Low-Cost Mobile LiDAR and RTK GNSS Integration for Georeferenced HBIM of Cultural Heritage

A Scan-to-BIM Workflow Based on Multi-Sensor Data Fusion for Accuracy Enhancement

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Abstract. This study discusses a scan-to-BIM workflow based on the integration of low-cost mobile LiDAR and RTK GNSS, focusing on cultural heritage, and compares the performance of two different portable scanning systems. An 18th-century Sibyan School was selected as a case study, managed by Mimar Sinan Fine Arts University (MSGSU), Istanbul. The study employed a viDoc RTK-enabled iPad Pro (photogrammetry + LiDAR) and a Realsee Galois M2 tripod-mounted panoramic 3D LiDAR scanner. Point cloud data obtained from both systems were georeferenced with RTK GNSS control points, and their location accuracies were comparatively assessed. The generated point cloud datasets were combined using a multi-sensor data fusion approach and fed into an HBIM-based modeling process. Component geometries were analyzed for detail, data gaps, and noise. The findings indicate that the RTK-enabled viDoc method offers advantages in terms of location accuracy and level of detail, while the Realsee Galois M2 stands out for its rapid deployment, indoor coverage, and practical field use. In conclusion, the study suggests that low-cost mobile systems should be considered as part of a multi-sensor hybrid cultural heritage documentation and digital twin production strategy rather than completely replacing terrestrial laser scanning and suggests a repeatable workflow for similar projects.

Keywords. Mobile LiDAR, RTK GNSS, HBIM, Scan-to-BIM, Data Fusion, Cultural Heritage, Digital Twin, Sibyan School, MSGSU

1. Introduction

Digital documentation of cultural heritage structures is critical for protecting them from disasters and destruction, and for their preservation for future generations. Digital twin and Historic Building Information Modeling (HBIM) approaches provide three-dimensional, semantic, and high-fidelity representations of heritage, providing decision

HUMANISTIC COMPUTATION AND INTELLIGENCE, Proceedings of the 31st International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2026, Volume 3, 71-80.

support in restoration, maintenance, and virtual exhibition processes (Murphy et al., 2009). ICOMOS (2020) and UNESCO (2021) promote HBIM models with high data accuracy and compatibility with open standards such as IFC/CityGML.

While traditional Terrestrial Laser Scanning (TLS) offers high accuracy, it is limited in terms of cost and flexibility (Kuçak et al., 2023). In contrast, mobile LiDAR sensors (e.g., iPad Pro) and SLAM-based systems provide low-cost and rapid data collection (Teppati Losè et al., 2022). However, absolute location accuracy decreases without GNSS support (Ubaidillah et al., 2023). Integration of GNSS receivers such as the Pix4D viDoc RTK Rover can improve the georeference accuracy of mobile LiDAR scans, providing positional accuracies close to those of traditional systems (Zollini & Marconi, 2025). Consumer-grade Matterport systems, with a dimensional accuracy of approximately 1% (±10 cm at 10 m), offer time and cost advantages in studies that do not require high precision (Matterport, 2025b; Fiorini et al., 2023; Hariffin et al., 2023; Wang et al., 2025). Mobile SLAM-based systems (iPad with viDoc RTK, Matterport Pro3, Realsee Galois, XGRIDS Lixel L2 Pro, etc.) introduce a new paradigm in terms of portability and speed (Pix4D, 2022; Realsee, 2025b). Literature shows that these low-cost mobile systems provide sufficient detail and accuracy in most scenarios. This study examines a scan-to-BIM workflow based on the integration of mobile LiDAR and RTK GNSS data at the cultural heritage scale. The aim is to georeference point cloud data collected with low-cost devices to the centimeter level to produce HBIM models and increase documentation accuracy. In this context, a repeatable and scalable method for historical structures is proposed by combining mobile scanning and high-precision positioning techniques. The following sections summarize related studies and technologies and evaluate the XGRIDS Lixel L2 Pro. A comparative study of the same sample structure using viDoc RTK + iPad Pro and Realsee Galois M2 is then presented, and data quality and HBIM integration are discussed.

2. Literature Review Mobile 3D Scanning Technologies

2.1. DEVELOPMENT OF MOBILE SCANNING METHODS

Traditional fixed Terrestrial Laser Scanners (TLS) have been reliable in detailed measurement of cultural heritage, but their high cost, heavy equipment, and multi-stage recording processes require time and expertise (Kuçak et al., 2023). These limitations have led to the rapid development of mobile laser scanning approaches that offer more flexible solutions in the field. Handheld/shoulder-type SLAM scanners and smartphone-based LiDAR systems reduce scanning time by allowing the operator to move freely, enabling measurements even in hard-to-reach areas.

This transformation has accelerated with the integration of LiDAR sensors into iPhone and iPad models after 2020; these sensors can generate 3D point cloud data at close range. Teppati Losè et al. (2022) demonstrated that the iPad Pro LiDAR sensor can perform rapid scans with a few centimeters of accuracy in cultural heritage measurement. However, drift accumulation due to IMU-based positioning can lead to deviations in large or long-term scans. To address this issue, solutions such as the viDoc RTK mounted on a smartphone significantly reduce drift by stamping absolute coordinates onto each frame with an RTK-GNSS receiver, providing global positioning accuracy of 1–3 cm under favourable conditions. Llabani & Kopliku

(2024) reported that an Ottoman bridge could be modeled with a precision of ±3 cm using a viDoc-enabled iPhone and that an archaeological site showed a difference of <1 cm from the TLS reference; this demonstrates that mobile scanning can compete with traditional instruments.

Another advantage of mobile scanning is the speed of data collection. The ability to scan while moving continuously allows for the documentation of larger areas at the same time. However, smartphone-based mobile scanning has limitations in terms of accuracy and noise: periodic position corrections are recommended for large areas and loop closure strategies in indoor environments. It is emphasized that mobile LiDAR points can be sparser and noisier than those of professional scanners, resulting in better results when combined with photogrammetry (Jeftha & Shoko, 2024).

2.2. INTEGRATED LIDAR CAMERAS (MATTERPORT VS REALSEE)

The Realsee Galois offers advantages such as long battery life (up to 8 hours), fast scanning time (93 m² scanned in ±15 minutes), and immunity to sunlight (capable of scanning outdoor historical structures). Most importantly, the scanning application allows previewing and merging data in the field; this provides a more flexible and controllable workflow compared to Matterport, which only enables cloud processing (Realsee, n.d.; Matterport, 2025c). The most striking aspect of Realsee is its open data outputs and ease of integration. E57/PLY point cloud files, OBJ/FBX mesh models, 2D floor plans (PNG), and 360° panoramas are automatically generated from data uploaded to the cloud; these outputs can be directly imported into software such as Autodesk Revit, AutoCAD, or CloudCompare. The business model is designed to allow device owners to upload and process unlimited scans free of charge while maintaining data ownership by charging only low-cost fees for web hosting/sharing (RobotShop, n.d.). In conclusion, the Realsee Galois M2 offers significant advantages over Matterport in terms of speed, ease of use, and open data outputs; Although its measurement accuracy lags that of classical TLS, it constitutes an accessible documentation alternative for a wide range of users (Realsee, n.d.; Matterport, n.d.).

2.3. SLAM BASED SCANNERS (XGRIDS LIXEL L2 PRO)

Although not field-tested in this study, the XGRIDS Lixel L2 Pro is a SLAM-based handheld LiDAR system developed for professional mapping and large-scale 3D scanning. Thanks to LiDAR–IMU–camera sensor fusion, it generates real-time point cloud data while the operator is on the move. Its 32-channel rotating LiDAR unit achieves a range of up to 300 m and positional accuracy of 2–3 cm. Its lightweight, ergonomic, and modular design (RTK kit, extension rod, vehicle/drone mount) adapts to various scanning scenarios, from single monuments to large historical urban areas (Epotronic, n.d.). The LixelStudio software within the XGRIDS ecosystem combines and filters raw data to produce LAS, E57, or mesh outputs. Lixel CyberColor Studio, based on 3D Gaussian Splatting, enables rapid export of photorealistic 3D models to web, Unity/Unreal, and AR/VR environments (Epotronic, n.d.). This allows the workflow from mobile scanning to a virtual navigable model to be largely automated.

While L2 Pro's direct cultural heritage applications are limited, similar SLAM-based systems demonstrate the technology's potential. Giuliani et al. (2024)

documented the Pisa city walls with mobile LiDAR (GeoSLAM Horizon) and RTK GNSS to produce an HBIM model with ±3–5 cm accuracy. Tanduo et al. (2023) achieved ±3 cm accuracy in the basement of Castello del Valentino. These examples demonstrate the potential of systems like L2 Pro to accelerate scan-to-HBIM processes by providing sufficiently accurate data in significantly less time than TLS, provided appropriate data fusion and control points are implemented; however, instrument cost and computational requirements remain significant constraints.

3. Scanning Comparison with ViDoc and Realsee

This section presents a comparative analysis of scans taken with viDoc RTK + iPad Pro and Realsee Galois M2 devices on the 18th-century Sibyan School and Fountain. The case study site is managed by Mimar Sinan Fine Arts University (MSGSU). Field access and on-site data acquisition were conducted with institutional authorization. The two-story structure, constructed in alternating stone and brick, has recently undergone restoration, and detailed documentation is crucial (Kültür Envanteri, n.d.).

3.1. DATA COLLECTION

Scanning was conducted using viDoc RTK hardware and Pix4Dcatch software, using the iPad Pro's LiDAR sensor, with the operator walking around the structure. Simultaneous RTK GNSS measurements (with NTRIP corrections) achieved centimeter-level accuracy, and the data was linked to the ITRF-based TUREF (Treccani et al., 2024). Thanks to the ViDoc RTK Rover's precise geotagging of each image frame, hundreds of photos and millions of LiDAR points obtained during the approximately one-hour scan were directly georeferenced. Additional photogrammetry shots were taken with a DSLR camera to document facades and interiors in one go, without interruption. Gaps identified during the instant preview during the scan were corrected with additional passes.

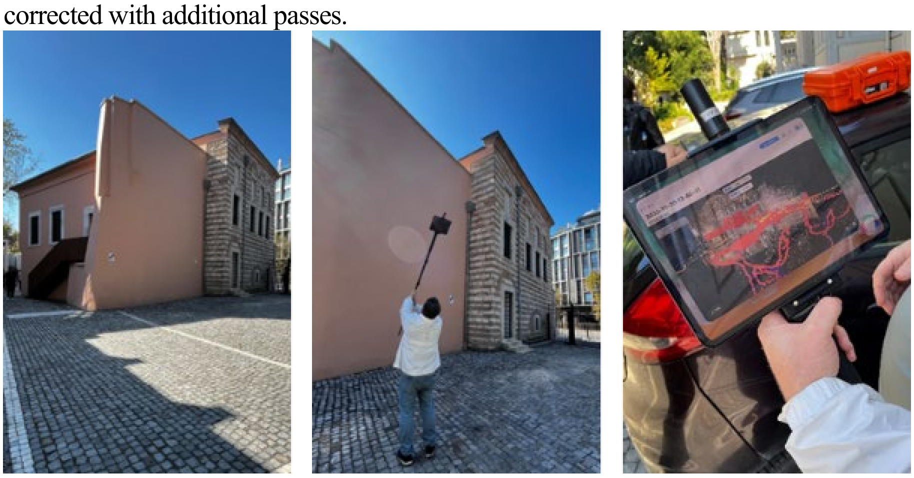

Figure 1. ViDoc – Pix4Dcatch Data Collection

The second scan was performed using a Realsee Galois M2, a static 360° multi-position scan. Sixty-seven tripod positions were identified to cover all facades and accessible interior spaces of the building. At each location, the device generated a color preview point cloud after internal pre-processing, and the interface provided feedback to the operator on the adequacy of overlap during movement between setups. Once all locations were complete, adjacent scans were automatically aligned using common points to create a unified point cloud. Total field time, including setup and location changes, was approximately two hours. During the sunny afternoon shooting, the panoramic camera's HDR feature ensured balanced exposures. Thanks to the LiDAR system's protection from sunlight, no significant degradation in data quality was observed.

Figure 2. Realsee Galois M2 Data Collection

Neither data collection method physically marked the structure. The viDoc + iPad approach produced direct georeferenced data in a short time thanks to free navigation, while the Realsee method provided high-resolution static scans at each location in exchange for longer field time. The viDoc scan recorded data directly into the national coordinate system using RTK GNSS. Because Realsee does not have an onboard GNSS, three RTK GPS control points near the structure were measured and used to convert the Realsee point cloud to the ITRF-based coordinate system. This conversion process allows both datasets to be compared within the same reference system.

3.2. POINT CLOUD PROCESSING

Point cloud datasets obtained from different sensors were subjected to rough alignment, noise filtering, density optimization, and georeferencing using open-source software such as CloudCompare (Çemrek et al., 2025). DSLR/drone photogrammetry data was integrated with the LiDAR cloud to enhance both geometric accuracy and visual realism, and color and texture were added (Ubaidillah et al., 2023).

For processing the viDoc data, RGB images collected from the iPad Pro and LiDAR depth data were transferred to Pix4Dmatic. Thanks to the precise position/direction information provided by viDoc, photogrammetric alignment was completed quickly, and LiDAR depth information was integrated into the solution to strengthen the model on surfaces where photogrammetry alone was challenging. In

Pix4Dmatic, using the "fused" point cloud option, the RGB-based dense point cloud and LiDAR points were combined into a single cloud, noise filtered, and exported in .las format (Pix4D, 2022). This process resulted in both a colored point cloud and a triangular surface mesh for visualization.

Despite the device's pre-merging, the final solution for processing the Realsee data was performed using the manufacturer's cloud-based Realsee Console platform. The platform automatically saved the multi-position scans and generated a full-resolution combined point cloud. After processing, the .e57 (colored point cloud), .obj (3D surface model), and 360° images/floor plan were downloaded. Although the Realsee point cloud was sparser than the viDoc cloud (approximately 1–2 cm point spacing), it was observed that both scans successfully represented the building geometry, demonstrating a high degree of overlap when overlaid in the same coordinate system.

Figure 3. Left side viDoc data displayed in CloudCompare .las format, Right side Realsee data displayed in Cyclone 3DR Viewer .e57 format

3.3. VERIFICATION AND OUTPUT

When compared to RTK GNSS points measured in the field, viDoc RTK supported iPad scanning provided high absolute accuracy for a mobile system, staying within ±2 cm at critical points (Pix4D, 2022; Zollini & Marconi, 2025; Llabani & Abazaj, 2024). In Realsee Galois M2, similar reference accuracy was achieved by aligning according to three RTK points instead of in-device positioning. In local precision, ±1–2 cm noise was observed on smooth walls in the viDoc + photogrammetry cloud, while the Realsee cloud provided a more homogeneous and smooth geometry thanks to the calibrated LiDAR sensor (Realsee, n.d.; Treccani et al., 2024). However, while point density decreased in shadowed areas in the Realsee scan, the ability of the operator to physically approach the blind spots mitigated this problem in the viDoc method. As a result, both methods provided accuracy at the centimeter level; viDoc is advantageous in absolute position, while Realsee is advantageous in surface continuity and smoothness.

Thanks to high-resolution photographs, the viDoc + iPad method captured millimetric details such as marble inscriptions and stone joints with an average point spacing of 4 mm. While Realsee's LiDAR data is limited to 1–2 cm with single-point precision, the continuity of the façade geometry is complete thanks to the approximately 44 million points generated from 67 scans. While the viDoc point cloud exhibits dense distribution at close range and sparse distribution at a distance, the integration of the photogrammetry cloud filled in the gaps by increasing the combined cloud to 108 million points. The colored point cloud data of both methods are sufficient to read material distinctions, but the viDoc model exhibits minor color seaming errors due to multiple photographs, while the Realsee model, thanks to HDR panoramas, produces more uniform tones and more controlled shadow/glow effects (Pix4D, 2022; Realsee, n.d.).

At the end of the viDoc + Pix4D workflow, a point cloud in LAS format of approximately 3.5 GB was generated. In addition, photogrammetric OBJ mesh and project files were obtained. The .e57 point cloud downloaded from the Realsee Console is approximately 3 GB in size and comes with HDR panoramas (JPEG) and a textured OBJ mesh. The fact that both methods offer industry-standard formats ensures compatibility issues during subsequent analysis and HBIM modeling stages. Realsee's automatic ground detection and scaled 2D floor plan generation offer a significant additional advantage (Realsee, n.d.), while a similar plan view was obtained by manually sectioning the point cloud on the viDoc side. These generated datasets were validated with TLS reference scanning and converted into an integrated HBIM data package containing plan-section-views, material inventory, and AR/VR integration files (Giuliani et al., 2024).

3.4. HBIM INTEGRATION

Point cloud datasets obtained from both mobile scanning systems are fully configurable into HBIM models using a similar workflow. The geo-referenced LAS point cloud generated with ViDoc + Pix4D was automatically aligned with the Turkish national coordinate system (ITRF-based), converted to .rcp format with Autodesk ReCap Pro, and imported into Autodesk Revit. The Realsee .e57 data, initially with local coordinates, was merged with CloudCompare to 67 scans. Then, the data was aligned with control points, exported to LAS format, and similarly converted to RCP using ReCap before being imported into Revit. This allowed the two data sets to be superimposed within a single project. Using the imported point clouds in the Revit environment as reference, it is possible to perform geometric and parametric modeling at the LOD 200–300 level, classify architectural components according to the IFC standard, and add material information and typological features to the model's semantic database (Rocha et al., 2020; Çemrek et al., 2025). This geo-referenced study offers the potential to transform the generated HBIM model into a digital twin readable by GIS systems, with its real location and environmental context. From a GeoBIM perspective, GIS-readable digital twins typically depend on open standards (IFC, CityGML, LADM), yet interoperability remains contingent on consistent georeferencing because BIM commonly uses local coordinates while geoinformation is defined in geographic coordinate frameworks, making cross-domain conversion unavoidable (Abdul Rahman, et al., 2026). In modeling studies, viDoc data provides detailed visual reference with its photo-based structure, while Realsee data, with its homogeneous colors from HDR panoramas, can be used for textural interpretation. The high accuracy achieved enables damage and deformation analyses; exporting the generated model in IFC format enables compliance with the open data standard and can be easily transferred to the VR environment and used in interactive presentations.

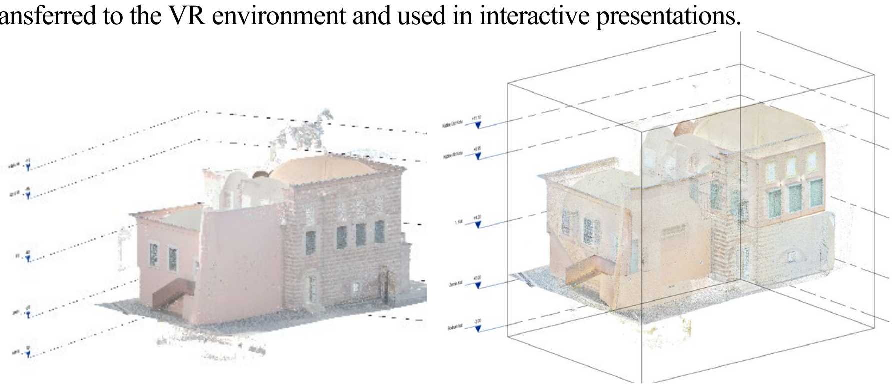

Figure 4. Comparison of ViDoc and Realsee Point Cloud in Revit

In conclusion, the Scan-to-BIM workflow has been successfully implemented with both viDoc and Realsee data, and both low-cost methods have been tested to produce HBIM outputs of sufficient quality for conservation projects.

4. Conclusion and Future Work

This study evaluated the usability of mobile SLAM-based systems in cultural heritage documentation using data acquired with the viDoc RTK-enabled iPad Pro and the Realsee Galois M2. While both systems offer low-cost and portable solutions, they also have distinct strengths. viDoc, with its centimeter-level absolute positioning accuracy thanks to its RTK GNSS integration and high detail with photogrammetry support, is particularly suitable for restoration and deformation monitoring applications requiring precise measurements. In contrast, its user-controlled workflow requires technical expertise and longer data processing times. Realsee Galois M2, with its automatic registration, cloud-based processing, and direct E57/OBJ output, stands out for its ease of use and speed. It offers a suitable tool for rapid documentation, virtual tours, and presentations to large audiences. However, its lack of absolute positioning and limited accuracy may necessitate calibration with external control points or viDoc-like systems in projects where measurement precision is critical. Overall, both devices can contribute to the widespread adoption of cultural heritage documentation by offering more accessible alternatives to traditional terrestrial laser scanning. The literature also demonstrates that low-cost mobile scanning combined with augmented reality applications can increase visitor engagement (Akbaylar et al., 2024).

This study demonstrated that a multi-sensor Scan-to-BIM workflow built with viDoc and Realsee data offers a scalable, repeatable framework suitable for HBIM production in cultural heritage structures. With rapid data collection in the field, minimal equipment, and relatively low operational costs, geo-referenced, information-rich models are produced, which can be used for restoration planning, due diligence, virtual exhibition, and training purposes.

The research also plans to apply XGRIDS Lixel L2 Pro to the same cultural heritage site to compare its quantitative and qualitative performance with viDoc and Realsee. Furthermore, by integrating AI-based automatic point cloud processing and semantic segmentation methods into the workflow, the HBIM production process is aimed at partially automating and improving output quality. The goal is to contribute to the development of tools and methods that will make the documentation of cultural heritage faster, more accurate and accessible to a wider range of users.

Acknowledgements

We would like to thank the professional surveying and scanning service providers for their support during the on-site data acquisition. This study was supported by Mimar Sinan Fine Arts University (MSGSU) Scientific Research Projects (BAP) under Project No: 36, titled "3D Mobil Lidar İle Yüksek Geo-Hassasiyetli Geo YBM Oluşturulması.".

References

A. Llabani* and N. Kopliku, Application of handheld mobile terrestrial laser scanning for cultural heritage documentation., in: *ISC2024*. URL https://www.scipedia.com/public/Llabani*_Kopliku_2024a

Abdul Rahman, A., Zamzuri, A., As Cemrek, H., & Isikdag, U. (2026). BIM for Geoinformation in Malaysia and Turkiye-Current Status. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 1–5. https://doi.org/10.5194/isprs-archives-XLVIII-4-W17-2025-1-2026

Akbaylar Hayreter, İ., Güleç Özer, D., & As Cemrek, H. (2024). Enhancing cultural heritage digitalization and visitor engagement through lidar scanning and gamification. In *The 29th Annual Conference for Computer-Aided Architectural Design Research in Asia (CAADRIA).* The Association for Computer-Aided Architectural Design Research in Asia.

Çemrek, H. A., Sönmez, S., & Işıkdağ, Ü. (2025) 'Mobile 3D LiDAR-based Scan2BIM Process: A comparison of point cloud processing tools', *Confluence – Proceedings of the 43rd Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2025),* Vol. 1, pp. 503–512. https://papers.cumincad.org/data/works/att/ecaade2025_589.pdf

Giuliani, F., Gaglio, F., Martino, M., & De Falco, A. (2024). A HBIM pipeline for the conservation of large-scale architectural heritage: the city Walls of Pisa. *Heritage Science*, 12(1), 35. https://doi.org/10.1186/s40494-024-01141-4

Epotronic. (n.d.). *XGRIDS – High-End Handheld Scanner & Professional 3D Modeling Software.* Retrieved November 12, 2025, from https://epotronic.com/eng/manufacturers/xgrids/

Fiorini, G., Tini, M. A., Montelli, F., & Bitelli, G. (2023). Comparison of two technologies in 3D surveying of real estate assets and cultural heritage. *Proc. MetroArchaeo*, 435-440.

Llabani, A., & Abazaj, F. (2024). A COMPARATIVE ANALYSIS BETWEEN PERSONAL AND TERRESTRIAL LASER SCANNING FOR THE DOCUMENTATION OF HERITAGE SITES. *Stavební obzor-Civil Engineering Journal*, 33(2), 199-214.

Hariffin, N. A. B., Razali, M. H. B., Luh, L. C., Sulaiman, S. A., & Hashim, M. A. B. M. (2023, October). The suitability of Matterport for building parcel dimension survey. In *2023 IEEE 13th International Conference on System Engineering and Technology (ICSET)* (pp. 239-244). IEEE.

Jeftha, K. J., & Shoko, M. (2024). Mobile phone based laser scanning as a low-cost alternative for multidisciplinary data collection. *South African Journal of Science*, 120(11/12).

Kuçak, R. A., Erol, S., & Alkan, R. M. (2023). iPad Pro LiDAR sensörünün profesyonel bir yersel lazer tarayıcı ile karşılaştırmalı performans analizi. *Geomatik*, 8(1), 35-41.
Kültür Envanteri. (n.d.). *Zevkî Kadın Sıbyan Mektebi*. https://kulturenvanteri.com/yer/zevki-kadin-sibyan-mektebi/.
Matterport. (2025a, August 1). *FAQ: Matterport E57 File.* Matterport Support. https://support.matterport.com/s/article/FAQ-Matterport-E57-File
Matterport. (2025b, August 14). *Measurement accuracy in Matterport Spaces.* Matterport Support. https://support.matterport.com/s/article/How-accurate-are-dimensions-in-Matterport-Spaces
Matterport. (2025c, October 1). *Matterport BIM File*. Matterport Support. https://support.matterport.com/s/article/Scan-to-BIM
Matterport. (n.d.). *BIM Files.* Retrieved November 10, 2025, from https://matterport.com/bim
Murphy, M., McGovern, E., & Pavia, S. (2009). Historic building information modelling (HBIM). *Structural Survey*, 27(4), 311–327. https://doi.org/10.1108/02630800910985108
Pix4D. (2022, March 2). *Joint LiDAR and photogrammetry workflow for 3D bridge model.* https://www.pix4d.com/blog/rtk-rover-bridge-restoration
Realsee. (2025a, June 19). *Exploring the future of 3D scanning with Louis Pont and Aerial Perspectives Australia.* https://home.realsee.ai/en/article/exploring-the-future-of-3d-scanning-with-louis-pont-and-aerial-perspectives-australia
Realsee. (2025b, June 19). *German startup Winobo uses Realsee digital twins to revamp half-timbered houses & monuments*. https://home.realsee.ai/en/article/german-startup-winobo-uses-realsee-digital-twins-to-revamp-half-timbered-houses-monuments
Realsee. (n.d.). *Galois – Specifications*. https://home.realsee.ai/en/specs-galois
RobotShop. (n.d*.). Realsee Technology Galois M2 3D LiDAR Camera Kit*. Retrieved November 10, 2025, from https://www.robotshop.com/products/realsee-technology-galois-m2-3d-lidar-camera-kit-us
Rocha, G., Mateus, L., Fernández, J., & Ferreira, V. (2020). A scan-to-BIM methodology applied to heritage buildings. *Heritage*, 3(1), 47–67. https://doi.org/10.3390/heritage3010004
Shults, R., Levin, E., Habibi, R., Shenoy, S., Honcheruk, O., Hart, T., & An, Z. (2019). Capability of matterport 3d camera for industrial archaeology sites inventory. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 1059-1064.
Tanduo, B., Teppati Losè, L., & Chiabrando, F. (2023). Documentation of complex environments in cultural heritage sites. A SLAM-based survey in the Castello del Valentino basement. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 489-496.
Teppati Losè, L., Spreafico, A., Chiabrando, F., & Tonolo, F.G. (2022). Apple LiDAR Sensor for 3D Surveying: Tests and Results in the Cultural Heritage Domain. *Remote Sensing*, 14(17), 4157. https://doi.org/10.3390/rs14174157
Treccani, D., Adami, A., Brunelli, V., & Fregonese, L. (2024). Mobile mapping system for historic built heritage and GIS integration: a challenging case study. *Applied Geomatics,* 16(1), 293–312.
Ubaidillah, M.R., Cahyadi, M.N., & Suhandri, H.F. (2023). Utilization of iPad Pro LiDAR and Low-Cost GNSS Ublox F9R for Data Collection of Road Assets in the Form of 3D Models. *IOP Conference Series: Earth and Environmental Science*, 1127(1), 012013. https://doi.org/10.1088/1755-1315/1127/1/012013
Zollini, S., & Marconi, L. (2025). Evaluation of Positioning Accuracy Using Smartphone RGB and LiDAR Sensors with the viDoc RTK Rover. *Sensors*, 25(13), 3867.
Wang, M., Liu, Y., Wang, H., Dong, H., & El Saddik, A. (2025). Empirical Studies of Large Scale Environment Scanning by Consumer Electronics. *IEEE Consumer Electronics Magazine.*