieldwork. The resulting 3D point clouds and models support multi-scale analysis at both the structural and material levels, enabling the quantitative identification of cracks, losses, wear, and other forms of material deterioration in stone structures [5,25,41].
Integrating TLS data with photogrammetry and UAV imagery allows the creation of geometrically and visually rich 3D models [5,20,39]. These models serve as reliable references for digital archiving and can be critical in cases of structural damage or collapse [18,20]. Moreover, TLS facilitates the monitoring of deterioration and changes over time, aiding in the prioritization of restoration efforts [25,39,42].
From a methodological perspective, scanning plans should be optimized in advance based on building height, detail density, and accessibility. During point cloud

merging, noise filtering and data validation steps must be carefully implemented. TLS data must be transformed into appropriate coordinate systems before integration with other data sources [1,5,20,25,39]. Regular scanning of cultural heritage sites allows for the monitoring of deterioration processes over time and supports restoration planning.

To ensure the effective use of TLS technology, field engineers, conservators, and researchers should receive regular training. Large datasets must be securely stored and made accessible to relevant stakeholders [1,7,18,20,43].

Future research should explore the use of artificial intelligence and machine learning techniques for point cloud analysis, the development of mobile TLS and drone-based scanning systems, and the correlation of TLS data with the mechanical properties of stone materials. These advancements will accelerate deterioration detection and data classification processes, make field operations more dynamic and flexible, and strengthen restoration planning. Furthermore, the use of 3D models in virtual and augmented reality environments will support restoration workflows while offering the public engaging and accessible cultural heritage experiences.

Recent studies have demonstrated the potential of artificial intelligence and deep learning techniques in automating heritage analysis. For example, convolutional neural networks (CNNs) have been used for automatic crack detection on stone surfaces, while machine learning classifiers such as Random Forest and SVM have achieved high accuracy in point cloud classification and material segmentation.

Acknowledgement

Author contributions

The contribution rates of the authors are equal.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Unal, M., Yakar, M., & Yildiz, F. (2004). Discontinuity surface roughness measurement techniques and the evaluation of digital photogrammetric method. In Proceedings of the 20th international congress for photogrammetry and remote sensing, ISPRS (1103), p. 1108.
2. Karataş, L., Alptekin, A., Karabacak, A., & Yakar, M. (2022). Detection and documentation of stone material deterioration in historical masonry buildings using UAV photogrammetry: A case study of Mersin Sarisih Inn. Mersin Photogrammetry Journal, 4(2), 53-61.
3. 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.
4. Yılmaz, H. M., & Yakar, M. (2006). Yersel lazer tarama teknolojisi. Yapı Teknolojileri Elektronik Dergisi, 2(2), 43-48.
5. Yakar, M., Orhan, O., Ulvi, A., Yiğit, A. Y., & Yüzer, M. M. (2015). Sahip Ata Külliyesi Rölöve Örneği. TMMOB Harita ve Kadastro Mühendisleri Odası, 10.
6. Yılmaz, H. M., Karabörk, H., & Yakar, M. (2000). Yersel fotogrametrinin kullanım alanları. Niğde Üniversitesi Mühendislik Bilimleri Dergisi, 4(1), 1.
7. Yılmaz, H. M., & Yakar, M. (2006). Lidar (Light Detection And Ranging) tarama sistemi. Yapı Teknolojileri Elektronik Dergisi, 2(2), 23-33.
8. Yakar, M., & Doğan, Y. (2017). Mersin Silifke Mezgit Kale Anıt Mezarı fotogrametrik rölöve alımı ve üç boyutlu modelleme çalışması. Geomatik, 2(1), 11-17.
9. 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.
10. Villi, O., & Yakar, M. (2022). İnsansız hava araçlarının kullanım alanları ve sensör tipleri. Türkiye İnsansız Hava Araçları Dergisi, 4(2), 73-100.
11. Alptekin, A., & Yakar, M. (2020). Mersin Akyar Falezi'nin 3B modeli. Türkiye Lidar Dergisi, 2(1), 5-9.
12. Alptekin, A., & Yakar, M. (2020). Kaya bloklarının 3B nokta bulutunun yersel lazer tarayıcı kullanarak elde edilmesi. Türkiye Lidar Dergisi, 2(1), 1-4.
13. Yakar, M., Yılmaz, H.M., Yıldız, F., Zeybek, M., Şentürk, H., & Çelik, H. (2010). Silifke-Mersin Bölgesinde Roma Dönemi eserlerinin 3 boyutlu modelleme çalışması ve animasyonu. Jeodezi ve Jeoinformasyon Dergisi, (101).
14. Şenol, H. İ., Kaya, Y., Yiğit, A. Y., & Yakar, M. (2024). Extraction and geospatial analysis of the Hersek Lagoon shoreline with Sentinel-2 satellite data. Survey Review, 56(397), 367-382.
15. 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.

16. 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.
17. Kanun, E., Alptekin, A., & Yakar, M. (2021). Cultural heritage modelling using UAV photogrammetric methods: A case study of Kanlıdivane archeological site. Advanced UAV, 1(1), 24-33.
18. Alyilmaz, C., Alyilmaz, S., & Yakar, M. (2010). Measurement of petroglyphs (rock of arts) of Qobustan with close range photogrammetry. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 38 (Part 5), 29-32.
19. Yakar, M., Uysal, M., Toprak, A. S., & Polat, N. (2013). 3D modeling of historical doger caravansaries by digital photogrammetry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40, 695-698.
20. Yılmaz, H. M., Karabörk, H., & Yakar, M. (2000). Yersel fotogrametrinin kullanım alanları. Niğde Üniversitesi Mühendislik Bilimleri Dergisi, 4(1), 1.
21. Mohammed, O., & Yakar, M. (2016). Yersel fotogrametrik yöntem ile ibadethanelerin modellenmesi. Selcuk University Journal of Engineering Sciences, 15(2), 85-95.
22. Kanun, E., Alptekin, A., & Yakar, M. (2021). Documentation of cultural heritage by photogrammetric methods: a case study of Aba's Monumental Tomb. Intercontinental Geoinformation Days, 3, 168-171
23. Karataş, L., Alptekin, A., & Yakar, M. (2022). Investigation of Molla Hari (Halil) Süleyman Paşa Mosque's material deteriorations. Advanced Engineering Days (AED), 4, 55-57.
24. Ulvi, A., Yakar, M., Alyilmaz, C., & Alyilmaz, S. (2017). Using the close range photogrammetry technique in 3-dimensional work: History of obrukhan sample. International Multidisciplinary Scientific GeoConference: SGEM, 17, 347-355.
25. 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.
26. Pulat, F., Yakar, M., & Ulvi, A. (2022). Three-dimensional modeling of the Kubbe-i Hasiye Shrine with terrestrial photogrammetric method. Cultural Heritage and Science, 3(1), 6-11.
27. Yakar, M., Yildiz, F., Alyilmaz, C., & Yilmaz, H. M. (2009). Photogrammetric study for Sircali Medrese Door. 9-th International Multidisciplinary Scientific GeoConference SGEM 2009, 879-884.
28. Yakar, M., Uysal, M., Toprak, A. S., & Polat, N. (2013). 3D modeling of historical doger caravansaries by digital photogrammetry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40, 695-698.
29. Yakar, M., Alyılmaz, C., Telci, A., Baygul, E., Çolak, S., Aydın, M., & Yılmaz, H. M. (2009). 3D laser scanning and photogrammmetric measurement of Akhan caravansaray
30. Karataş, L., Alptekin, A., & Yakar, M. (2022). 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
31. Karabacak, A., & Yakar, M. (2023). Giyilebilir Mobil LiDAR'ın Kadastroda Kullanılabilirliği. Türkiye Lidar Dergisi, 5(2), 52-60.
32. Khan, N. A., Carabin, G., & Mazzetto, F. (2025). Mobile Laser Scanning in Forest Inventories: Testing the Impact of Point Cloud Density on Tree Parameter Estimation. Sensors, 25(18), 5798. https://doi.org/10.3390/s25185798
33. Guidi, G., Russo, M., Ercoli, S., Remondino, F., Rizzi, A., Menna, F., (2009). A multi-resolution methodology for the 3D modeling of large and complex archeological areas. Int. J. Archit. Comput.,(7), 39–55.
34. Jung, J., Yoon, S., Ju, S., Heo, J., (2015). Development of kinematic 3D laser scanning system for indoor mapping and as-built BIM using constrained SLAM. Sensors, (15), 26430–26456.
35. Shafaat ,O.S., Kauhanen, H., Julin, A., Vaaja, M.T., (2025). 3D Change Detection of Urban Vegetation Using Integrated TLS and UAV Photogrammetry Point Clouds, Ieee Journal Of Selected Topıcs In Applıed Earth Observatıons And Remote SensınG, VOL. 18, 24976-24989
36. Liu, J., Azhar, S., Willkens, D., and Li. B., (2023). Static terrestrial laser scanning (TLS) for heritage building information modeling (HBIM): A systematic review. Virtual Worlds 2 (2): 90–114
37. Karagianni, A., (2021). Terrestrial laser scanning and satellite data in cultural heritage building documentation. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVI-M-1-2021 (Aug): 361–366
38. Nazari, S. W., Akarsu, V., & Yakar, M. (2023). Analysis of 3D Laser Scanning Data of Farabi Mosque Using Various Softwaren. Advanced LiDAR, 3(1), 22-34
39. Hoon, Y. J., and S. Hong. , (2019). Three-dimensional digital documentation of cultural heritage site based on the

convergence of terrestrial laser scanning and unmanned aerial vehicle photogrammetry." ISPRS Int. J. Geoinf. 8 (2): 53.

40. Pena-Villasenín, S., Gil-Docampo, M., Ortiz-Sanz, J., (2019). Professional SfM and TLS vs a simple SfM photogrammetry for 3D modelling ofrock art and radiance scaling shading in engraving detection. Journal ofCultural Heritage, 37, 238–246.
41. Gautier Q.K., Garrison T.G., Rushton, F., Bouck, N., Lo, E.,Tueller, P., Schurgers C., Kastner, R., (2020). Low-cost 3D scanning systems for cultural heritage documentation. J Cult Heritage Manage Sustain Dev 10 (4): 437–455.
42. Camina, J., Javier Sánchez-Aparicio, L., Mayo, C., Gonzalez-Aguilera, D., (2022). Analysis of a SLAM-based laser scanner for the 3D digitalization of underground heritage structures. A case study in the wineries of Baltanas (Palencia, Spain). In: Furferi R et al. (Eds). The future of heritage science and technologies: ICT and digital heritage. Cham: Springer International, vol 1645, 42-56
43. Vatan, M., Selbesoglu, M.O.,Bayram, B., (2009). The use of 3D laser scanning technology in preservation of historical structures Wiadomości Konserwatorskie, 26, 659-669