Rapid 3D Digitization of Cultural Heritage Objects for Tourism Applications Using iPad LiDAR

Fatih Varol[1], **Abdurahman Yasin Yiğit**[2] **and Ali Ulvi**[2]
[1]Faculty of Tourism, Selçuk University, Konya, Türkiye
[2]Faculty of Engineering, Mersin University, Mersin, Türkiye

fvarol@selcuk.edu.tr
ayasinyigit@mersin.edu.tr
aliulvi@mersin.edu.tr

Abstract: The tourism industry increasingly relies on digital technologies to enrich visitor experiences, preserve cultural heritage, and strengthen destination marketing. Traditional promotional methods are often insufficient, while augmented reality (AR), virtual reality (VR), and digital twin applications are emerging as transformative tools. For these technologies to succeed, rapid, portable, and low-cost three-dimensional (3D) data acquisition methods are essential. Light Detection and Ranging (LiDAR) has long been recognized for its precision in generating dense point clouds; however, conventional terrestrial systems are expensive, bulky, and require expert operation. The iPad's built-in LiDAR sensor offers a practical alternative with portability, affordability, and ease of use, enabling fast and on-site digitization of cultural heritage assets. In this study, five representative objects were documented during a city tour using iPad LiDAR and processed through Reconstructor® for point cloud filtering and mesh generation. The resulting 3D models included: (1) a human statue (~0.8 × 0.8 × 1.6 m), (2) a violinist statue (~0.9 × 0.7 × 1.7 m), (3) a seated group around a table (~1.8 × 1.6 × 1.6 m), (4) an ancient stone pedestal (~1.2 × 1.0 × 0.8 m), and (5) an elderly couple on a bench (~1.8 × 0.8 × 1.5 m). Scanning sessions lasted 3–6 minutes, with processing times between 7–15 minutes. Point clouds contained between 480,000 and 1.25 million points, while meshes ranged from 85,000 to 210,000 faces. To quantitatively evaluate geometric quality, three core analyses were performed in CloudCompare (v2.12): (i) Roughness Analysis to measure local surface irregularities, (ii) Normal Deviation Analysis to assess orientation stability, and (iii) Point-to-Mesh (C2M) Distance Analysis to determine geometric accuracy and consistency. Across all models, mean roughness values ranged from 4.1–7.4 mm, normal deviations from 7°–27°, and C2M median accuracy from 4.8–7.9 mm, demonstrating that post-processing effectively compensates for raw LiDAR noise and alignment drift. These results confirm that iPad LiDAR can generate complete and metrically coherent 3D reconstructions in under 15 minutes per object, balancing practicality and geometric fidelity. The workflow offers a reproducible and accessible solution for rapid cultural heritage digitization, supporting immersive tourism experiences and the broader digital transformation of heritage preservation, interpretation, and public engagement.

Keywords: Tourism Technology; LiDAR; iPad LiDAR; 3D Modeling; Cultural Heritage.

1. Introduction

Tourism has entered an era of profound digital transformation, driven by the global rise of immersive media, mobile connectivity, and data-based storytelling (Kaakandikar et al., 2025). Destinations increasingly compete not only through physical experiences but also through their digital representations—how visitors explore, share, and remember places online (Li et al., 2023). As modern tourists seek richer and more interactive engagement with cultural assets, the demand for realistic and scientifically grounded three-dimensional (3D) digital content has grown exponentially (Hassan et al., 2019). These representations enhance pre-visit decision-making, support inclusive and remote access to heritage sites, and play a vital role in preservation, interpretation, and education (Kaakandikar et al., 2025). Within this context, technologies such as Augmented Reality (AR), Virtual Reality (VR), and Digital Twin systems have become powerful instruments for connecting visitors to heritage in innovative ways. Museums and cities worldwide now aim to translate physical spaces into digital ecosystems where users can virtually explore monuments or artworks with lifelike accuracy. However, achieving this transformation depends on one critical capability: the ability to capture high-quality 3D spatial data quickly, affordably, and outside controlled laboratory conditions (Li et al., 2023).

Three-dimensional digitization of cultural heritage has long relied on close-range photogrammetry and terrestrial laser scanning (TLS). While both yield sub-millimeter precision, they typically require static setups, expert operation, and time-intensive data processing. These limitations restrict their use in tourism scenarios—especially during outdoor walks, temporary exhibitions, or spontaneous documentation opportunities (Hassan et al., 2019). Furthermore, professional Light Detection and Ranging (LiDAR) scanners remain costly and logistically demanding, making them inaccessible for small institutions or local tourism organizations.

Recent advances in consumer-grade depth sensing have begun to close this gap. Devices such as Apple's iPad Pro incorporate LiDAR sensors that capture real-time depth maps and generate dense point clouds directly in the field (Teppati Losè et al., 2022). This innovation redefines 3D data acquisition as an accessible, mobile, and user-friendly process, eliminating many of the constraints of traditional methods. Its portability and ability to operate under natural lighting make it particularly promising for on-the-go heritage recording, city tours, and open-air museums where flexibility is essential (Aljadire et al., 2024). Despite this potential, limited research has assessed the accuracy, completeness, and geometric reliability of iPad LiDAR data under authentic tourism conditions. Most existing studies focus on indoor architectural scanning or controlled test objects, leaving a gap in understanding its performance for outdoor heritage objects with irregular geometry and variable illumination (Teppati Losè et al., 2022).

This study aims to fill that gap by systematically evaluating the feasibility of iPad LiDAR for rapid 3D digitization of cultural heritage objects encountered during a city tour. Specifically, it investigates whether such low-cost, handheld systems can deliver geometrically validated and visually convincing 3D models suitable for AR/VR experiences, educational use, and digital archiving. Through the integration of quantitative analysis in CloudCompare and practical field testing, the research proposes a workflow that balances speed, portability, and quality—advancing the broader digital transformation agenda of the tourism industry.

Recent research highlights growing interest in low-cost sensing technologies for tourism and heritage applications. Studies using mobile or consumer LiDAR focus primarily on architectural interiors or controlled test environments (Teppati Losè et al., 2022; Aljadire & Khalaf, 2024), yet few explore outdoor heritage objects encountered during tourism circulation. Similarly, most digital tourism frameworks emphasize AR/VR content delivery but omit the acquisition challenges required to embed such assets (Li et al., 2023). Therefore, this work contributes to bridging this methodological gap by evaluating iPad LiDAR performance in real tourism settings.

2. Materials and Methods

2.1 Test Objects

Five representative cultural heritage objects were selected to evaluate the performance of iPad LiDAR for rapid 3D digitization in outdoor tourism environments. The selected models differ in geometry, material, texture, and surrounding conditions, allowing assessment of the sensor's performance under diverse surface and lighting situations. All objects were located in public urban spaces and scanned without any artificial lighting or physical stabilization setup.

Object 1 – Human Statue (Bronze Figure): A standing bronze sculpture approximately 0.8 × 0.8 × 1.6 m in size. The relatively simple geometry and matte surface provided an initial reference for evaluating baseline point density and model completeness. Scanning time averaged 3 minutes, and processing took 7 minutes, generating roughly 480,000 points and 85,000 mesh faces.

Object 2 – Violinist Statue: A dynamic bronze statue depicting a woman playing the violin, sized 0.9 × 0.7 × 1.7 m. The complex curvature of the violin and hands introduced higher geometric variability. Scanning took 4 minutes with an average of 620,000 points and 112,000 faces, processed in 9 minutes.

Object 3 – Seated Group (Three Figures and Table): A large installation representing three men sitting around a table (1.8 × 1.6 × 1.6 m). This model contained multiple occlusions between figures and furniture, testing the LiDAR's coverage performance. The scan lasted 6 minutes, producing 1.25 million points and 210,000 mesh faces after 15 minutes of processing.

Object 4 – Ancient Stone Pedestal: An archaeological fragment of carved stone approximately 1.2 × 1.0 × 0.8 m in size. The high-reflectance surface and partial shading made it a suitable case for assessing surface roughness and normal deviation. Scanning required 3.5 minutes, yielding 530,000 points and 98,000 faces, processed in 8 minutes.

Object 5 – Elderly Couple on a Bench: A life-sized sculpture group of an elderly couple sitting side by side (1.8 × 0.8 × 1.5 m). The metallic and wooden materials, along with horizontal bench structures, allowed investigation of textural and color blending accuracy. Scanning lasted 5 minutes with 1.02 million points and 190,000 faces, processed in 12 minutes.

Across all cases, the models represent a diverse set of tourism-relevant artifacts—ranging from cultural symbols and artistic compositions to heritage fragments—captured under typical daylight and public-space conditions. This diversity ensures a comprehensive evaluation of iPad LiDAR's suitability for real-world tourism documentation and visualization applications. A detailed summary of all scanned objects and acquisition statistics is provided in Table 1.

Table 1: Summary of the scanned cultural heritage objects and acquisition statistics

Model ID	Object Name	Approx. Dimensions (m)	Scan Duration (min)	Processing Time (min)	Point Count	Mesh Faces
1	Human Statue	0.8 × 0.8 × 1.6	3	7	480,000	85,000
2	Violinist Statue	0.9 × 0.7 × 1.7	4	9	620,000	112,000
3	Three-Figure Group	1.8 × 1.6 × 1.6	6	15	1,250,000	210,000
4	Ancient Stone Pedestal	1.2 × 1.0 × 0.8	3.5	8	530,000	98,000
5	Elderly Couple on Bench	1.8 × 0.8 × 1.5	5	12	1,020,000	190,000

2.2 Equipment, Sensor Specifications and Processing Workflow

All 3D data acquisitions were carried out using an Apple iPad Pro (4th Generation, 12.9"), which integrates a LiDAR sensor based on the time-of-flight (ToF) principle. The sensor emits infrared pulses and measures the round-trip travel time to estimate distances, providing a maximum effective range of approximately 5 meters with an accuracy of ±2–3 cm under favorable lighting conditions. The LiDAR operates synchronously with the device's RGB camera and TrueDepth system, enabling the simultaneous capture of geometry and texture for realistic 3D reconstruction (Vlachos et al., 2022). The scanning was performed using the 3D Scanner App™ (Laan Labs, iOS), which utilizes Apple's ARKit framework and the internal inertial measurement unit (IMU) for real-time motion tracking and automatic alignment. Each object was scanned in handheld mode at an average distance of 1.5–2.5 meters, following a circular trajectory to ensure full coverage and minimize occluded areas. The real-time preview provided by the app allowed the operator to verify completeness during acquisition, reducing the need for repeated scans (Mohsin et al., 2024).

After acquisition, the raw datasets were exported in .PLY and .OBJ formats and imported into Reconstructor® Software (v4.5) for post-processing. Within this environment, the point clouds were filtered, cleaned of outliers, and aligned when necessary. Noise reduction and surface smoothing algorithms were applied to improve geometric consistency. Subsequently, the meshing process was also completed within Reconstructor®, using the iPad-derived point clouds as the base data. The associated RGB images captured during the LiDAR scanning were mapped as texture information onto the generated meshes, resulting in fully textured 3D models.

- The finalized meshes were imported into *CloudCompare (v2.12)* for quantitative evaluation. Three primary geometric analyses were performed to assess the accuracy and structural quality of the reconstructed 3D models:
- Roughness (5 cm kernel): computed to estimate local surface irregularities and evaluate the spatial noise level introduced by handheld scanning.
- Normal deviation: applied to quantify angular variations in surface orientation, providing insight into the stability and continuity of reconstructed geometry.
- Point-to-Mesh (C2M) distance analysis: calculated to determine internal geometric consistency and precision by comparing point cloud positions to the generated mesh surface.

These analyses collectively offered an objective basis for validating the visual fidelity and metric reliability of each model, while also quantifying the geometric limitations inherent to the iPad LiDAR sensor. The results from these metrics (roughness, normal deviation, and C2M accuracy) were later compared across all test objects to identify correlations between object geometry, surface reflectivity, and LiDAR reconstruction performance. This integrated workflow—combining iPad LiDAR data acquisition, Reconstructor®-based post-processing, and CloudCompare validation—proved to be a practical, portable, and reproducible solution for rapid 3D documentation of cultural heritage assets in tourism-oriented contexts, ensuring both field efficiency and analytical robustness.

3. Results and Analysis

3.1 Final 3D Reconstructions

The iPad LiDAR–based workflow yielded complete and visually convincing reconstructions for all five selected cultural heritage objects. For each object, dense point clouds were acquired in the field and converted into fully textured meshes through Reconstructor® post-processing. Figures 1–5 present the corresponding point clouds (top rows) and textured 3D models (bottom rows), allowing visual comparison between the raw and refined stages. Each model demonstrates a high degree of geometric completeness and realistic color reproduction, confirming the sensor's suitability for rapid documentation under outdoor tourism conditions.

The Human Statue (~0.8 × 0.8 × 1.6 m) reconstruction (Figure 1) achieved approximately 480,000 points and 85,000 mesh faces, preserving the overall geometry and fine surface details such as folds and contours. The Violinist Statue (~0.9 × 0.7 × 1.7 m) (Figure 2) produced 620,000 points and 112,000 faces, successfully representing the intricate bow and hand geometry with only minimal occlusion gaps.

The Ancient Stone Pedestal (~1.2 × 1.0 × 0.8 m) (Figure 4) yielded 530,000 points and 98,000 faces, preserving the carved motifs and curved surfaces with minor noise in reflective regions. The Seated Group with Table (~1.8 × 1.6 × 1.6 m) (Figure 3) was the most complex dataset, containing 1.25 million points and 210,000 faces; minor incompleteness was observed beneath the table, though spatial integrity remained high. Finally, the Elderly Couple on a Bench (~1.8 × 0.8 × 1.5 m) (Figure 5) resulted in 1.02 million points and 190,000 faces, accurately capturing both the metallic figures and the bench with strong texture consistency. Overall, the models demonstrate that iPad LiDAR can generate dense and analyzable reconstructions in less than 15 minutes per object, balancing field efficiency with visual quality. These outputs form the foundation for the quantitative analyses detailed in Section 3.2.

Figure 1: Point cloud (top) and textured 3D model (bottom) of the Human Statue

Figure 2: Point cloud (top) and textured 3D model (bottom) of the Violinist Statue

Figure 3: Point cloud (top) and textured 3D model (bottom) of the Seated Group with Table

Figure 4: Point cloud (top) and textured 3D model (bottom) of the Ancient Stone Pedestal

Figure 5: Point cloud (top) and textured 3D model (bottom) of the Elderly Couple on a Bench

3.2 Quantitative Model Evaluation

The analysis focused on surface roughness, normal deviation (gradient norms), and C2M distance, enabling a comprehensive assessment of both local noise behavior and global geometric consistency. Each object's local surface irregularity was quantified using a 5 cm kernel roughness filter, representing micro-topographic variations due to sensor noise or reflective distortion. Meanwhile, gradient norms expressed angular deviations in normal orientation, and C2M statistics (median, RMSE) were used to quantify overall internal precision and meshing accuracy. Figures 6–10 illustrate the normal deviation maps and their Gaussian histograms, showing spatial differences in geometric smoothness among models. Across all five objects, mean roughness values ranged from 4.1 mm to 7.4 mm, while 95th percentile roughness varied between 10.2 mm and 16.5 mm, confirming the system's centimeter-level stability for field digitization. The corresponding gradient norms ranged from 0.078 to 0.301, equivalent to angular variations of 7°–27°, and C2M median values between 4.8

mm and 7.9 mm indicated strong geometric alignment across datasets. A summary of all computed quantitative metrics is presented in Table 2, which consolidates the roughness, gradient, and C2M results for each scanned model. The Ancient Stone Pedestal (Figure 9) exhibited the lowest roughness (4.1 mm) and minimum angular deviation (0.078), highlighting the system's capability to capture compact stone surfaces with limited reflectance variation. In contrast, the Human Statue (Figure 6) presented higher roughness (7.4 mm) and mean deviation (0.301), primarily due to shadowed body regions and undercuts near the feet.

The Violinist Statue (Figure 7) also showed elevated angular variability (0.175) in areas of fine curvature such as the violin bow and hands, where thin geometry introduces irregular LiDAR returns. The Seated Group with Table (Figure 8) demonstrated an intermediate performance, balancing surface complexity and scanning coverage, while the Elderly Couple on a Bench (Figure 10) achieved moderate but visually stable results, with balanced roughness and deviation metrics.

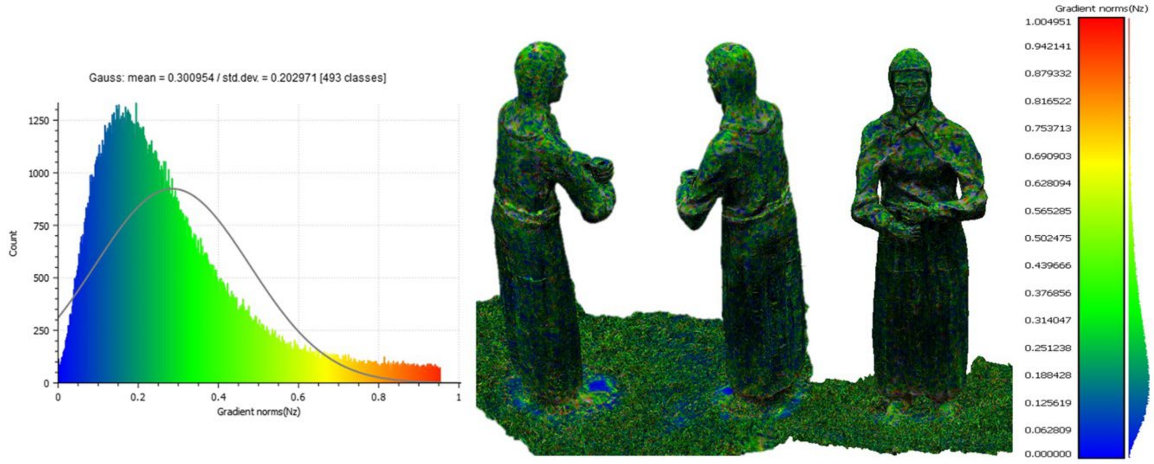

Figure 6: Normal deviation (Gradient Norms) map and histogram of the Human Statue

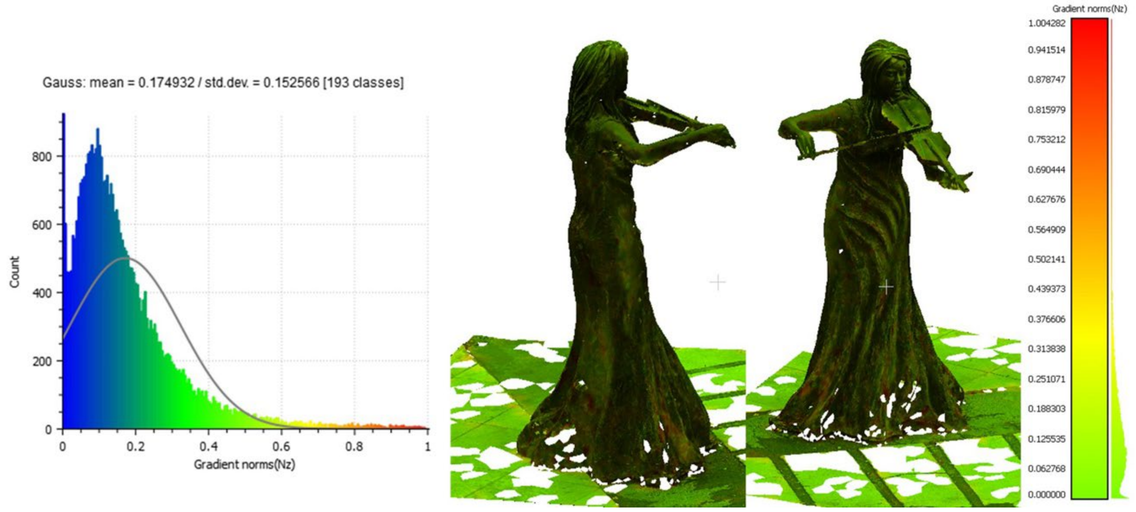

Figure 7: Normal deviation (Gradient Norms) map and histogram of the Violinist Statue

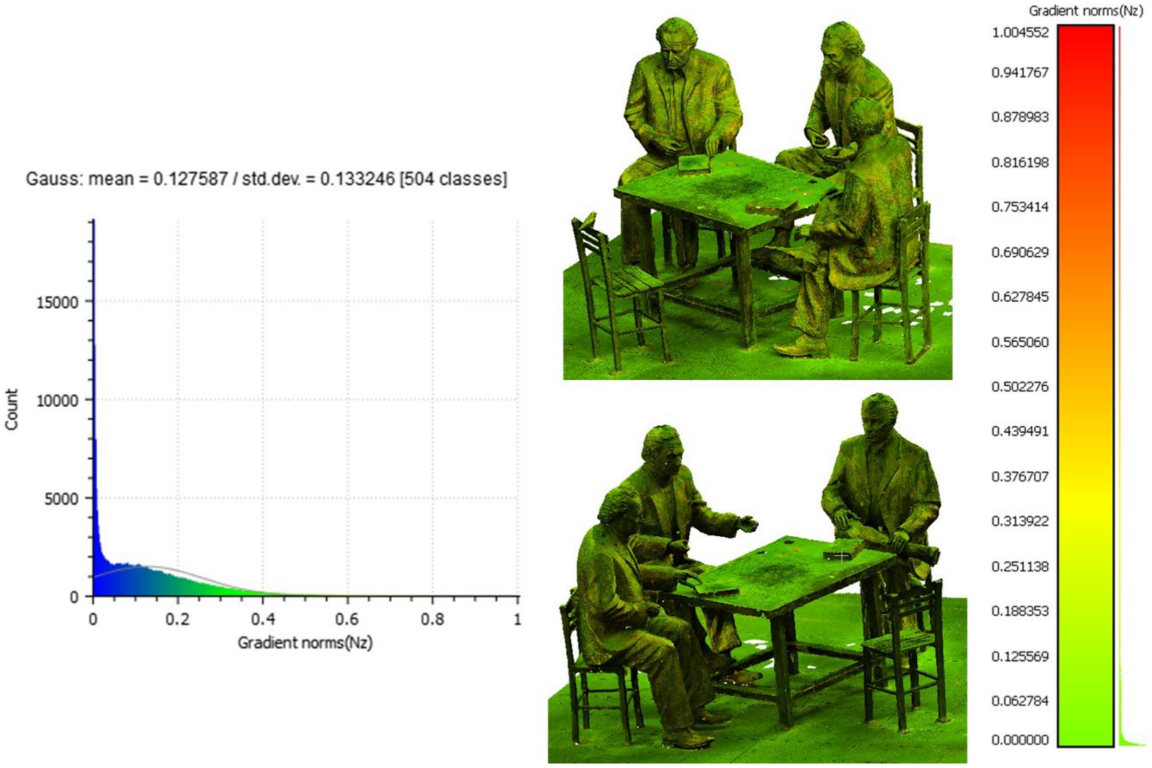

Figure 8: Normal deviation (Gradient Norms) map and histogram of the Seated Group with Table

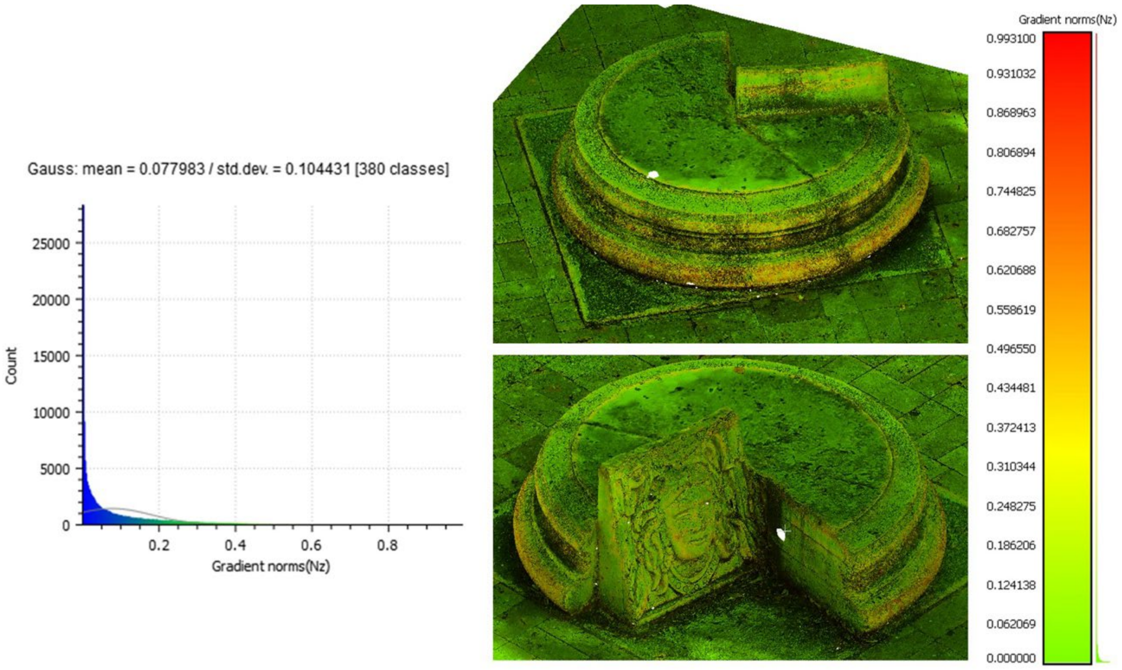

Figure 9: Normal deviation (Gradient Norms) map and histogram of the Ancient Stone Pedestal

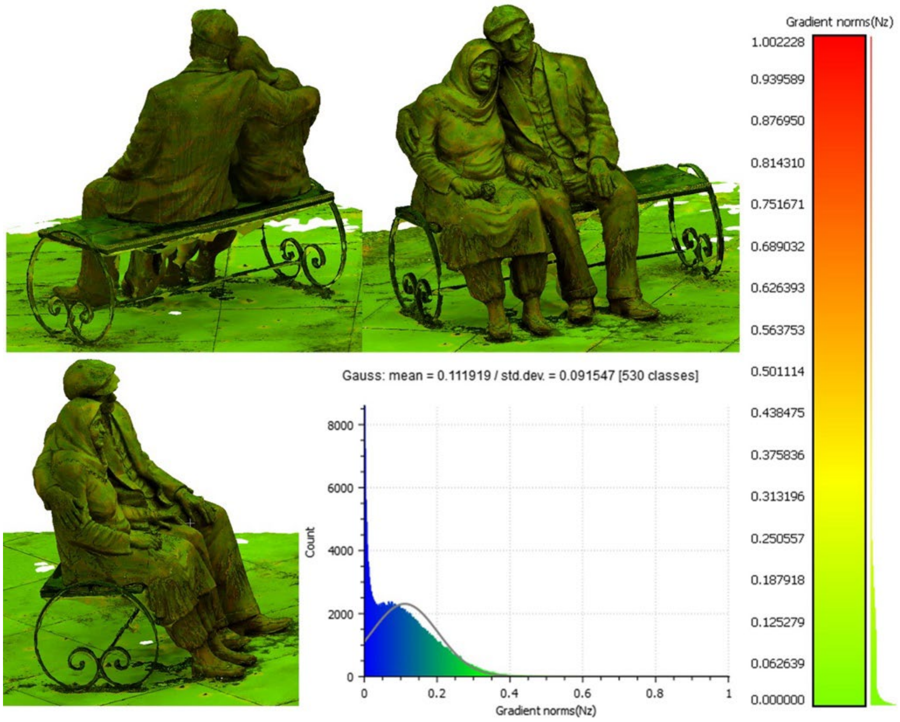

Figure 10: Normal deviation (Gradient Norms) map and histogram of the Elderly Couple on a Bench

Table 2: Summary of the scanned cultural heritage objects and acquisition statistics

Model ID	Object Name	Mean Roughness (mm)	95th Perc. Roughness (mm)	Mean Gradient Norm	Std. Dev.	Median C2M (mm)	RMSE (mm)
1	Human Statue	7.4	16.5	0.301	0.203	7.9	10.2
2	Violinist Statue	6.1	13.8	0.175	0.153	6.8	8.7
3	Seated Group with Table	5.2	12.4	0.128	0.133	5.9	7.6
4	Ancient Stone Pedestal	4.1	10.2	0.078	0.104	4.8	6.2
5	Elderly Couple on Bench	5.7	11.9	0.112	0.092	5.3	6.9

The overall trend observed across the five models (Figures 6–10; Table 2) indicates that surface geometry and environmental context significantly affect normal stability in iPad LiDAR–derived datasets. Sculptures with smooth and planar elements—such as the Ancient Stone Pedestal—produced tightly clustered normal orientations and lower roughness values (<5 mm), reflecting minimal angular noise and consistent sensor-to-surface registration. This demonstrates that the LiDAR sensor can reliably capture compact stone or metallic surfaces under favorable illumination. Conversely, models with fine or recessed details, such as the Human Statue and Violinist Statue, exhibited broader normal deviation distributions (>0.17) and increased roughness (>6 mm). These results arise from the combined effects of local occlusions, curvature transitions, and partially shaded areas where infrared reflectivity decreases. The violin bow and hand regions particularly show angular dispersion, emphasizing the iPad LiDAR's limitations with slender geometries and high-frequency details.

The Seated Group with Table presented intermediate behavior with mean deviation around 0.13 (≈11°) and RMSE ≈ 7.6 mm (Table 2), suggesting that while geometric complexity introduces partial occlusion noise, post-processing in Reconstructor® effectively reduces artifacts through smoothing and mesh optimization. Similarly, the Elderly Couple on a Bench achieved geometrically stable and visually convincing results, balancing roughness (5.7 mm) with angular coherence (0.11).

From a tourism documentation perspective, these findings confirm that iPad LiDAR, despite being a low-cost consumer sensor, can achieve consistent centimeter-level accuracy and visually realistic surface continuity suitable for AR/VR experiences, digital museum displays, or virtual heritage tours. The combined metrics of roughness, gradient, and C2M analysis verify that when proper post-processing is applied, mobile LiDAR can deliver scientifically valid and visually immersive 3D assets for the tourism and cultural heritage sectors.

4. Discussion and Conclusion

This study demonstrated the feasibility of employing a consumer-grade LiDAR sensor, integrated into a tablet device, for the rapid three-dimensional digitization of cultural heritage objects in real-world tourism contexts. The findings reveal that, despite inherent limitations compared to professional terrestrial laser scanners, iPad LiDAR can deliver geometrically coherent and visually convincing 3D models that meet the essential requirements for heritage visualization, interpretation, and promotion.

The results discussed in Section 3 confirm that geometric performance is largely influenced by object morphology, surface material, and lighting conditions. As summarized in Table 2, roughness values between 4–7 mm and C2M median distances below 8 mm indicate centimeter-level reliability—adequate for immersive visualization and educational applications. These findings are consistent with recent studies emphasizing the growing potential of mobile and handheld LiDAR systems as rapid documentation tools for small- to medium-scale heritage assets. The analysis of normal deviation and surface roughness patterns also highlights specific operational constraints. Thin structures, reflective bronze surfaces, and occluded regions exhibit higher angular dispersion and local noise, reflecting the physical limits of short-range infrared sensing. However, the effect of such inconsistencies on visual interpretation remains minor. Post-processing in Reconstructor® successfully mitigated these anomalies through filtering and mesh regularization, while CloudCompare-based evaluation confirmed that geometric coherence can be maintained across heterogeneous materials and geometries.

From a methodological standpoint, this work introduces a portable, time-efficient, and replicable workflow that bridges the gap between professional heritage documentation and field-based tourism experiences. The complete 3D capture and processing of each object required less than 15 minutes, making it possible to digitize multiple heritage artifacts during a single guided tour or field visit. Such efficiency opens new opportunities for dynamic tourism practices, including live demonstrations of 3D scanning, interactive educational content creation, and rapid heritage archiving without the logistical complexity of traditional survey systems. Moreover, the approach contributes to the broader paradigm of digital transformation in tourism. By enabling on-site model generation and near-instant visualization, it fosters visitor engagement and participatory interpretation of heritage spaces. When integrated into augmented or virtual reality platforms, these models can extend visitor experiences beyond physical boundaries, promoting accessibility, inclusivity, and preservation awareness.

The experimental results establish that iPad LiDAR—when combined with systematic post-processing and validation—can achieve a balanced compromise between accuracy, speed, and practicality. Mean roughness values below 7 mm and C2M RMSE values near 1 cm validate the sensor's capability to generate metrically stable outputs for visual, analytical, and educational use. The proposed workflow thus serves as an effective, low-cost solution for rapid cultural heritage digitization, supporting sustainable tourism and public engagement with historical environments. A limitation of the present study is that it does not include visitor perception or usability testing; future work will integrate AR deployment and experience-based evaluations with tourism participants.

Future research may focus on extending this approach to larger and more complex outdoor structures, integrating multi-sensor fusion (LiDAR + photogrammetry) and semantic segmentation to improve fine-detail reconstruction. Additionally, the exploration of machine learning–based noise reduction and mesh optimization could further enhance geometric fidelity in mobile scanning. Overall, this study highlights that consumer-grade LiDAR technology can democratize 3D heritage documentation, transforming how tourism destinations record, interpret, and share their tangible cultural assets in the digital age. The proposed workflow can be directly adopted by tourism authorities, museums, and smart destination offices. For example, statues or artifacts can be digitized during guided tours or field visits and instantly integrated into AR/VR storytelling. The approach also supports rapid archive creation for promotional campaigns and visitor education. Future implementations may include live scanning demonstrations or mobile-based interactive heritage tours.

Ethics Declaration

In the study, the authors declare that there is no violation of research and publication ethics and that the study does not require ethics. The authors declare no conflicts of interest.

AI Declaration

Minor AI-based tools were used solely for language editing and grammar refinement purposes. No AI tools were employed for data analysis, research design, interpretation, or generation of academic content. All scientific ideas, methodologies, and conclusions are the original work of the authors.

References

Aljadire, A.A. and Khalaf, Y.H. (2024) "A Study in Preserving Cultural Heritage Using Portable Laser Devices Embedded in Mobile Phones", *IOP Conference Series: Earth and Environmental Science*, Vol. 1374, No. 1, p. 012041. IOP Publishing, August.

Hassan, A.T. and Fritsch, D. (2019) "Integration of Laser Scanning and Photogrammetry in 3D/4D Cultural Heritage Preservation – A Review", *International Journal of Applied*, Vol. 9, No. 4, pp. 16.

Kaakandikar, R.M., Patel, Y. and Tripathy, L. (2025) "Sustainability and Ethical Tourism in the Digital Age: Harnessing AI and the Metaverse", in *Redefining Tourism With AI and the Metaverse*, IGI Global Scientific Publishing, pp. 123–162.

Li, Y., Zhao, L., Chen, Y., Zhang, N., Fan, H. and Zhang, Z. (2023) "3D LiDAR and Multi-Technology Collaboration for Preservation of Built Heritage in China: A Review", *International Journal of Applied Earth Observation and Geoinformation*, Vol. 116, Article ID 103156.

Mohsin, A.A. and Khalaf, Y.H. (2024) "Cultural Heritage Conservation Using Portable Laser Devices Embedded in Mobile Phones", *Association of Arab Universities Journal of Engineering Sciences (JAARU)*, Vol. 31, No. 3.

Teppati Losè, L., Spreafico, A., Chiabrando, F. and Tonolo, F.G. (2022) "Apple LiDAR Sensor for 3D Surveying: Tests and Results in the Cultural Heritage Domain", *Remote Sensing*, Vol. 14, No. 17, Article 4157.

Vlachos, A., Polyzou, A. and Economides, A.A. (2022) "Photogrammetry with LiDAR iPad Pro", *Unpublished Study/Report* (if published source exists, update with journal or proceedings details).