3D DOCUMENTATION TOWARDS HERITAGE CONSERVATION: A RAPID MAPPING APPROACH APPLIED TO BAHRAIN FORTS

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ABSTRACT:

Rapid mapping techniques based on UAV photogrammetry and portable systems are increasingly helping cultural heritage sites' digitization, in case of large contexts or complex accessibility. At the same time, a wider range of more consolidated image- and range-based approaches could be useful, but challenging to be applied depending on materials, accessibility, or light conditions. However, the fundamental issue of integrating and optimizing the large amount of metric data of different origins in 3D accurate models remains open. An integrated system is needed to support the work of expert conservator and restorers, as well as archaeological investigation, on onsite work and, mainly, on remote activity. This paper aims to present the metric survey project carried out in the Fort component of theWorld Heritage property Qal'at al-Bahrain – the Ancient Harbour and Capital of Dilmun. The Bahrain Authority for Culture and Antiquities (BACA) started the initiative towards the conservation of the historic forts of the Kingdom of Bahrain. This requires a tailored approach to the uniqueness and outstanding significance of the sites. The digital products are baseline data and support the future conservation decisions. The validation of the integrated approach adopted for the survey of the Qal'at al-Bahrain will be presented and discussed in this paper. The validation aims for the integrated pipelines are targeted focusing on the aspects connected to the repeatability and the applicability of the methodological approach in the other sites with the same context and features, and this may also lead to further future reflections related to the sustainability of the survey.

1. INTRODUCTION

From a digital heritage perspective, in the wide debate of heritage conservation and monitoring, managing the complexity and quantity of data acquired is a significant task for the surveyor. Methods and strategies for recording and digitization are investigated by the interdisciplinary scientific community involved in heritage preservation to develop procedures and guidelines that are object- and context-oriented. In this case, the endorsed principles devoted to digital documentation and conservation can be continuously applied and updated to validate standards and guidelines. These could be based on a combination of innovative and efficient digital technologies.

The latest technological and methodological developments oriented to accurate 3D recording and digitization related to the geomatics techniques are increasingly targeted to rapidity and suitability in various frameworks and complexity, thanks to portability and compactness of advanced sensors equipping digital devices (Tucci et al., 2017). These researches need to be context-oriented experiments and users-oriented, and then to be standardized in the direction to broaden their applicability.

Rapid mapping techniques based on the remote control of drones for UAV photogrammetry and portable systems increasingly help on-site works where the context is wide and accessibility is complex (Vileikis & Khabibullaeyev, 2021, Chiabrando et al., 2016). Consolidated approaches as static LiDAR scanning and close-range photogrammetry, on the other hand, are challenging to apply in complex contexts as they depend on materials, accessibility, and light conditions. The fundamental issue of integrating and optimizing the metric data of different origins in 3D accurate models oriented to specific targets remains open (Murityos et al., 2019; Ortiz-Coder & Sánchez-Ríos 2020).

1.1 Case study

Figure 1. Orthoimage produced from unmanned aerial vehicle (UAV) photogrammetry captured at 100m flight height. It shows the forts, archaeological tell and surrounding agricultural lands, World Heritage Site property of Qal'at al-Bahrain - Ancient Harbour and Capital of Dilmun Source: authors data processing.

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In 2021, the Bahrain Authority for Culture and Antiquities (BACA) initiated a project to conserve and restore the historic forts of the Kingdom of Bahrain. The preliminary study phase of the interdisciplinary project included the documentation of four forts: 1) Qal'at al-Bahrain - the Ancient Harbour and Capital of Dilmun; 2) Bu Maher Fort, a site component of Pearling, Testimony of an Island Economy; 3) Shaikh Salman bin Ahmed Al Fateh Fort in Riffa, and 4) Arad Fort in Muharraq, the two earlier registered on the UNESCO World Heritage List (BACA, 2021). The present paper focuses on the 3D documentation of one of the forts surveyed, the Qal'at al-Bahrain. It represents the most challenging of the surveyed forts considering the higher dimensions, the higher morphological complexity, and the most important deterioration of some external walls. The data collection procedure for the metric survey project was carried out in June 2021 aiming to enhance the baseline data and support future conservation decisions. A multi-sensor and multi-scale approach was utilized to respond to the uniqueness of the sites and their outstanding local and international significance. In particular harsh environmental conditions and technical site constraints required a tailored human and technological resource deployment. Among the challenging environment conditions, strong light irradiance, high temperature, wind and humidity caused limited accessibility to the site and restrained the hours of site work to early morning hours. Furthermore, the material characterization of surfaces and colors, according to the aforesaid light settings, did not facilitate the use of sensing methods in a routine way.

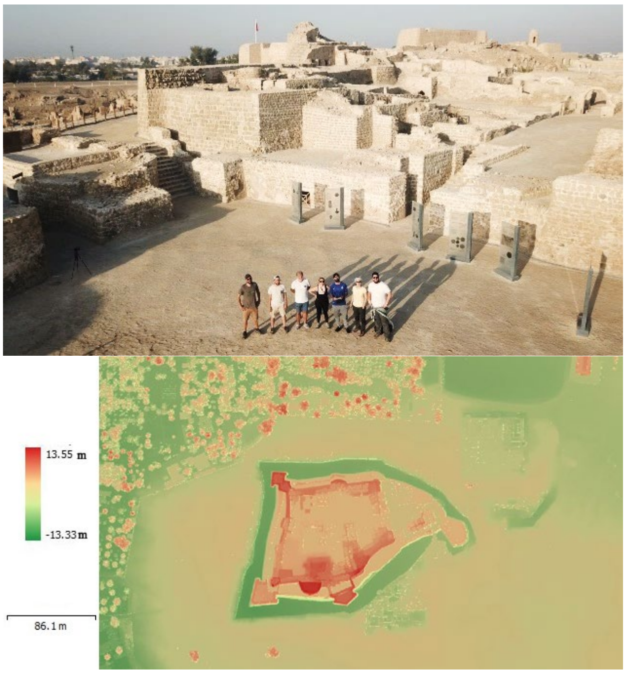

Figure 2. The team during the survey mission, June 2021 (upper). The Digital Surface Model (DSM) of the surveyed area by UAV photogrammetry (bottom). Source: authors and BACA.

2. METHODS

Several crucial points considered during the planning of the survey were related to the rapid solutions connected to data acquisition and to the repeatability of the applicability of the adopted strategies. Since the different tasks associated to the conservation strategies required different representation scales and, consequently, different accuracies, level of detail, and resolution of the delivered 3D metric products, a multi-sensor and multi-scale approach has been followed during the presented research.

The proposed methods integrate different documentation techniques including topographic survey, photogrammetry, LiDAR and SLAM. The use of passive and active techniques for the recording of architectural assets represents nowadays a well-known, consolidated and reliable resource in the framework of the 3D metric documentation, and for this reason these technologies are widely adopted in many disciplines connected to the heritage preservation (conservation, restoration, archaeology, etc.). In the presented case, in order to optimise the rapid recording approach, both digital close-range photogrammetry and (Terrestrial Laser Scanning) TSL have been used where higher accuracies, level of detail and resolution were required for the aims of the conservation strategies.

The following methodologies were implemented:

- Measurement of a *topographic network* in order to provide a common reference system – supporting the co-registration of the acquired point clouds – and to perform an accuracy check during the processing of the data. For this reason, a set of points, both checkboard targets and natural points, have been measured using a total station and GNSS receivers.
- *UAV photogrammetry*. A set of integrated flights – at different heights – have been performed to achieve a multi-scale 3D mapping of the area and provide a general documentation of the surveyed object (Figure 2). The employed UAV system is a DJI Phantom 4 Pro, equipped with a high-resolution camera. A nadir flight (height: 100 m, Flight 1) was performed to acquire the Qal'at Al Bahrain fort and the adjacent area, while a set of flights (height: 40 m, Flight 2) both nadir and oblique (45°) (Aicardi et al., 2016) – to acquire both vertical and horizontal surfaces of the fort, – was performed with the aim to put a higher focus on the building, achieving a higher resolution of the final data (Table 1). The flights were performed mainly at the dawn, o avoid the strong morning light and the consequent problem of the shadows and the high contrast. (Sammartano et al., 2020).

Flight	N° Images	Tie points [N° points]	Dense cloud [N° points]	GSD [cm/px]	Shooting distance [m]
1	437	410,419	831,078,113	2.98	≈ 100
2	1,230	2,237,854	94,479,811	1.36	≈ 40

Table 1. Main details of the photogrammetric flights.

The photogrammetric blocks have been processed with the SfM-based software Agisoft Metashape. Artificial markers (figure 3) were positioned on the ground and measured using traditional topographic techniques (Total Station Survey) to use it as Ground Control Points (GCPs) – to orient and scale the model – and as Control Points (CPs), for evaluating the metric quality. The accuracies achieved after the bundle block adjustment can be observed in Table 2.

		RMSE [m]			
		X [m]	Y [m]	Z [m]	XYZ [m]
Flight 1	GCPs [12]	0.006	0.006	0.014	0.017
	CPs [8]	0.008	0.009	0.017	0.021
Flight 2	GCPs [18]	0.005	0.007	0.016	0.019
	CPs [6]	0.006	0.007	0.019	0.021

Table 2. Metric Control of UAV data

The different number of GCPs and CPs is due to different extension of the two performed photogrammetric flights: the first flight covered an area characterised by a larger extent and

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therefore a higher number of targets were employed. The output of this process, value-added products like dense cloud and orthophotos, have been produced to support the subsequent monitoring phase.
According to the achieved results reported in Table 2 is possible to underline that the quality of the photogrammetric process allow to extract suitable architectural representation at a scale 1:100 (precision ± 2 cm).

Figure 3. UAV Dense Cloud of Qal'at al-Bahrain, flight altitude 100m. Source: authors and BACA.

- *SLAM-based handheld MMS* (Mobile Mapping System). The flexibility of this relatively recent kind of technology – based on SLAM algorithms – has allowed the range-based acquisition of dense and accurate point clouds of the complex and enclosed environments that characterise the surveyed fort during the movement of the operator, greatly increasing the rapidity of the data collection (compared to traditional static solutions). (Rodriguez et al., 2017). The mobile scanner used during the presented study is the ZEB-Revo RT system, which allowed to effectively survey with adequate accuracy the indoor spaces of the fort, connecting indoor-outdoor spaces (Fig. 4). Altogether, 20 scans have been acquired with the MMS collecting 137 million points in almost 2h of walking work (Table 3).

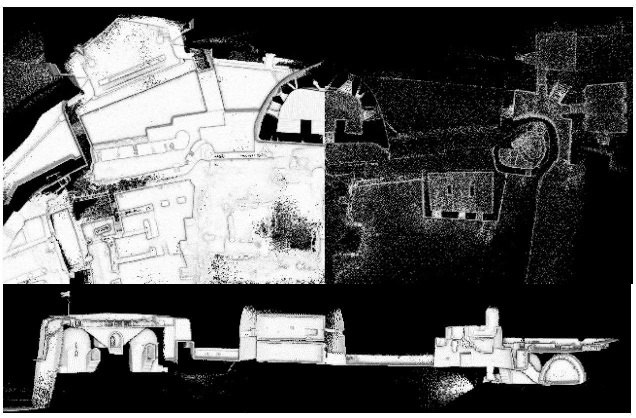


Figure 4. SLAM Point Cloud of the interior and exterior of the bastion of Qal'at al- Bahrain. Source: authors and BACA.

In the processing phase the scans have been merged in the Geoslam Hub, this merge consists in a first manual alignment of scans and allow the correction of drift errors. After this process the goal is obtain the ZEB point clouds in the same coordinate system of the other data, through point-based strategy to the UAV dataset. For the scans that includes the southern areas 12 points have been individuated to complete this alignment process. (Table 4).

	N° Scans	N° Points	Time [min]
Area 1 (moat)	1	2,248,084	15
Area 2 (519 site)	2	3,570,587	20
Area 3 (520 site)	2	27,079,187	15
Area 4 (entrance)	2	25,238,427	20
Area 5 (indoor spaces)	5	59,777,448	30
Area 6 (courtyard)	2	11,716,103	10
Area 7 (higher courtyard)	6	7,661,158	20
Total	20	~137mln	~2h

Table 3. Detail of the ZEB scans

MMS-UAV	Control points-based alignment (12 control points)
Mean [cm]	6.2
St. dev. [cm]	3.3

Table 4. Results of the ZEB data alignment

- *LiDAR static scanning* represents a consolidated solution for build heritage documentation. This documentation project has been carried out also with the Time of Flight (ToF) TLS Faro Focus3D X 330. The ranging error of this device is ± 2 mm in the distance measurement and the measuring range can reach 330 m outdoors. The scans have been performed to reduce the time of acquisition, with the horizontal field of view of ≈ 180°. A total amount of 43 scans has been recorded with a resolution of 1/5 and a quality of 4x spending about 10 minutes for each scan. Despite this is took 4 days of work to collect the entire dataset, due the high temperature reached by the sensor, after 2 hours of acquisition, subjected to high thermal stress.

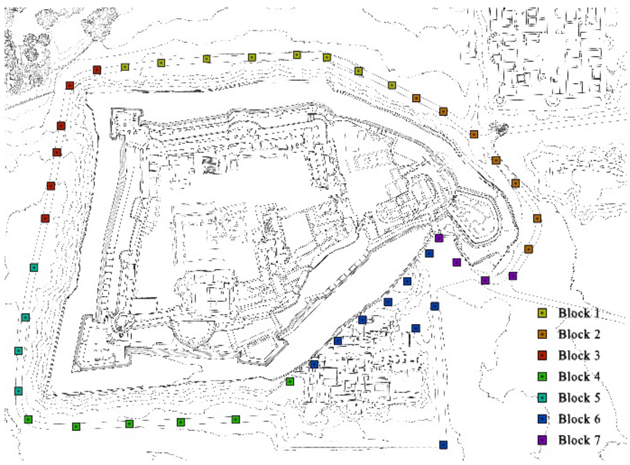


Figure 5. Scans top view with identification of the blocks

Because of the size and the complexity of the survey area, in the processing phase, the scans have been divided into 7 blocks (Fig.5). After the subdivision of the blocks the first registration is carried out using a Iterative Closest Point (ICP) algorithm, subsequently the registered point clouds have been georeferenced through the checkboard targets placed on the walls (as for the photogrammetric process the LiDAR target were previously measure via a total station survey).
Table 5 and 6 show the accuracy result of the registration phase.

Block	N°of Scans	ICP algorithm	
		Mean scan pt tension [mm]	Scan pt deviation < 4 mm [%]
1	8	4.68	47.3
2	7	3.98	55.9
3	6	3.98	53.1
4	6	5.48	42.9
5	3	4.95	47.3
6	9	3.35	58.0
7	4	3.50	58.9
	mean	4.27	51.9

Table 5. Accuracy results based on ICP algorithm

N. scans	Target based [mm]	
	Mean error on target	St. dev. on target
43	24.55	10.74

Table 6. Target based accuracy results

- *Close-range photogrammetry*, as well as the LiDAR approach described in the previous section, represents a widely used solution in the framework of the heritage digitization (Girelli et al., 2017). In addition to the flexibility of this solution and to the cost-effectiveness, this strategy allows to achieve high detailed 3D models characterised by high-resolution radiometry, representing a valuable and efficient tool for the knowledge processes at the base of the conservation plan. In particular, the conservation strategies require different representation scales and, consequently, different level of detail and resolution of the delivered 3D metric products and connected traditional products such as 2D plans, sections and facades. In the case of the presented research, a close-range photogrammetric approach has been used when a higher level of detail was necessary for a better reading of the wall texture, such as some parts of the external and internal walls of the fort (Figure 6).

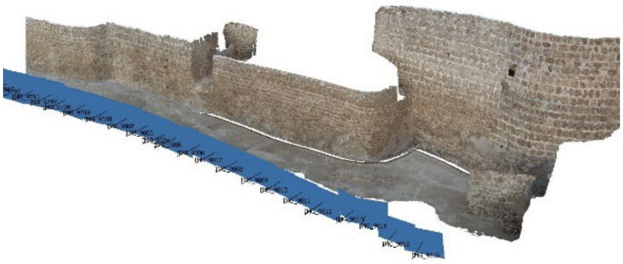


Figure 6. Close-range photogrammetric point cloud model, interior wall of Qal'at al-Bahrain.

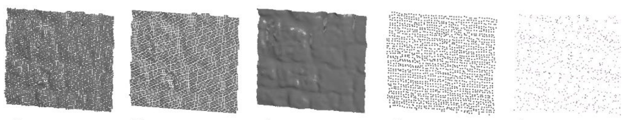
3. DATA INTEGRATION AND ANALYSIS

Considering the complexity, the density and the redundancy of 3D data collected during the survey mission, some considerations on the organization, integration and suitability of them is nowadays mandatory. First, it is required to evaluate, with respect to the planned and expected result, the real outcome of the geometric products according to context dependent variables, for the generation of the digital documentation needed for the conservation strategies of the entire area and the digitization of the specific stratified masonries surfaces. Secondly, it is important to establish the validity of an integrated method that can be applicable and repeatable in similar cases.
During the survey plan, as introduced, a targeted strategy for multi-scale rapid mapping of the site was implemented.
Parallel to the consolidated use of the static laser scanner, mostly used here as a ground-truth, the integrated use of a SLAM and photogrammetric mapping was tested (Sammartano, 2018).

The validation phase of the dataset starts considering the specific geometric features, intended as planar and 3D density, roughness of the surface, and radiometry of point clouds. To support the examination a sample of the fort structure has been selected, characterized by a strong three-dimensionality: the south-western bastion and specifically the wall and the corner.
The three approaches that have been evaluated using the static Lidar dataset as ground-truth are:
- the SLAM mapping, used for enclosed spaces and complex paths, as an alternative wherever the use of the static laser with topographical support was not easily feasible, or as an essential 3D model to have a primary overview of the complex to increase the scale where necessary. The areas that are too large, very regular and poor in features have not proved suitable for the technology.
- the UAV photogrammetric flight on the entire area of the fort for 3D reconstruction of the high scale topography of the terrain and the structures, and the digitization of the topmost parts of the masonry's structures.
- the close-range photogrammetric approach was highly influenced by the light condition in the early morning. It was utilized wherever a high scale geometric and radiometric detail of structures, especially the masonries elements, are required.

3.1 Geometric features

In this framework, the characterization of the point cloud surface greatly influences the 3D reconstruction and quality of the masonry legibility and detection: this was one of the main documentation tasks.
In Figure 7 1mq sample of the masonry of the bastion wall is reported and analysed in its surface density. In the acquisition condition followed in the Qal'at al-Bahrain site, the dense matching in the close-range digital photogrammetric reconstruction provides the highest values: almost 30k pts/m^2 with the embedded radiometric values.



a) b) c) d) e)

Figure 7. Surface density analysis (1mq). a) Lidar data; b) optimized Lidar data; c) close-range photogrammetric data; d) UAV photogrammetric data; e) SLAM data.

		Density [pt/m^2]
a)	LiDAR	10.800
b)	Optimized LiDAR	5.300
c)	Close-range phot.	27.700
d)	UAV phot.	1600
e)	SLAM	770

Table 7. Surface density index

If we consider the density from a spatial point of view, Figure 8 shows the points distribution along the bastion wall façade and the problem of uniformity distribution. In this case, the close-range photogrammetric point clouds and the LiDAR approaches show great values and homogeneity of density of points distribution, as visible from the histogram curve distribution.
In fact, as visible in Figure 6, the photogrammetric block was organized to ensure the maximum overlapping and image-matching, as well as the scans positioning, Figure 5, that allows surface covering and no lack of data. Figure 8 demonstrate also

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the SLAM points density is the most nonuniform (large histogram) because it is the most operator- and path-dependent.

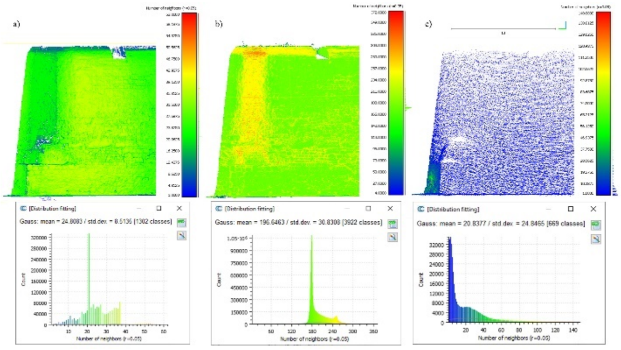

Figure 8. Density analysis (radius 5 cm). left) optimized Lidar data; middle) close-range photogr. data; right) SLAM data.

One of the most essential geometric features characterizing the points surface and, consequently the quality of geometry extraction and the efforts directed into the 3D surface reconstruction (by mesh triangulation or NURBS by reverse modeling), is the noise errors distribution, identifiable as the roughness index, representing the distance of each point from the best fitting plane computed on its nearest neighbours (Figure 9). (Remondino, 2003)

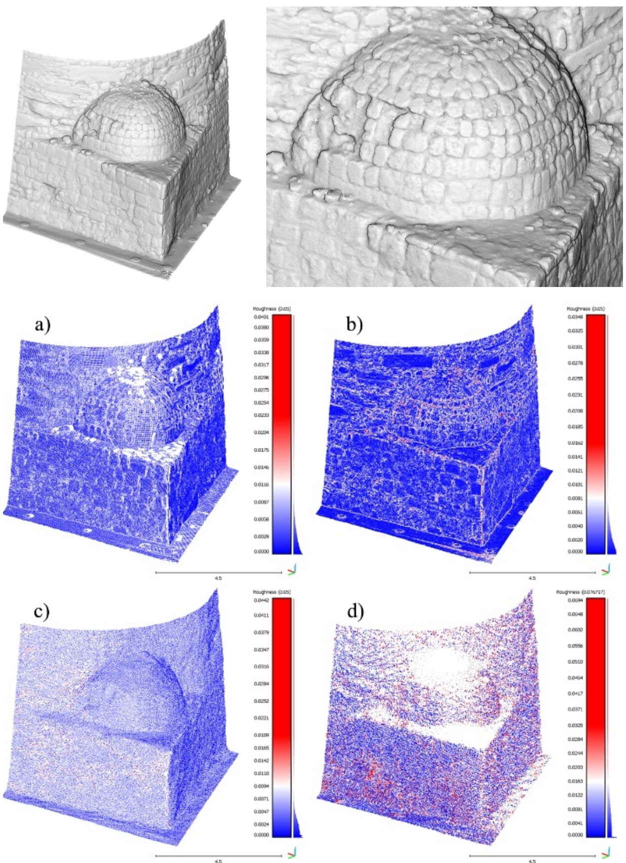

Figure 9. The indication of the bastion corner detail in the close-range photogrammetric points surface. The roughness analysis (radius 5 cm). a) optimized Lidar; b) close-range photogrammetry; c) UAV photogrammetry; d) SLAM.

The histogram curve amplitude tended toward red points indicates a large and distributed roughness in the SLAM point cloud in d) and, at the opposite, in b) the noise errors concentrated in detail corners and mortar joints of the masonry, probably due to the lower image correlation and poor feature surface.

Consequently, if the three point cloud surfaces are compared with the Lidar ground-truth, as in Figure 10, the deviation maps clearly indicate the different surface characterization of the masonry texture from high quality detail (close-range photogrammetric approach) to the loss of some of 3D details (UAV photogrammetric reconstruction), or the absence of them (SLAM).

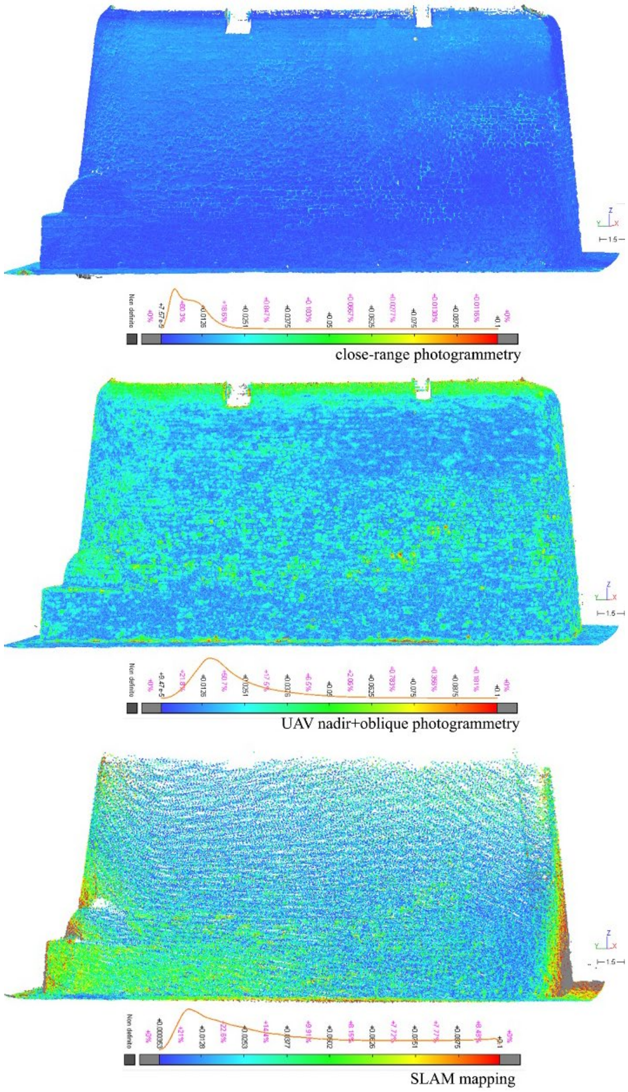

Figure 10. Deviation maps for point clouds comparison. Lidar as ground truth.

3.2 Radiometric quality

The radiometric data derived from image-based sensors, as well known, is crucial for the generation of thematic information regarding materials, state of conservation, specific damages or maintenance processes. Normally this content, especially for ancient heritage surfaces, should be optimized, with colour intensity boosting and exposure balancing.

Usually, the masonry texture is one the fundamental information that can be derived and reconstructed in the 2D and 3D representation. Nowadays semi-automatic process of vectorization and classification based on Machine Learning (ML) algorithms are available (Wang et al. 2021; Pellis et al. 2022) and they can be further tested based on these datasets (see Conclusion). To apply these semi-automatic approaches, the

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geometric characteristics of the surface and the radiometric contrast must be optimal for applying pixel-based or point-based strategies or integrating them.

The comparison with the ortho-projection derived from the dataset (Figure 11), allows the assessment of the quality of radiometric content and the continuity and completeness of the metric product. In Figure 11d is visible the photogrammetric orthoimage where are clearly marked the masonry pattern and the state of conservation of the mortar. An improvement in the balance of colour and density for Lidar-based dataset is confirmed in the cloud Figure 11b from Figure 11a, but in any case, the radiometric product derived from Lidar clouds rasterization according to a pre-determined resolution, does not have the attributes of a HD continue orthoimage. In addition, the light condition and the flight elevation with contribution of nadir and oblique camera configuration, in this case, did not allow to derive a radiometrically valid product from the UAV photogrammetric flight for the wall elevation (Figure 11d). Although the aerial orthophoto generated in dawn-time window can perfectly distinguish the elements present in the floor plan of the area (Figure 12b, c).

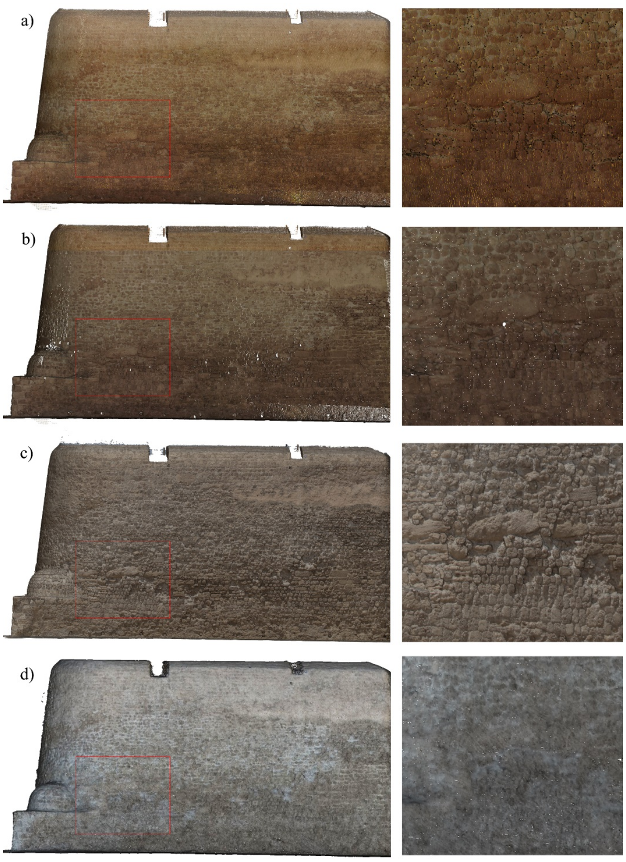

Figure 11. Zoomed area from orthoimage of the south-western bastion wall: a) original Lidar data; b) optimized Lidar data; c) UAV oblique photogrammetric dataset; d) close-range photogrammetric dataset.

4. DISCUSSION

When a survey pertains a complex architectural heritage, one of the most challenging activities is related to the data optimization, harmonization and fusion. Technological innovation on sensors' compactness and portability increase performances in time acquisition, despite the overabundance of data availability, that should be then strongly decimate, clean and optimized.

Figure 12. Orthoimage of the site and zoomed views.

For this reason, in the case of extensive 3D surveys, a range-based approach utilizing portable SLAM sensors is increasingly preferred, and, if necessary, it is locally integrated by very high density LiDAR surveys in circumscribed areas. The details relating to material conditions, structure's morphology, degradation or the presence of particularly decorative apparatus may require this increase in precision in the documentation.

In the same way, the adoption of UAV-based acquisitions for digital photogrammetry allows a comprehensive documentation of the area and of all the elevated areas that would otherwise be difficult to achieve.

From a radiometric point of view, both SLAM mapping and UAV-based image capturing have potential and bottlenecks. On the one hand, some available SLAM systems have not yet implemented the radiometric component (such as the sensor tested here). This can be a huge lack of data .Then, the sensors equipping drones, although often compact and with high resolution, cannot yet reach a resolution that ensures a geometrically and radiometrically product, comparable to a close-range photogrammetry performance (Figure 11).

Further, UAV photogrammetry demonstrate low performance in the 3D reconstruction of masonry texture details, despite the use of the oblique flight (figure 13).

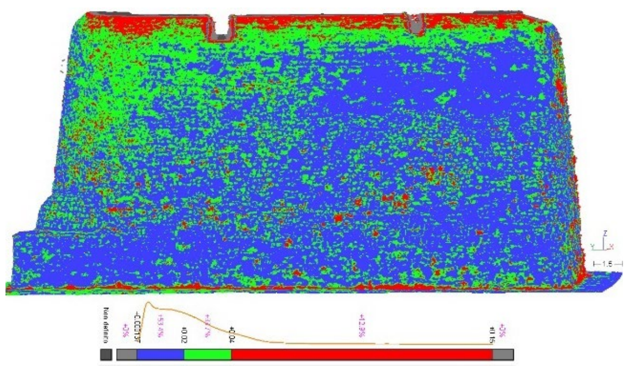

Figure 13. Deviation maps from point clouds comparison between UAV-based and close-range 3D reconstruction.

The light condition deeply influences the metric product consistency. The orientation of light in the sunrise-sunset time, selected for the flights, change quickly yet, together with the use of oblique images, where high contrast areas are present. So, wide areas are difficulty to control for the radiometric uniformity. The use of the confidence level index for the points filtering helps the improvement of point clouds precision. It is based on the points quality, due to noise errors or low time points matching (figure 14).

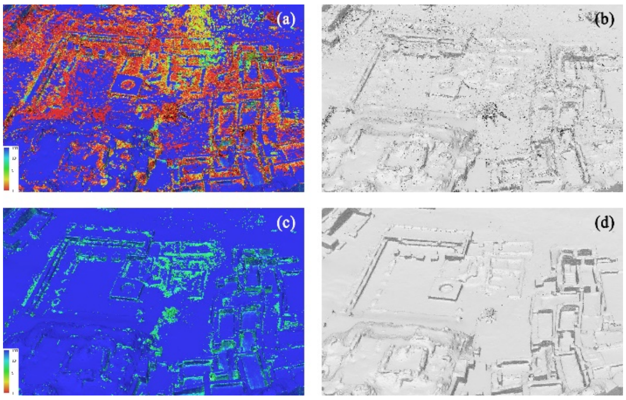

Figure 14. UAV photogrammetric point cloud analysis based on the confidence level. (a) and (b) point cloud before the optimisation; (c) and (d) point cloud after the optimisation.

Figure 15. LiDAR point optimisation (filtering and radiometric balancing). (a) LiDAR point cloud before the optimisation; (b) LiDAR point cloud after the optimisation.

Also for the LiDAR dataset, due to material surface refraction and light conditions, a final radiometric balancing for Lidar clouds was due, for optimizing points distribution and overlapping areas, density and noise errors (Figure 15).

Due to its own characteristics and working principle, SLAM dataset, can be often affected by distributed and dense noise errors, and shows huge problem of path drift wherever surfaces, are regular and flat (bastion corner wall in the in the moat (Figure 16), up to 5m, in comparison with LiDAR ground truth.

Here the preliminary results obtained from the integrated survey are discussed, to reflect as well as on the performances of the methodological approach, also on the actual answers to the research questions related to conservation plan and restoration expertise's activities along time, considering the necessities influencing the survey detail and scales. However, these factors are no longer influenced only by an expectation on 2D results, but also they are driven toward the generation of enriched 3D models with high quality radiometric content and high-scale reconstruction of morphological aspects, as well as easy and confident sharing and interoperability of information.

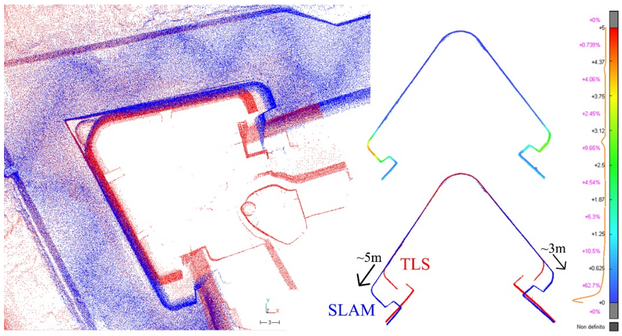

Figure 16. Detection of the drift error in the moat scan (Area1) around the south-western bastion. From the deviation analysis the bigger distance is up to 5m

This paper has presented the contribution and the metric results of rapid mapping methodologies integration in the balancing of resources for the on-site work and wants to recall the role of accurate methodologies and the role of expert operator in the conscious use of digital techniques and metric products, also related to further evaluation on the overall sustainability of the survey. The validation of the integrated approach adopted for the survey of Qal'at al- Bahrain could be replicated in the other sites with similar characteristics.

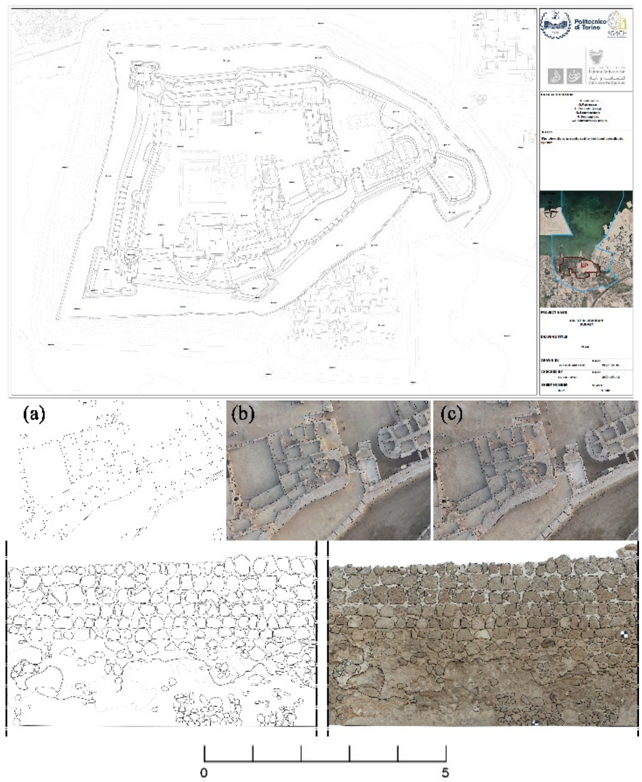

Figure 17. 3D elevation plan with orthoimage of the area derived from the integrated metric survey of Qal'at al-Bahrain and its surrounding. Source: authors and BACA.

5. CONCLUSION AND FUTURE PERSPECTIVES

In conclusion, it is necessary to summarize and underline the still current need to streamline the whole process of data optimization and information mining from high-density 3D model.

Existing bottlenecks in the provision of data, which need to be deepened in the context of the present research is mainly the restricted automation in geometry generation, especially by segmentation and classification of datasets which characterise many processes in the framework of heritage assets digital documentation. In fact, many procedures – such as vectorialisation, information extraction, decay detection, classification, etc. – are still onerous and time-consuming, often requiring the manual involvement of an operator. In many case the required degree of accuracy for these tasks is very high and not always it is possible to rely on fully automatic solutions.

It therefore becomes necessary to develop new strategies to effectively and efficiently carry out these tasks improving the automatism level of processing workflows and practices.

Modern technologies involving Artificial Intelligence – specifically Machine Learning and Deep Learning algorithms and techniques – may represent an effective solution for time-consuming and repetitive procedures. Researchers operating in different disciplines – including heritage valorisation – are focusing their attention in this direction, with the goal to develop new strategies aimed at the optimisation of the processes without scarifying accuracy criteria. Finally, to meet the limits of a localized and sectorial management of 2D-3D data and information, the availability of online platforms also proves to be an important direction in which to invest research and development efforts.

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REFERENCES

ICOMOS, (2005). Advisory Body Evaluation - Qal'at al-Bahrain (Bahrain) No 1192. https://whc.unesco.org/en/list/1192

Aicardi, I., Chiabrando, F., Grasso, N., Lingua, A., Noardo, F., & Spanò, A. T. (2016). UAV photogrammetry with oblique images: first analysis on data acquisition and processing. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLI-B1, 835–842.

Chiabrando, F., D'Andria, F., Sammartano, G., & Spanò, A. T. (2016). 3D MODELLING FROM UAV DATA IN HIERAPOLIS OF PHRIGIA (TK). In J. L. Lerma & M. Cabrelles (Eds.), Proceedings of the ARQUEOLÓGICA 2.0 – 8th International Congress on Archaeology, Computer Graphics, Cultural Heritage and Innovation.

Conservation and Restoration of the Cultural Heritage "Qala'at al-Bahrain". Mission Report at Bahrain (31 March – 7 April 1987), UNISCO. (Prepared by Andrea Bruno, UNESCO Consultant Architect).

Letellier, R., & Eppich, R. (Eds.), 2015: Recording, documentation and information management for the conservation of heritage places. Routledge.

Girelli, V. A., Borgatti, L., Dellapasqua, M., Mandanici, E., Spreafico, M. C., Tini, M. A., & Bitelli, G. (2017). Integration of geomatics techniques for digitizing highly relevant geological and cultural heritage sites: the case of San Leo (Italy). International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 42.

Murtiyos, A., Grussenmeyer, P., Suwardhi, D., Fadilah, W. A., Permana, H. A., & Wicaksono, D., 2019: Multi-sensor 3D recording pipeline for the documentation of Javanese Temples. International Archives of the ISPRS. XLII-2/W15, p829-834

Ortiz-Coder, P., & Sánchez-Ríos, A. (2020). An Integrated Solution for 3D Heritage Modeling Based on Videogrammetry and V-SLAM Technology. Remote Sensing, 12(9), 1529.

Pellis, E., Murtiyoso, A., Masiero, A., Tucci, G., Betti, M., Grussenmeyer, P., 2022. An image-based deep learning workflow for 3D heritage point cloud semantic segmentation. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-2/W1-2022, 429-434.

Remondino, F. (2003). FROM POINT CLOUD TO SURFACE: THE MODELING AND VISUALIZATION PROBLEM. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences Remote Sensing, 34.

Rodríguez-Gonzálvez P, Jiménez Fernández-Palacios B, Muñoz-Nieto Á, Arias-Sanchez P, Gonzalez-Aguilera D (2017) Mobile LiDAR system: new possibilities for the documentation and dissemination of large cultural heritage sites. Remote Sens 9(3):189.

Sammartano, G. (2018). Optimization of Three-Dimensional (3D) Multi-Sensor Models For Damage Assessment in Emergency Context: Rapid Mapping Experiences in the 2016 Italian Earthquake. In F. Remondino, A. Georgopoulos, D. Gonzalez-Aguilera, & P. Agrafiotis (Eds.), Latest Developments in Reality-Based 3D Surveying and Modelling (pp. 141–168). MDPI.

Sammartano, G., Chiabrando, F., & Spanò, A. (2020). OBLIQUE IMAGES AND DIRECT PHOTOGRAMMETRY WITH A FIXED WING PLATFORM: FIRST TEST AND RESULTS IN HIERAPOLIS OF PHRYGIA (TK). ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B2-2(B2), 75–82.

Tucci, G., Bonora, V., Conti, A., & Fiorini, L. (2017). Digital workflow for the acquisition and elaboration of 3d data in a monumental complex: the Fortress of Saint John the baptist in Florence. International Archives of the ISPRS, 42.

Usmani, A. R. A., Elshafey, A., Gheisari, M., Chai, C., Aminudin, E. B., & Tan, C. S. (2019). A scan to as-built building information modeling workflow: a case study in Malaysia. Journal of Engineering, Design and Technology.

Vileikis, O., & Khabibullaeyev, F., 2021: Application of Digital Heritage Documentation for Condition Assessments and Monitoring Change in Uzbekistan. Annals of the ISPRS (Vol. 8, No. M-1-2021, pp. 179-186).

Wang, Y., Zorzi, S., Bittner, K., 2021. Machine-learned 3D Building Vectorization from Satellite Imagery. IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), 1072-1081.