INTEGRATION OF PHOTOGRAMMETRY AND PORTABLE MOBILE MAPPING TECHNOLOGY FOR 3D MODELING OF CULTURAL HERITAGE SITES: THE CASE STUDY OF THE BZIZA TEMPLE

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ABSTRACT:

In this paper, we present a multi-sensor approach employed to obtain the 3D model of the Roman temple of Bziza (Lebanon) and its surroundings, a work carried out as part of the archaeological Northern Lebanon Project (NoLeP). The integration of photogrammetry and portable mobile mapping technology was tested to overcome the weaknesses of each individual surveying method, with the aim of producing a complete and realistic 3D reconstruction of the whole site, as well as capturing at high-resolution the architectural features of the main structure. Moreover, this case study serves to further investigate the accuracy that can be reached with mobile laser scanners, highlighting benefits and limitations of this rapid and efficient mapping technique also in the field of Cultural Heritage documentation.

1. INTRODUCTION

Acquiring complete, accurate and high-resolution 3D models is an essential starting point for the documentation, development and dissemination of Cultural Heritage (Di Stefano et al., 2021). Nowadays, reality-based digitization and modeling allow not only data archiving and metric information extraction for conservation purposes, but also play a crucial role for the digital access to heritage and archaeological sites and for the implementation of Virtual Reality applications (Farella et al., 2016, Demetrescu et al., 2020). In this context, the survey of large-scale, complex sites can be a challenging task, which is increasingly solved with multi-scale and multi-sensor approaches (Bitelli et al., 2017, Murtiyoso et al., 2018). Besides photogrammetry and Terrestrial Laser Scanning (TLS), the most common surveying techniques employed for digital recording of Cultural Heritage (Bayram et al., 2015, López et al., 2016), the recent spread of portable Mobile Mapping Systems (MMSs) has offered new opportunities for rapid and cost-effective mapping, opening up the possibility of increasingly automated survey operations (Maset et al., 2022). Their integration with well-established geomatics techniques ensures to overcome the weaknesses of each individual technology, providing hybrid 3D models that can be used in different domains (Chiabrando et al., 2018, Chiabrando et al., 2019).

Leveraging on Simultaneous Localization and Mapping (SLAM) algorithms, that allow concurrently the estimation of the sensor position and the creation of a map of the surveyed environment even in the absence of Global Navigation Satellite System (GNSS) signal, portable laser scanners have been initially developed to facilitate the digitization of large buildings and infrastructures. Several works can be found in the literature that are devoted to the validation of backpack and handheld devices in urban scenarios (Nocerino et al., 2017, Tucci et al., 2018), reporting an accuracy of few centimeters for the survey of civil structures and a noise level of the obtained point cloud higher than the one provided by TLS technique, but anyway ranging between 1 cm and 3 cm (Maset et al., 2021). Nowadays, portable MMSs are increasingly applied also for the documentation of Cultural Heritage. Their advantages in this field are deeply discussed in (Zlot et al., 2014), where their use is suggested to fast capture the overall structure of complex sites and to map otherwise inaccessible areas. Furthermore, thanks to the ease of use and the (almost) automatic data processing workflow, portable MMSs can be profitably employed even by non-expert surveyors. SLAM-based mapping technology represents today the most effective solution also for the 3D mapping of underground built heritage (Di Stefano et al., 2021) and allows to significantly speed up the survey activities, which is of utmost importance for heritage and archaeological sites with consistent flow of visitors (Campi et al., 2022).

In this work, we present the multi-sensor approach that was applied to reconstruct the 3D model of the Roman temple of Bziza (Lebanon) and its surroundings, with the aim of testing the complementary potential of photogrammetry and portable MMSs for documenting the current state of the archaeological site. Moreover, this case study serves to further investigate the accuracy that can be reached with mobile laser scanners, highlighting benefits and limitations of this increasingly widespread surveying technique.

2. CASE STUDY: THE ROMAN TEMPLE OF BZIZA

Bziza is a village in the Koura district, North Governorate, south to the city of Tripoli, Lebanon (Figure 1). Its main monument is the Roman temple, a well preserved structure oriented

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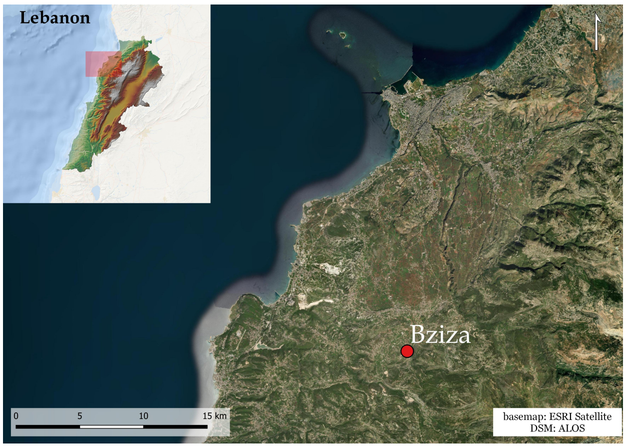


Figure 1. Location of the Bziza temple (basemap: source ESRI Satellite; DSM: source ALOS).

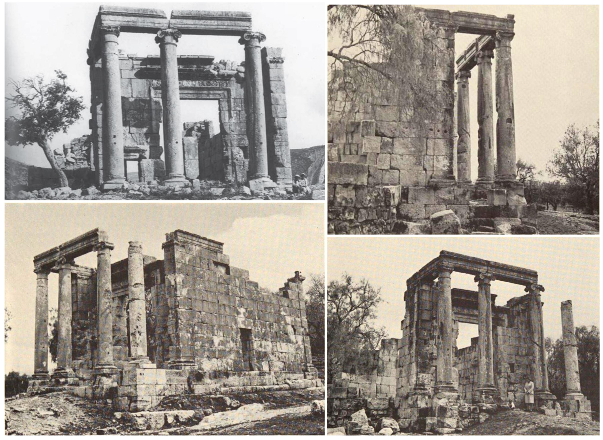


Figure 3. Historical pictures of the Bziza temple, after Fani (1995) – upper left corner – and Taylor (1971), modified.

NorthWest-SouthEast with the frontal columns still in place and a single *cella* (Figure 2). The structure is characterized by a plan of dimensions 14 m × 9 m and a height of 7.5 m. During the early Byzantine period the temple became a church, later named "Our Lady of the Columns" by the most distinguishing elements of the building; other modifications occurred also during the Middle Ages. A cross carved on the architrave and two apses, set perpendicularly to the original main axis, are the most visible elements of these changes. The building was later abandoned and became an historical landmark. Archaeological excavations were performed in the area in the second half of 20th century (Taylor, 1971, Fani, 1995, Vinci and Ottati, 2021) together with photographic documentation of the temple, as testified by the historical pictures shown in Figure3.

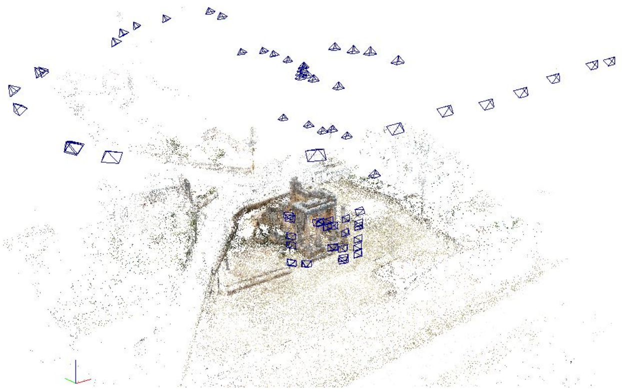
Figure 2. The Bziza site and its Roman temple. Details of the images acquired during terrestrial and aerial photogrammetric surveys.

The work described in this paper was carried out as part of the Northern Lebanon Project (NoLeP), a joint Italian – Lebanese survey investigation of a significant portion of the district of Koura (Iamoni et al., 2019). By means of extensive and intensive surveys NoLeP aims at reconstruct the ancient regional settlement with a particular focus on Amioun and its plain, a fertile land crossed by the River Abu Ali and separated from the coast by the high plateau of Jebel Qalhat. Among the many questions that the project aims to answer, key issues of particular relevance are the origin and formation of Bronze Age societies and their development during the Iron Age, the relationship between inland and the coast, and the study of contacts between Levantine settlements and eastern (e.g., Mesopotamian) and western (e.g., Mediterranean) societies. A second target of equal importance is the promotion and dissemination of the local cultural and archaeological heritage that NoLeP has brought to light after five survey seasons. Among the 120 sites documented by the NoLeP team, the Roman monuments of Bziza and Qasr Naous/Ain Akrine play a major role for archaeological significance and visual impact. The work carried out at Bziza and presented hereafter must be therefore seen as a first attempt to use modern digital techniques to further valorise this great example of Roman religious architecture. To this end, the survey of the Bziza site performed during the June 2021 campaign represents a first trial to apply a multi-sensor approach within NoLeP for producing a realistic, updated 3D model of the Roman temple and its surroundings. This can constitute the starting point for the subsequent creation of a virtual tour that should help disseminate the knowledge of Bziza and its valuable cultural heritage among the local communities of Koura and potential national/international visitors.

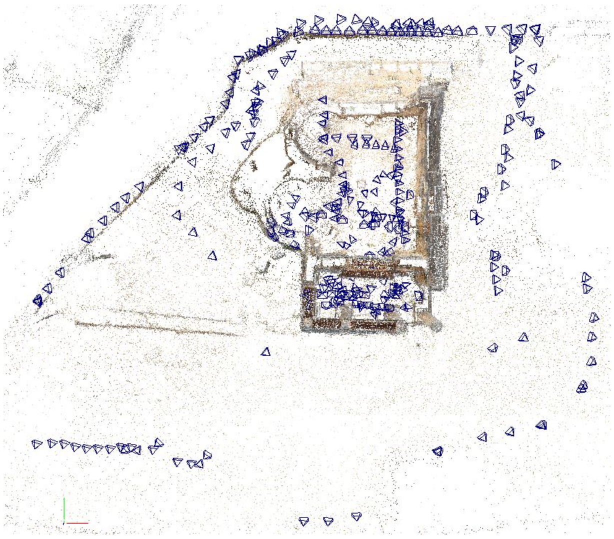
3. DATA ACQUISITION AND PROCESSING

As already introduced in Section 1, the survey of the Bziza temple was carried out with different methods and instruments, in order to obtain a high-resolution 3D model of the temple and at the same time to completely reconstruct its surroundings. In particular, terrestrial and close range aerial photogrammetry was used as main source to record the geometry of the temple. Both acquisitions were carried out in manual mode and not following a fixed pattern because of the multiple obstacles both on the ground (trees, narrow spaces) and in the air (electric cables). Two sets of aerial images were taken, close to the building following its morphology and at higher altitude (approx. 35 m), the latter to capture also the area around the temple. A low-cost commercial camera Canon EOS 250D with a CMOS sensor of dimensions 22.3 × 14.9 mm and an Ummanned Aerial Vehicle (UAV) DJI Phantom 4 Pro equipped with an integrated 1" camera sensor (12.8 mm × 7.2 mm) were used to acquire the images. An overall number of 377 cameras were recorded, 306 from the ground and 71 from the UAV, with an average Ground Sampling Distance (GSD) of 2.5 mm. The image distribution is visible in Figure 4.

A topographic network was established around the temple to



(a) UAV photogrammetric survey



(b) Terrestrial photogrammetric survey

Figure 4. Pose of the images (shown as blue pyramids) acquired during (a) the UAV and (b) the terrestrial photogrammetric surveys, together with the sparse point cloud obtained by processing simultaneously both datasets.

provide Ground Control Points (GCPs) to be used in the image processing pipeline and for local georeferencing. A number of 14 checkerboard targets were uniformly placed both on the ground and on vertical surfaces around the building and then measured from different station points with a Leica TCR407 Ultra total station, ensuring an uncertainty in the final coordinates lower than 1 cm. Global georeferencing was not performed and goes beyond the scope of this work.

The photogrammetric processing of the images was carried out with 3DF Zephyr software (v. 6.010) by 3Dflow[1]. The Structure from Motion (SfM) algorithm was run on the entire set of 377 cameras (UAV + terrestrial) simultaneously, and the 14 GCPs were used as constraints in the Bundle Adjustment step, obtaining an average 3D error of 0.5 cm between the model and the topographically measured coordinates. To compute a high-detailed dense point cloud, images were then processed at full resolution by the Multi-view Stereo (MVS) algorithm. Please note that, in order to avoid precision loss in the upper part of the temple due to the UAV images acquired at higher altitude and characterized by higher GSD value, the building was masked in these photos that were therefore employed only to reconstruct the dense cloud of the area nearby the temple. Furthermore, also the sky was accurately removed from all the images to reduce noisy points and outliers in the final reconstruction. Figure 4 shows the sparse point cloud, whereas the dense point cloud can be appreciated in Figure 7(a).

The whole study site was then re-mapped using HERON Lite, a handheld device by Gexcel srl (Gexcel srl, 2022). The system is characterized by a Velodyne Puck LITE laser scanner able to acquire up to 300,000 points per second at a maximum distance of 100 m, coupled with a XSens MTI Inertial Measurement Unit (IMU). The scanning head was mounted on top of a telescopic pole that could be easily carried by a surveyor, who performed the mapping operations by simply walking through the site (Figure 5).

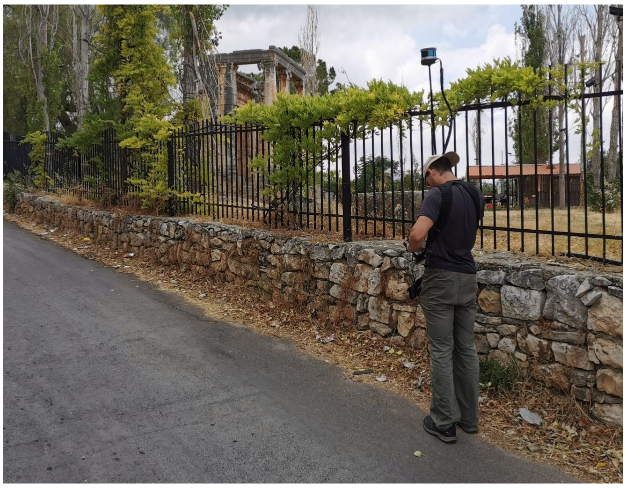


Figure 5. Surveyor performing the mapping of the Bziza temple and its surroundings with the HERON Lite system.

A first trajectory of total length 431 m (shown in blue in Figure 6) was covered to entirely capture the area of interest, following closed-loop paths outside and inside the structure in order to avoid no-data zones. Due to the limited vertical field of view (30°) of the scanner, an additional survey was carried out keeping the sensor with an inclination of approximately 45° to better record the upper parts of the walls and columns. This second trajectory followed the path shown in red Figure 6, for a total length of 108 m. Particular attention was paid during both surveys to guarantee loop closures in the paths, which are essential to reduce drift in the sensor position estimation.

The global point cloud was then obtained via the Simultaneous Localization and Mapping methods implemented in the HERON Desktop software (v. 2.3.3). As described in (Maset et al., 2021), the processing workflow is composed of three stages. In the first one, a rough estimate of the sensor trajectory is retrieved thanks to an on-line SLAM algorithm that exploits also the information registered by the IMU. Then, the trajectory is split into overlapping rigid local maps that can be considered as static acquisitions. Finally, a full SLAM approach is applied to perform a global registration among all local maps, relying on closing loops and minimizing drift and misalignment errors. The processing pipeline is automatic, except for the final stage that usually requires the manual identification of the loop closures.

To compare and subsequently integrate the photogrammetric and the handheld MMS point clouds, their alignment was performed using the Iterative Closest Point algorithm available in

[1] https://www.3dflow.net/

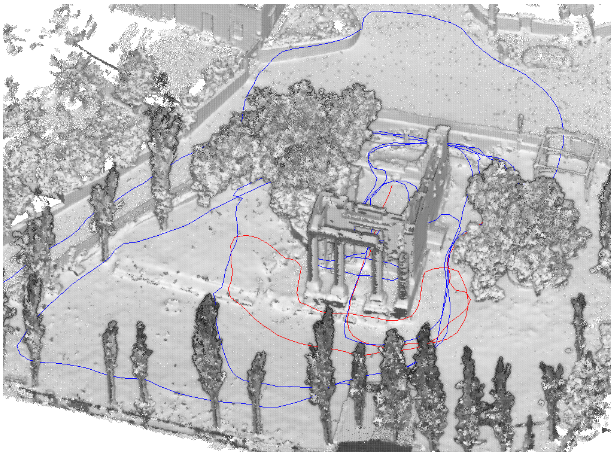


Figure 6. Trajectories followed while scanning the environment with the HERON Lite system. The red one was performed keeping the sensor with an inclination of approximately 45° to better record the upper parts of the temple.

JRC 3D Reconstructor (v. 4.3.1). A final mean 3D error of 1.3 cm was obtained on the 35,000 corresponding points identified by the software. The use of the checkerboard targets was not possible in this phase because of the difficulty in identifying their center with high precision and reliability in the handheld MMS point cloud. Please note that the HERON Lite device adopted in this work is not integrated with a RGB camera, and the obtained point cloud can be viewed in greyscale according to the reflectance values registered by the laser scanner. For a more photorealistic model, the handheld MMS point cloud was therefore finally colorized inside 3DF Zephyr by projecting the points into the RGB images acquired during the photogrammetric survey. The result is shown in 7(b).

4. RESULTS AND DISCUSSION

To bring out advantages and weaknesses of the employed surveying techniques, qualitative and quantitative comparisons are carried out in this section.

As very first evaluation, the time required for data acquisition and processing, reported in Table 1, clearly highlights the efficiency of mobile mapping solutions. Thanks to its portability and ease of use, the handheld laser scanner facilitated the survey of areas difficult to access, especially where the image capturing was challenging or incomplete due to the presence of vegetation, requiring also very limited acquisition time (15 minutes). Moreover, even the data processing workflow is faster, with minor manual operations needed. The SfM and MVS steps, instead, required several hours of computation for a workstation Intel Core i7-9700x CPU @3.00Ghz, 64GB RAM and a Nvidia GeForce RTX 2070 Super GPU. Please note that the 15 hours reported for photogrammetric processing include the time spent to manually identified the GCPs in the images and to mask the photos.

In order to assess the accuracy of the HERON Lite point cloud compared to the photogrammetric model (considered as ground truth), cloud-to-cloud absolute distances were estimated using CloudCompare software[2], obtaining an average value of 2.7 cm (± 2.6 cm). From Figure 8 it is possible to note that higher differences are located on the columns; however, no significant deformations are visible between the two models.

[2] https://www.danielgm.net/cc/

(a) Photogrammetric point cloud

(b) Handheld MMS point cloud

Figure 7. Reconstructed 3D model of the temple of Bziza and its surroundings, obtained via photogrammetric process (a) and using a handheld MMS (b).

	Photogrammetry	Portable MMS
Acquisition time	45 min	15 min
Processing time	15 h	45 min
Number of points	28,758,928	40,964,967

Table 1. Main characteristics of the photogrammetric and handheld MMS surveys. The number of points has been evaluated after clipping the 3D point clouds on the same area of interest.

Another relevant advantage of the handheld MMS emerges from Figure 7, where the higher completeness of the mobile laser point cloud compared to the photogrammetric one can be easily appreciated. In fact, the MVS algorithm failed to reconstruct vegetation points and data gaps are also visible due to the difficulties of acquiring images with adequate overlap in narrow or vegetated spaces. This aspect is further confirmed by the total number of points, which is lower for the photogrammetric model (Table 1). On the other hand, the aerial point of view provided by the UAV photogrammetric survey and the integration of terrestrial and aerial images allowed the complete reconstruction of the top of the temple walls, that could not be scanned by the handheld device (see the top views in Figure 9). Moreover, the terrestrial image distribution proved to be effective to document with the expected level of detail and without occlusions the main architectural features of the temple, as shown by the frontal view in Figure 9(a).

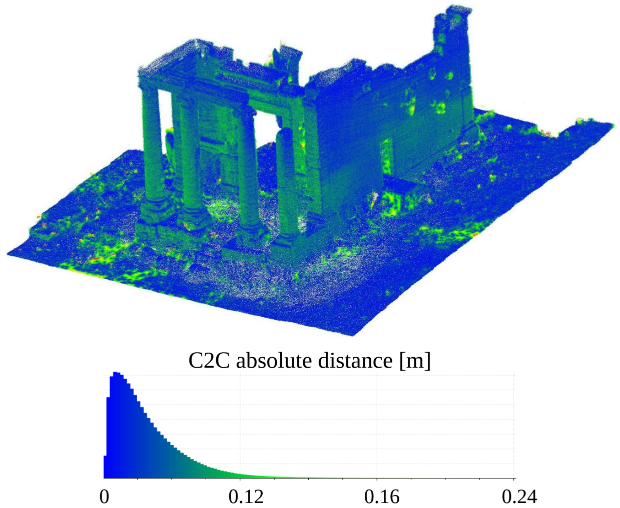


Figure 8. Cloud-to-cloud absolute distances computed between the handheld MMS model and the photogrammetric point cloud. Please note that spots characterized by distances > 10 cm (in light green) are mainly due to the presence of vegetation or data gaps in the photogrammetric point cloud.

(a) Photogrammetry

(b) Handheld MMS

Figure 9. Top and frontal views of the 3D point clouds of the Bziza temple, obtained from the photogrammetric survey (a) and with the handheld MMS (b).

As already pointed out by several works (Nocerino et al., 2017, Maset et al., 2021) the 3D point clouds provided by portable laser scanners are characterized by significant higher noise when compared to standard geomatics techniques such as photogrammetry and TLS. This feature clearly proves also in this case study (Figure 9(b)) and is particularly visible in correspondence of the temple columns, that appear much sharper in the photogrammetric model (Figure 10). The absence of large planar surfaces in the study area do not allow the common quantitative estimation of the noise level, usually performed by fitting planar patches on regular walls or floors and computing the distances between actual points and the fitted surface (Maset et al., 2022). However, for a deeper assessment of the noise that affects the MMS point cloud and the consequent lower level of detail, the surface roughness was estimated with CloudCompare software on the best preserved wall of the temple, following (Campi et al., 2022). The roughness value can be considered a local measure of the noise, since it consists in the distance between a point and the best fitting plane computed on its neighbors. Results, obtained using a neighboring radius $r =$ 5 cm, are reported in Figure 11 and show an average roughness value of 0.3 cm ($\pm$ 0.3 cm) for the photogrammetric point cloud and of 0.9 cm ($\pm$ 0.6 cm) for the handheld MMS model. The outcomes confirm that portable devices are currently not appropriate to capture geometric details with high precision.

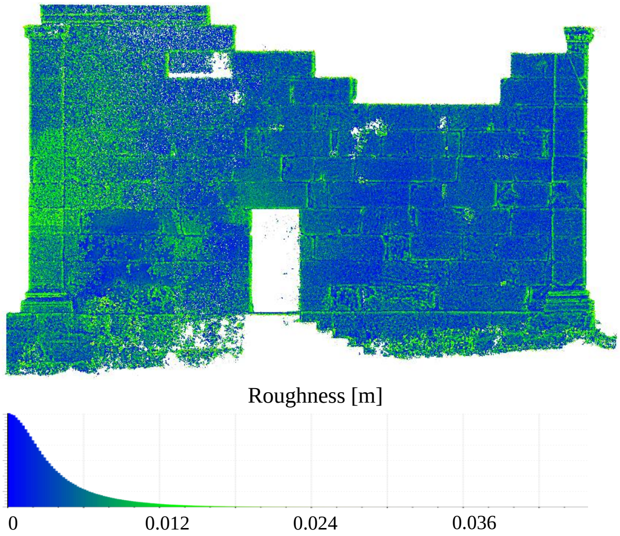
(a) Photogrammetry (b) Handheld MMS

Figure 10. Detail of the point clouds, showing the columns of the temple. The higher noise that characterizes the handheld MMS can be appreciated in (b).

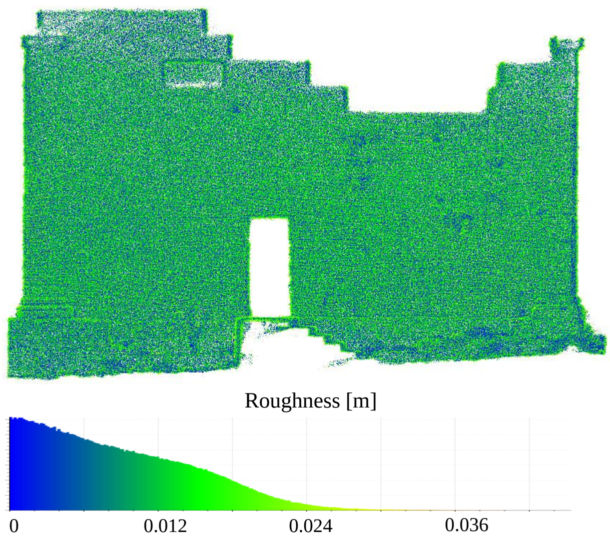
Pros and cons of the two adopted surveying technologies clearly emerge from these results. On the one hand, photogrammetry produces high-detailed, precise point cloud and it is particularly suited to model the temple. On the other, the MMS technology allows to capture a complete view of the area, useful to create immersive virtual visits. The appropriate integration of the two surveying techniques provides therefore the best solution for the complete 3D modeling of the study site.

5. CONCLUSION

When documenting large or complex archaeological sites, a single survey technique is often not suitable for capturing a complete yet highly detailed 3D model. The work presented in this paper is a further confirmation that a multi-sensor approach often represents the most efficient solution in these scenarios. The use of a handheld laser scanner during the survey campaign of the Bziza site turned out to be an interesting test for the application of MMSs also for mapping archaeological structures. One of the points of strength of these systems is undoubtedly the portability and the user friendly approach, with few operations to be programmed and carried out on the field. This aspect makes the MMSs a valuable solution for fast assessments of endangered cultural heritage or sites in difficult locations, especially for a preliminary record that could be later used for



(a) Photogrammetry



(b) Handheld MMS

Figure 11. Roughness values ($r = 5$ cm) computed on the best preserved wall of the temple for the photogrammetric model (a) and the handheld MMS point cloud (b).

planning a more complete surveying. On the other hand, the possibility of making scans in a rapid way without the need of a robust topographic network to be used as GCPs opens to a planned and frequent use of this technique for the assessment of the material preservation and of potential damages or changes due to weather-related events or human intervention. However, close range photogrammetry and TLS are still the most appropriate surveying methods when precise, high-resolution models are required. Finally, it is worth underlying that this case study allowed us to establish good practices and a robust workflow for 3D model reconstruction with a multi-sensor approach, that will be adopted in future campaigns carried out within the NoLeP project, but can be further generalized also for other archaeological investigations.

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