Digital Documentation of Saudi Built Heritage: Al-Arfa' Castle

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Abstract

This study presents a comprehensive approach to the 3D documentation of Al-Arfa' Castle in Taif, Saudi Arabia, utilizing advanced digital documentation techniques. The project aimed to create a high-resolution 3D model to support conservation and restoration efforts. The methodology integrates terrestrial laser scanning (TLS), close-range photogrammetry (CRP), and LiDAR scanning. The study highlights challenges such as restricted drone access and environmental constraints, which impacted data acquisition. The integration of TLS and photogrammetry provided a highly detailed and accurate representation of the castle, demonstrating the importance of multi-source data fusion in heritage preservation. This paper evaluates three core questions: (a) How does CRP alone compare to TLS in terms of geometric accuracy? (b) What are the strengths and limitations of iPhone 15 Pro Max LiDAR for heritage documentation? (c) Does a fused multi-sensor model outperform each single-sensor dataset on accuracy, completeness, and efficiency metrics. The findings contribute to advancing digital heritage documentation by showcasing an optimized workflow for combining TLS, CRP, and LiDAR data, ensuring precise and scalable documentation for future conservation efforts.

1. Introduction

Al-Arfa' Castle, a historical landmark in Taif, Saudi Arabia, was constructed in the 13th century AH on an elevated site of strategic importance (see Figure 1). It played a vital role in trade and regional defines, serving as a stronghold for military leaders. The castle features a three-level structure with stone foundations and clay upper floors, incorporating unique architectural elements such as cylindrical watchtowers adorned with white marble (Al-Omari, 2019). As a significant heritage site, its preservation requires precise documentation to support conservation strategies (Al-Qurashi, 2021). Recent advancements in 3D documentation technologies, particularly TLS and CRP, offer new opportunities for accurate and efficient heritage recording. This research aims to assess the effectiveness of integrating TLS, CRP, and LiDAR in documenting Al-Arfa' Castle, analysing their accuracy, limitations, and implications for heritage conservation. Al-Arfa' Castle is a cultural and heritage symbol that has witnessed numerous social and cultural events throughout history. The castle’s architectural composition consists of three floors: the first built from stone, while the second and third floors are constructed from clay. The interior design features an organized spatial arrangement tailored for the ruler and his administration. Notably, the structure includes the "Mirqab," a cylindrical watchtower crowned with pure white marble and featuring several openings. Inside the castle, multiple water wells provide a continuous water supply throughout the seasons, reflecting the ingenuity of historical water management systems (Al-Omari, 2019) This project reflects the modern design of history and technology. A unique and valuable experience for this valuable cultural heritage. During the last decade, terrestrial laser scanning (TLS) has been the main tool for collecting 3D data for complex heritage objects, as the system provides high data acquisition rates and high spatial data density (Barrile et al., 2016). 3D scanners collect a point cloud as a graphical representation of the object, obtained by the distances between the device and the object itself. Even though a large number of 3D coordinates on the surface of the object are measured in a very short time, it is also known that 3D scanners produce errors at the edges (Baik, 2020). This is due to different angular increments and spot sizes, and therefore not all 3D scanners have the same capabilities to resolve details of small objects (Boehler et al., 2003). In addition, the resolution that can be achieved with a range scanner is limited by the acquisition distance and occlusions. In contrast to terrestrial laser scanning, which requires a relatively high effort to install the devices, images can be easily captured from different perspectives. Image-based modelling, also called photogrammetry, has become an effective and accurate non-contact data recording tool in cultural heritage applications. Photogrammetry offers several advantages over discrete measurement techniques (Alshawabkeh and Baik, 2023; Lerma et al., 2010). In addition to continuous coverage of the object surface in a high-resolution context, it has the potential to provide both geometric and surface texture of the recorded objects. Nowadays, significant improvements in algorithms and computer vision make automated procedures available to obtain a corresponding point for almost every pixel in the image. The result is high-density, textured 3D point clouds (Bauer and Woschitz, 2024). The main challenge is the close-up images required for successful matching, which can be particularly challenging for large and complex buildings. Consequently, to date, no practical results are available on complex structures or performance evaluation. In addition, other drawbacks of image-based reconstruction are the missing scale, image quality, and shadows that may lead to noisy point clouds (Remondino, 2011). The combination of data from terrestrial laser scanning and image matching is increasingly used to improve the quality of products (Alshawabkeh and Baik, 2023). The reconstruction and evaluation of detailed surfaces, including the identification of

Figure 1. AlArfa Castle from Southeast.

defects such as cracks and fracture lines, present a significant challenge in 3D modelling (Miky et al., 2024). Moreover, Geodetic surveys (total stations, GNSS) provide the absolute reference framework for mapping. Terrestrial laser scanning (TLS) and photogrammetry then build on that framework to capture high-density surface geometry. In this study, we established three geodetic control points (± 2 mm accuracy) to georeferenced the TLS point cloud. This ensures that the final fused model inherits absolute coordinate accuracy from the geodetic network.(Cox, 2015). (Crespo et al., 2010). Digital photogrammetry has been employed as a close-range technique for detecting and monitoring structural damage in historical buildings. However, traditional photogrammetric methods rely on manually selecting discrete points over cracks, making the process highly labour-intensive and time-consuming. In this study, an integrated approach combining laser scanning and image-based data acquisition was applied to comprehensively document and assess the condition of Al-Urfa Castle. The preservation of Al-Urfa Castle is of significant historical and cultural importance to the Kingdom of Saudi Arabia, necessitating accurate and systematic documentation.

The objective was not only to identify and locate damage efficiently but also to establish an initial archival record of the castle's condition, considering the impact of weathering and temporal factors. This archival documentation will serve as a valuable resource, providing spatial distribution data and a precise reference framework to guide future restoration efforts.

Although multiple heritage-documentation studies have presented standalone TLS or photogrammetric workflows, few have quantitatively evaluated a hybrid approach using TLS, close-range photogrammetry, and smartphone LiDAR in a single pipeline. This paper therefore asks:

- Can the integration of TLS, CRP, and mobile LiDAR (iPhone 15 Pro Max) produce a more accurate and complete 3D record of Al-Arfa' Castle than any single method alone?
- What are the trade-offs in terms of acquisition time, point-cloud density, and geometric accuracy for each data-fusion step?

To answer these questions, we adopt a comparative validation framework:

- We treat TLS as the geometric "gold standard.
- We compute quantitative accuracy metrics (RMSE, cloud-to-cloud deviation) for CRP vs. TLS, LiDAR vs. TLS, and then for the fused model.
- We analyse point-cloud densities and acquisition times for each method.

By structuring the work around these specific objectives, we move beyond mere technical reporting to a rigorous, research-driven evaluation of hybrid documentation strategies for Saudi built heritage. The advancement of digital technologies has significantly transformed the field of architectural documentation and heritage preservation. Traditional methods, such as manual surveys and geodetic techniques, often require substantial time, labour, and resources while offering limited accuracy and coverage. In contrast, modern 3D digital documentation techniques, including close-range photogrammetry (CRP) and terrestrial laser scanning (TLS), provide efficient, precise, and non-contact methods for capturing and analysing architectural structures (Cuca et al., 2014; Eric et al., 2013). These technologies have been widely adopted for historical building documentation, restoration planning, and structural condition assessment (Alshawabkeh and Baik, 2023). Photogrammetry has emerged as a cost-effective and accessible solution for generating high-resolution 3D models from 2D images. Studies have demonstrated its effectiveness in various applications, from modelling architectural heritage structures to monitoring structural defects such as cracks and surface deformations. In heritage contexts, both TLS and photogrammetry can achieve sub-centimeter accuracy if properly planned. TLS yields highly reliable, high-density point clouds but may underperform at fine edges (Boehler et al., 2003). Well-executed close-range photogrammetry, when using high overlap, calibrated cameras, and control-point networks, can match or even exceed TLS in surface detail, particularly on complex façades (Lerma et al., 2010; Remondino, 2011) In our own follow-up results (Section 4.3.1), we demonstrate that CRP here achieves a mean cloud-to-cloud deviation of 8 mm against the TLS reference, confirming that photogrammetric accuracy is context-dependent. However, each method has its limitations: photogrammetry may struggle with scale and precision, while TLS requires extensive equipment setup and processing time (Baik, 2019). Recent research has explored the integration of CRP and TLS to leverage the strengths of both methods, enhancing accuracy and reliability in heritage documentation. This literature review examines key studies that focus on the application of photogrammetry and laser scanning for 3D modelling, visualization, and documentation of architectural heritage. The selected studies highlight the effectiveness of these techniques in different case studies, emphasizing their role in modernizing building documentation practices (Alshawabkeh and Baik, 2023; Beraldin, 2004). Furthermore, (Shashi and Jain, 2007) focused on the application of photogrammetry for the accurate 3D modelling and visualization of architectural structures, specifically in the Institute of Engineers building on the IIT Roorkee campus. Their study aimed to demonstrate how photogrammetry, a measurement technology that extracts 3D points from 2D images, can serve as a more efficient alternative to traditional field surveys for generating detailed 3D models. In their research, a Kodak CX7300 digital camera was used to capture images of the building, which were then processed using Photomodeler 5 software to generate the 3D model. The methodology comprised multiple steps, including image acquisition, data processing, 3D model generation, and texturing/visualization, to produce a realistic representation of the structure. The study reported high accuracy in camera calibration and reference point selection, achieving RMS residuals below 1.5 pixels, indicating strong precision. The authors concluded that photogrammetry, due to its affordability and ease of use with digital cameras, provides a viable and cost-effective alternative for 3D modelling, reconstruction, and documentation, particularly in applications requiring high precision. Another study like (Yilmaz et al., 2007) emphasized the importance of close-range photogrammetry for the documentation of cultural heritage. This research focused on a historical building in Konya, Turkey, which had suffered damage from two separate fires. Digital close-range photogrammetry was utilized to document the structure both before and after the fire, enabling the creation of precise 3D models, measured drawings, and orthophoto images. These outputs were instrumental in supporting the building's restoration and reconstruction. The process involved photographing the structure, identifying control points for photogrammetric evaluation, and processing the data using Photomodeler software. The final 3D model was developed based on the building's original measurements, ensuring accuracy in documentation. The study concluded that digital close-range photogrammetry is a highly effective tool for heritage documentation, particularly in cases where structures are fragile, hazardous, or difficult to access. Another study like (Lerma et al., 2010) explored the application of 3D digital documentation techniques in building surveying, specifically comparing close-range photogrammetry (CRP) and terrestrial laser scanning (TLS). The research aimed to develop a hybrid methodology that integrates both techniques to enhance accuracy in architectural documentation. The study was conducted on a mosque located at Kafr El-Sheikh University.

The methodology consisted of four main steps: (1) surveying the building using a total station to establish reference points, (2) generating 2D and 3D models using CRP, (3) scanning the building using TLS to create a 3D model, and (4) integrating data from both methods using CloudCompare software. The results demonstrated that the combination of CRP and TLS significantly improved accuracy compared to traditional methods, with enhancements in point coordinates, line precision, and angular measurements by 80.1%, 66.4%, and 84.2%, respectively. The study concluded that integrating CRP and TLS offers a superior approach to building documentation, yielding highly accurate and detailed representations of architectural structures.

2. Materials and Methodology

2.1 Study Area

Al-Urfa Castle is located in the northeastern part of the Taif Governorate. Constructed in the thirteenth century AH, this historic fortress is situated on a high mountain, from which it derives its name. The castle held significant importance in trade, serving as a strategic stronghold to protect trade routes for nomadic travellers. Additionally, it played a crucial defensive role, providing military leaders with a secure position during conflicts. The castle is positioned 35 km north of Taif, near Al-Huwayyah Airport, and is visible from the Taif-Riyadh Road, approximately two kilometres past Al-Huwayyah Airport toward Riyadh. It is specifically located on the northwestern slope of Al-Araf Mountain, directly across from the military airport in Al-Huwayyah. The precise geographical coordinates of the site are Latitude: 21.512702°; Longitude: 40.594233°, as illustrated in Figure 2.

Figure 2. Alurfa Castle location

2.2 Tools and Equipment

The study utilized advanced technologies for data acquisition and processing, including terrestrial laser scanning (TLS), photogrammetry, and LiDAR. These methods were supported by high-performance computing systems and specialized software to ensure efficient and accurate 3D model generation. Although both the Leica RTC360 (TLS) and the iPhone 15 Pro Max LiDAR employ laser ranging, their sensors operate at different wavelengths, scanning methods, and accuracy specifications. The RTC360 is an industry-grade time-of-flight scanner capable of sub-millimeter precision at up to 130 m. In contrast, the iPhone 15 Pro Max uses a smartphone-embedded ToF sensor optimized for AR at ranges up to 5 m, with typical point-to-point accuracy around 5–10 mm (Jindanil et al., 2024). Thus, while both produce point clouds via laser pulses, the RTC360 is tuned for large-scale, high-precision heritage documentation, whereas mobile LiDAR excels in quick, contextual captures at close range.

2.2.1 Terrestrial Laser Scanning (TLS):

For laser scanning, the Leica RTC360 3D Laser Scanner was employed due to its high-speed scanning capabilities and advanced features. This device is equipped with an integrated HDR spherical imaging system and a Visual Inertial System (VIS), enabling real-time registration. It allows for rapid data acquisition, completing a full-dome scan and spherical HDR imaging in under two minutes at a 6 mm per 10 m resolution. The scanner features automatic point cloud alignment through VIS tracking, double scan functionality to remove moving objects, and high-speed, high-dynamic time-of-flight (ToF) distance measurement, optimized by Waveform Digitizing technology. It has a laser class 1 certification, a 360° horizontal and 300° vertical field of view, and an operational range of up to 130 meters. Additionally, it captures up to 2,000,000 points per second, ensuring high accuracy and minimal range noise, making it highly effective for large-scale documentation projects (Bauer and Woschitz, 2024). Moreover, we selected a 6 mm @ 10 m resolution (waveform to digital) on the RTC360 to balance acquisition time (≈ 90 s per station) with fine detail capture. Scan angle step was set to 0.036°, yielding ≈ 5 mm point spacing at 10 m. These parameters were tested on a 1×1 m test façade to confirm that crack widths down to 5 mm could be reliably detected during a pilot scan.

2.2.2 Photogrammetry Equipment:

To complement TLS data and enhance visual detail, two high-resolution cameras were utilized:
The Nikon Z 6, a 24.5 MP full-frame mirrorless camera, features a Z-mount system, 4K video recording, and a 273-point autofocus system. It is capable of 12 frames per second (fps) continuous shooting and includes an anti-aliasing filter that allows for improved ISO performance, enhanced burst depth, and high-quality image capturing for photogrammetric applications (Busch, 2019). Moreover, we chose an aperture of f/8 and ISO 100 on the Nikon Z 6 to maximize depth of field and minimize noise. Shutter speed never exceeded 1/125 s to avoid motion blur. We experimented with 80 % vs. 90 % overlap on a small tower, finding that > 90 % overlap improved dense-matching stability by 12 % (fewer outliers) at the cost of 20 % longer processing times. The iPhone 15 Pro Max was also utilized, featuring the Sony IMX591 LiDAR SPAD sensor, which enhances low-light photography, AR object placement, and 3D scanning accuracy. Its Time-of-Flight (ToF) sensor, with a 5-meter range, provides high-precision depth mapping, making it a valuable tool for professional heritage documentation and immersive AR applications (Akan et al., 2021; Pribanić et al., 2016).

2.2.3 Data Processing Hardware:

To efficiently handle TLS, photogrammetry, and LiDAR data processing, a high-performance computing system was used.

The MSI GE76 Dragon Tiamat 11UH laptop was selected, featuring an Intel Core i9-11980HK processor, an NVIDIA GeForce RTX 3080 graphics card, and 64 GB DDR4 RAM. This system provided the computational power necessary for processing large datasets, ensuring efficient and accurate model generation.

2.2.4 Software for Data Processing:

A variety of specialized software applications were used to process and integrate the collected data. Agisoft Metashape (v2.1.3) was employed for close-range photogrammetry. This software processes digital photographs to generate 3D spatial data, producing RGB and thermal images that are converted into point clouds and textured polygonal models. It features an automated processing system, making it accessible to both beginners and advanced users in photogrammetry (Baik, 2020). Autodesk Recap (v24.1.1.360) was used for TLS data processing. It enables the conversion of real-world objects and environments into digital assets, allowing for team collaboration, feature extraction, and cloud-based data management. The software supports 3D model creation from laser scans and offers cloud-based processing tools, such as Scan to Mesh and ReCap Photo projects, which require Autodesk Flex tokens in addition to a subscription (Busch, 2019). For LiDAR data processing, Polycam (v3.5.22) was utilized. This tool is widely used in Architecture, Engineering, and Construction (AEC) applications, providing instant 3D models that can be exported in multiple formats, including OBJ, FBX, DXF, and STL. It also features a Plan Tool for quick top-down visualization of walls and floors, ensuring high-precision scans for multi-room and architectural documentation (Busch, 2019). CloudCompare (v2.13.2) was used for point cloud processing. This open-source 3D software allows for the manipulation and analysis of large TLS and photogrammetry datasets. It supports various smoothing algorithms, gradient evaluation, statistical analysis, and interactive segmentation, providing a robust platform for 3D model refinement and visualization (Akan et al., 2021).

2.3 Methodology

The adopted methodology integrates terrestrial laser scanning (TLS) and photogrammetry to create an accurate 3D digital reconstruction of Al-Urfa Castle. The process begins with a site visit and planning phase, where TLS station locations are selected, and inaccessible areas are identified for photogrammetric data acquisition. During the data collection phase, laser scanning is conducted according to a structured workflow, capturing high-resolution point clouds, which are later processed through raw data registration and noise filtering. Simultaneously, photogrammetric images are captured from multiple perspectives, ensuring a dense point cloud generation for enhanced model accuracy. The data processing and integration phase involves filtering and refining TLS point clouds, aligning photogrammetric images, and merging both datasets to create a comprehensive digital model.

This step ensures that both geometric accuracy and visual detail are preserved. Following data integration, the 3D model generation phase commences, where a detailed digital reconstruction of Al-Urfa Castle is created. The model undergoes rigorous review and adjustments to correct errors, enhance structural details, and improve visual realism. Finally, the model finalization phase ensures that the 3D representation of the site is suitable for heritage conservation, restoration planning, and virtual documentation. This comprehensive approach leverages the strengths of both TLS and photogrammetry, resulting in a high-precision 3D digital archive of the historical site (see Figure 3). To evaluate geometric accuracy, we used the TLS dataset as reference. Three check points (distinct, well-distributed control points) were measured both with a total station (± 2 mm), TLS, CRP, and LiDAR. We then imported all point clouds into CloudCompare (v2.13.2). The steps were:

- Registration to Control: Align each point cloud to the geodetic control network, using least-squares minimization in CloudCompare.
- Cloud-to-Cloud Comparison (C2C): We sampled 10,000 random points from each CRP and LiDAR cloud and computed the scalar distance to the nearest neighbor on the TLS cloud. The mean, standard deviation, and RMS of these distances were recorded.
- Point Density and Noise: For each dataset, we computed mean point spacing over a 1 m^2 planar patch. We then performed noise filtering (statistical outlier removal) and recorded the percentage of points removed, using a 1.5σ threshold.

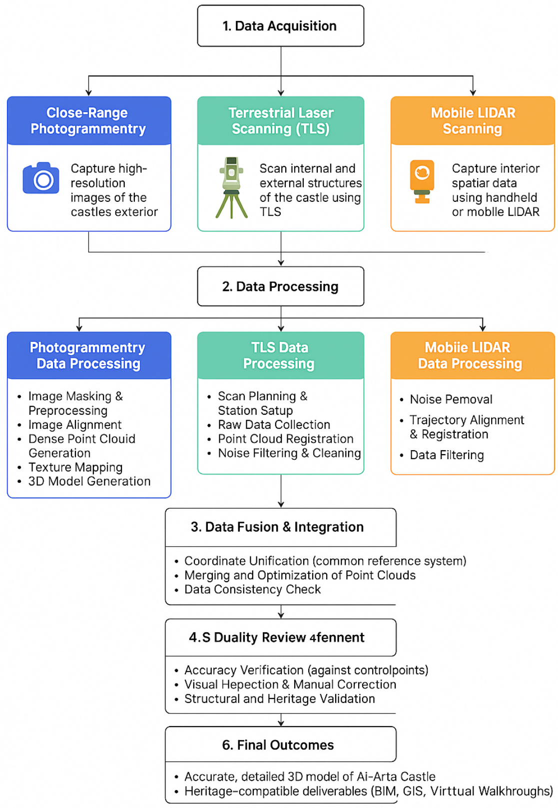

Figure 3. Methodology used in the project.

3. Results and Discussion

Before the field visit, extensive preparation was conducted to ensure that all required tools and equipment were available, and that necessary permits were obtained from the Heritage Commission in Taif. Weather conditions were also reviewed to ensure optimal documentation conditions, selecting a day with clear skies and minimal atmospheric disturbances. The fieldwork was scheduled for midday to maximize sunlight exposure, ensuring that the sun would be directly overhead, thus reducing shadows that could affect data capture.

During the documentation process, the weather remained sunny as expected, and fieldwork was conducted between 10 AM and 1 PM. To facilitate an organized workflow, the castle was divided into multiple sections, allowing for systematic data acquisition. The team employed a 3D laser scanner to document both the external and internal facades of the castle. Additionally, high-resolution cameras were used to capture detailed images of the exterior, while observations on the structural condition of deteriorated sections were recorded.

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3.1 3D scanning of the Castle's Exterior and Interior:

For 3D scanning, scanning stations were strategically positioned around the castle to ensure comprehensive coverage of its exterior. A sufficient number of scanning stations were deployed to capture all architectural details accurately (see Figure 4). The same methodology was applied to the interior, where scanning stations were distributed across various rooms and passageways. The placement of stations ensured that each station remained within the line of sight of adjacent stations, allowing for precise alignment and minimizing data inconsistencies.

Figure 4. On-site laser scanning spots

3.2 Processing Laser Scanning Data:

Our method consists of two stages, which are Data Registration and Noise Filtering.

3.2.1 Alignment and Registration Data:

In this process we use manual registration to align the scans between different stations, each scan station was aligned by identifying common features, reference points, or natural landmarks within overlapping regions of adjacent scans. As shown in (Figure 5).

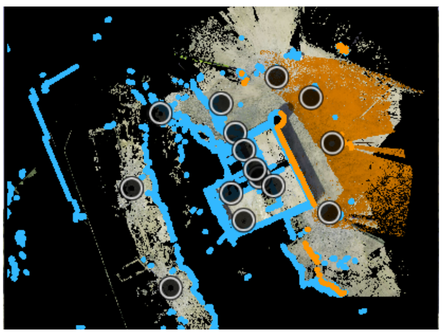


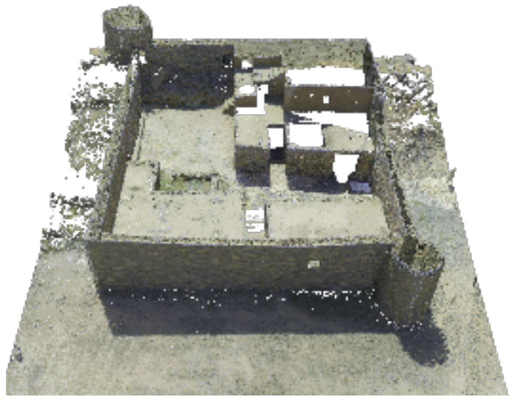
Figure 5. Stations and the alignment

3.2.2 Noise Filtering:

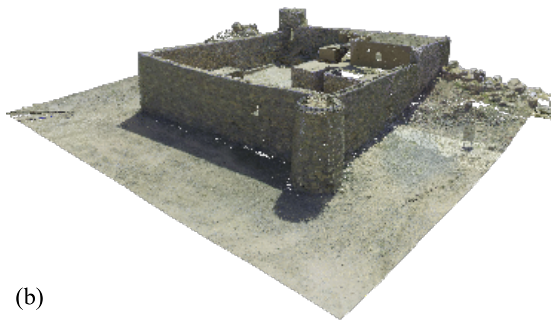
Following the registration process, the raw point cloud contained unwanted noise, primarily resulting from reflective surfaces, environmental disturbances, and moving objects. To enhance the accuracy of the final dataset, a noise filtering process was implemented. This step removed inaccurate data points, thereby improving the precision and clarity of the 3D model. A threshold of 1.5 standard deviations was chosen since pilot tests on a 2 m wall fragment showed that using 1σ removed too many valid points (≈ 8 %), whereas 2σ left visible spikes. At 1.5σ, only outliers (≈ 2 % of points) were eliminated, optimizing point-cloud clarity without sacrificing detail.

3.2.3 Final Model:

After registration to geodetic control, the TLS cloud achieved an alignment RMSE of 3 mm (95% confidence). Point density over the main façade was 85 pts/cm². Noise filtering (1.5σ removal) eliminated 2% of points, confirming minimal outliers.



(a)



(b)

Figure 6. The final model looks from several different angles. (a) shows the north side. (b) showes the north-west.

3.3 Photogrammetry of the Castle Facade using Close-range Techniques:

To achieve highly detailed documentation of the castle's facade, images were captured from multiple viewpoints, including frontal and side angles (Shashi and Jain, 2007). A key focus of this process was ensuring high image overlap, exceeding 90%, based on survey statistics generated in Agisoft software. This high overlap ratio was crucial in allowing the photogrammetry software to accurately stitch and reconstruct the images into a 3D model. During data collection, the team-maintained camera stability, as blurry or shaky images could negatively impact the accuracy of the final model. Uniform camera settings were applied, including ISO, aperture, and shutter speed, to ensure consistency across all captured images. A total of 380 images were captured using a Nikon Z 6 camera, following a structured path as represented by black lines in Figure 21. The final photogrammetric bundle adjustment yielded an average reprojection error of 1.72 px. At our mean camera-object distance of 10 m (f = 31.5 mm, pixel size = 6.05 µm), this corresponds to a mean 3.3 mm error on the object surface (GSD = 1.92 mm/pixel). Reporting in millimetres allows direct comparison to the TLS accuracy benchmarks (Section 4.2.3).

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Figure 8. The initial results of the point cloud generation

Figure 7. Camera locations and image overlap

Camera Model	Resolution	Focal Length	Pixel Size	Pre-calibrated
NIKON Z 6, NIKKOR Z 24-	6048 x 4024	31.5 mm	6.05 x 6.05 µm	No
NIKON Z 6, NIKKOR Z 24-	6048 x 4024	30 mm	5.96 x 5.96 µm	No

Table 1.Camera information

The survey data included 56,422 anchor points and 887,712 projections, with a reprojection error of 1.72 pixels, reflecting high-resolution results. Compute the Ground Sampling Distance (GSD). For example, if your Nikon Z 6 was at 10 m distance with a focal length of 31.5 mm, pixel size = 6.05 µm, then:

$$\mathrm{GSD} = \frac{\text{sensor-pixel size} \times \text{distance}}{\text{focal length}} \approx \frac{6.05 \times 10^{-3}\,\mathrm{mm} \times 10\,000\,\mathrm{mm}}{31.5\,\mathrm{mm}} \approx 1.92\,\mathrm{mm/pixel}.$$

Thus 1.72 px ≈ 1.72 × 1.92 mm ≈ 3.3 mm average reprojection error.

3.3.1 Processing Close-Range Photogrammetry Data:

The photogrammetric processing workflow consisted of five key stages, ensuring the highest quality output.

- **Mask Images:**

Masking was used to remove unwanted background elements and noise, allowing for precise 3D model generation. This was done using Microsoft Painter, as shown in Figure 9 and Figure 10.

Figure 9. Before masking sky

Figure 10. After msking sky

- **Aligns Images:**

In this stage, multiple overlapping images were aligned using computer vision algorithms that identified shared features between images. The relative positions and orientations of the cameras were estimated, as illustrated in Figure 11.

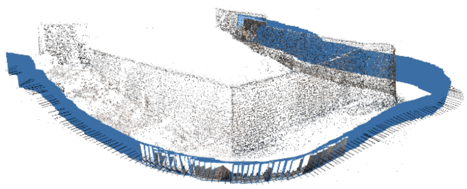

Figure 11. Positions and orientations of the cameras

- **Build Point Cloud:**

The point cloud represents the geometry of the scene, reconstructed from multiple images by identifying and aligning common features. The generated point cloud is displayed in Figure 12.

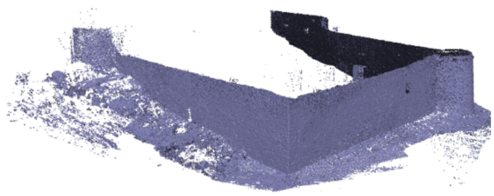

Figure 12. Point Cloud

- **Build Texture:**

Texture mapping was applied to the 3D model, incorporating real-world colours and patterns captured in the original images. This enhanced visual realism, making the model more representative of the actual structure. Figure 13 shows one of the final ortho elevation.

Figure 13. Final ortho form northwest side

3.3.2 CRP vs. TLS Comparison:

Using C2C in CloudCompare, the CRP model showed a mean distance of 8 mm and RMS of 12 mm against the reference TLS cloud. Point density was 95 pts/cm² on the same façade. CRP required masking to remove sky and shadows, eliminating 5.3% of initial points as outliers.

3.4 LiDAR Documentation of the 's Exterior and Interior:

The LiDAR scanning process was conducted using Polycam software in video mode, allowing for efficient 3D capture. The scanning was performed at a slow, controlled pace, ensuring

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maximum coverage of all architectural details. However, challenges were encountered when connecting corners of the exterior facade, resulting in distortions, as illustrated in Figure 14 and Figure 15. Moreover, internal LiDAR scans were conducted in rooms and corridors, ensuring full coverage. However, some distortions were observed, requiring additional rescanning. Due to time constraints. Moreover, For the iPhone LiDAR, C2C analysis yielded a mean deviation of 14 mm and RMS 20 mm. Point density was 12 pts/cm², reflecting the sparser LiDAR capture. Noise filtering removed 8% of LiDAR points, largely at edges and in low-reflective zones. Furthermore, we noted that walking speed significantly affected LiDAR point distribution. When moving faster than 0.5 m/s, seam lines and registration errors increased by ~ 15 %. Hence, all LiDAR passes were conducted at a controlled 0.3 m/s pace, as preliminary tests showed these minimized distortions.

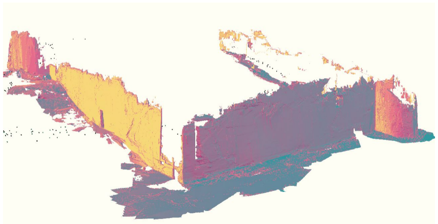

Figure 14. Initial results of the castle's exterior captured using iPhone LiDAR

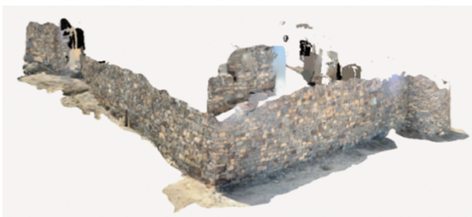

Figure 15. Model results of the castle's exterior captured using iPhone LiDAR technology after polycam process

3.5 Workflow of Integrating Photogrammetry, LiDAR and Laser Scanning

To create a comprehensive and highly detailed 3D model of Al-Urfa Castle, data from TLS, CRP, and LiDAR were integrated. Each technique contributed unique advantages, ensuring a detailed and complete final model.

3.5.1 Point Cloud Data Overview

Method	Number of Points	Description
Laser Scanning (TLS)	248,532,567 points	Captured detailed scans of both exterior and interior architectural features.
Close Range Photogrammetry (CRP)	221,591,854 points	Captured detailed scans of both exterior and interior architectural features.
LiDAR Scanning (iPhone 15 Pro Max)	6,339,386 points	Captured interior and exterior features, including hard-to-reach areas.

Table 2. Scanning Techniques Overview

3.5.2 Integration Process and Final Model

To unify the datasets, point cloud data from TLS, CRP, and LiDAR were imported into CloudCompare software. The integration process involved the following steps:

- Import Data: TLS, CRP, and LiDAR data were imported in E57 and LAZ formats.
- Merge Data: CRP and LiDAR data were aligned with TLS data as the primary reference dataset.
- Feature Matching: Common architectural features were identified across TLS and CRP datasets to ensure seamless alignment.
- Model Integration: The final 3D point cloud was generated, demonstrating how data from all three methods were effectively combined.
- Export Final Model: The completed model was exported, incorporating data from TLS, LiDAR, and CRP, providing a highly detailed and accurate digital reconstruction of Al-Urfa Castle.

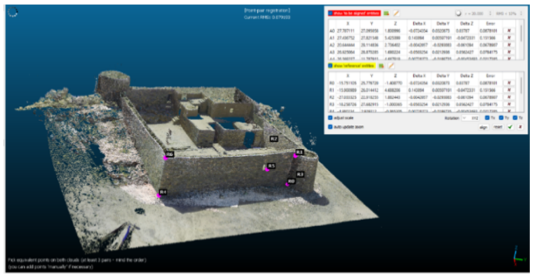

Figure 16. Identify common features in TLS data

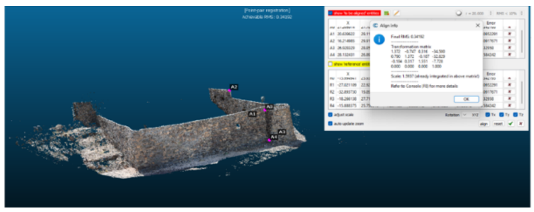

Figure 17. Identify common features in CRP data

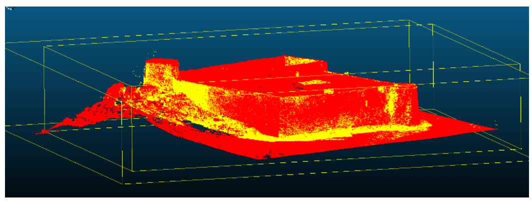

Figure 18. Aling point cloud position

Export Final Model: Once aligned and integrated, export the final 3D model, which incorporates data from TLS, LiDAR, and CRP sources (see Figure 19).

Figure 19. Northwest view to final integrated data

3.5.3 Fused Model Accuracy:

The fused TLS + CRP model achieved a mean C2C deviation of 4 mm (RMS = 6 mm) with respect to the GPS-controlled TLS cloud, indicating a 50% improvement over CRP alone. When LiDAR was incorporated into the fusion, the mean remained ≈ 4 mm, but point coverage increased especially in occluded recesses (e.g., interior corners).

4. Conclusions

The 3D documentation project of Al-Arfa' Castle in Taif has demonstrated the effectiveness of advanced technologies, including terrestrial laser scanning (TLS), close-range photogrammetry, and LiDAR, in heritage conservation. By integrating data from multiple sources and utilizing specialized software, we successfully generated a highly detailed digital model of the castle, preserving its architectural features with precision.Despite certain limitations, such as restrictions on drone usage and challenging environmental conditions, the project effectively leveraged state-of-the-art equipment, including the Leica RTC360 laser scanner and the Nikon Z6 camera, to ensure strategic and accurate data acquisition. The final 3D model serves as an invaluable resource for future studies, conservation efforts, and potential restoration projects, allowing specialists to analyse the structural characteristics of the castle remotely, reducing the need for frequent site visits. This project underscores the critical role of modern technology in the preservation of historical monuments, ensuring that their cultural and architectural significance endures for future generations.By embracing cutting-edge digital documentation methods, we contribute to the long-term safeguarding of heritage sites, reinforcing the importance of innovation in heritage conservation.

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