FROM 3D METRIC SURVEY TO HBIM MODEL. TESTING OF DIFFERENT SCAN2BIM APPROACHES FOR THE ARCHAEOLOGICAL DOCUMENTATION.

L. Teppati Losè [1]*, F. Diara[2], A. Spadaro[3] , F. Chiabrando[1]

[1] LabG4CH, Department of Architecture and Design (DAD) - Politecnico di Torino, Viale Mattioli 39, 10125 Torino (Italy) - (lorenzo.teppati, filiberto.chiabrando)@polito.it

[2] Historical Studies Department, University of Turin, Via Sant'Ottavio 20, 10124 Turin, Italy - filippo.diara@unito.it

[3] Postgraduate School of Architectural Heritage and Landscape, Politecnico di Torino, Viale Pier Andrea Mattioli, 39, 10125 Torino (Italy) - s305313@studenti.polito.it

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ABSTRACT:

The research presented in this work is focused on describing part of the activities related to the 1st edition of the SUNRISE Summer School (Seashore and UNderwater documentation of aRchaeological herItage palimpSests and Environment) and a comprehensive approach to the documentation of an archaeological site. In the paper data acquisition and processing will be described in detail, together with the design of the survey project and the main specifications of the sensors and techniques adopted. The 3D metric data derived from the use of these consolidated geomatics techniques were validated during the processing and used as the basis for the generation of other added-value products: traditional 2D drawings and an HBIM model. More specifically, two different approaches for the modelling phase were followed: a more consolidated approach driven by the 2D representation and a more experimental one that foresaw NURBS modelling from the point clouds. The pros and cons of both approaches will be analyzed, and a metric validation of each strategy will be presented. In the paper's conclusions, some considerations are summarized on the use of HBIM for the management of the archaeological data, together with some further perspectives.

1. INTRODUCTION

The research presented in this paper relates a comprehensive experience concerning the documentation process of an archaeological site using cutting-edge technologies: from data acquisition, via data processing, and finally to the generation of added-value metric products such as 2D drawings and HBIM (Historical Building Information Modelling) model.
Since its early definition, the archaeological practice has been concerned with the documentation problem (Remondino & Campana, 2014), being this the results of a stratigraphical excavation or the study of standing historical buildings.
In the last decades, the geomatics community of researchers has been working to support the archaeological documentation process with the most up-to-date instruments and methodologies (Balletti et al., 2015; Drap et al., 2017; Hatzopoulos et al., 2017; Spanò et al., 2018).
A consistent part of this work is the promotion of opportunities to create synergies between students and researchers of both disciplines. These joint activities foster cooperation, understanding the needs of the documentation process, and finding the best solutions possible.
A crucial phase of the overall process of documentation is the design of the survey project (Teppati Losè et al., 2023, which needs to be tailored to the final aims of the survey and to the needs of the final users of the data. It is clear that the selection of specific techniques and sensors can lead to different outcomes in terms of informative contents, accuracy and level of detail; thus also the choice of which techniques to use is crucial and needs to be carefully completed in the framework of a multisensor and multi-scale approach to the documentation.

1.1 The SUNRISE experience

The first edition of the SUNRISE (Seashore and UNderwater documentation of aRchaeological herItage palimpSests and Environment) summer school was organized in 2022. The school was organized between the 3 and the 9 September 2022 by several Italian universities and research centers with the support of the International Society of Photogrammetry and Remote Sensing Student Consortium (ISPRS), the Società Italiana di Fotogrammetria e Topografia (SIFET), and several private companies (Balletti et al., 2023). The school involved 20 students from Europe and the USA (archaeologists, engineers, architects, professionals) and 17 tutors. It was organized together with the Soprintendenza dei Beni Culturali e Ambientali di Ragusa and the Soprintendenza del Mare. During the summer's school activities, the participants documented both terrestrial and underwater sites[1].
The main aim of the summer school was to disseminate best practices for the study, documentation, knowledge generation, and communication of the coastal heritage using cutting-edge geomatic technologies for acquiring, processing, and managing 3D data. The idea was to bring together students with different backgrounds to foster cooperation between different disciplines and exchange different approaches for the documentation and study of Cultural Heritage, specifically the archaeological one.

1.2 The Arab Bath of Mezzagnone

The research presented in this work will focus on the terrestrial site that was documented during the summer school's activities:

* Corresponding author

[1] https://poliflash.polito.it/studenti_polito/conclusa_la_prima_edizione_della_summer_school_sunrise_in_sicilia

the so-called Arab Bath of Mezzagnone (Santa Croce Camerina, Sicily) - Figure 1.
The name of the remains of Mezzagnone is derived from the function that the buildings took at a certain point in its history, the one of a small thermal construction, it is also known as "Bagno di Mare".
It is located west of the urban center and near a spring called Fonte Paradiso. Over the past two centuries, this archaeological site has been the object of extensive historiographical debate. The site's history, its dating and evolutions, and its original functions are still not defined and further studies are needed.
Today, the complex consists of a building measuring 14.60 meters (northeast/southwest) x 9.90 meters (southeast/northwest). The architectural structure is distinguished by massive masonry made of large square limestone. A dome and a barrel vault in the nearby ambient are still preserved on the main building. The complex remains largely unexplored - having not yet been the subject of extensive surveys until recent times – and a large section of masonries are visible near the main block of remains (Licitra et al., 2019).

Figure 1. Aerial view of the Arab Bath of Mezzagnone

As highlighted by the summer school's activities, the documentation of the remains of the Arab Bath with the most up-to-date technologies could contribute to the historical debate and interpretation of the site. Moreover, as will be further detailed in the paper, data collected can be used to derive both traditional 2D products and 3D products, such as HBIM, supporting the archaeological documentation process.

2. DATA ACQUISITION AND PROCESSING

The field activities at the Arab Bath foresaw different steps following consolidated approaches for the data acquisition. The first step consisted in the creation and measurement of a topographic network using TS (Total Station) and GNSS (Global Navigation Satellite System) receiver. A total number of 9 vertices were materialized and measured. The network was then adjusted using three CORS (Continuously Operating Reference Stations) of the Hexagon SmartNet network, adopting the UTM 33N /WGS84 reference system.
After creating and measuring the first-order network, 30 GCPs (Ground Control Points) were measured to georeference the data acquired with the different techniques into the same reference system and evaluate the accuracy of the different approaches during the processing phase. GCPs mainly consisted of checkboard paper targets placed on the wall masonries, but also recognizable natural features of the building were measured for this purpose.
Afterward, the Arab Bath was documented using different techniques: TLS (Terrestrial Laser Scanner), SLAM (Simultaneous Localisation And Mapping) systems, aerial LiDAR, and Photogrammetry (aerial and terrestrial).

In this work, the focus will be on the data derived from the integration of TLS and aerial and terrestrial photogrammetry (Figure 2).

(a) (b) (c)

Figure 2. Instruments used for the survey of the Arab Bath of Mezzagnone. FARO Focus Premium (a), DJI Mini Pro 3 (b) and Sony Alpha 7R (c).

2.1 TLS data acquisition and processing

Concerning TLS, data were acquired with the FARO Focus Premium (main specifications in Table 1); 19 scans were acquired in the field. The acquisition scheme was designed to cover all the building features and to guarantee a sufficient overlap between individual scans. The position of the different scans acquired in the field is shown in Figure 3.

Range	0.5-350 m
Acquisition speed	2.000.000 points/second
3D precision	2 mm at 10 m
Field of View	300° (vertical) x 360° (horizontal)
RGB	Integrated camera (13 Mpixel)

Table 1. FARO Focus Premium main specifications

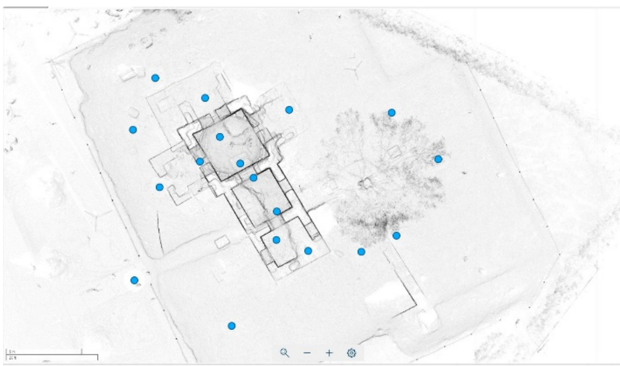

Figure 3. Planimetric view of TLS scan positions (blue dots representing single scan positions)

The data were then processed using the FARO SCENE software following a consolidated two-step approach: a cloud-to-cloud registration followed by a target-based registration.
In the first step, the cloud-to-cloud registration, scans are aligned using an ICP (Iterative Closest Point) algorithm. The position of the registered scans is then blocked and the group of scans is georeferenced using the GCPs measured on the field (via a rigid rototraslation). The results of the TLS processing are reported in the following Table 2.

TLS data processing		
C2C	Cloud2Cloud registration	0.003 m
	N° of points with an error < 0.004 m	67 %
Target	Target-based registration	0.012 m

Table 2. TLS data processing results

2.2 Photogrammetric data acquisition and processing

The photogrammetric data acquisition was performed both from the ground using a DSLR (Digital Single Lens Reflex) and from the air using a UAS (Uncrewed Aerial System). Terrestrial photogrammetric data were acquired using a Sony Alpha 7R (main specification in Table 3); while aerial photogrammetry data were acquired using a DJI Mini 3 Pro (main specification in Table 4).

Sensor	CMOS Exmor R full-frame 35 mm
Pixel Size	4,51 µm
Lens	24 mm
Effective Pixels	61 Mpixel

Table 3. Sony Alpha 7R main specifications

Weight	249 g
Dimensions	251×362×70 mm
Sensors	CMOS 1/1.3”
Pixel Size	2,40 µm
Effective Pixels	48 Mpixel

Table 4. DJI Mini 3 Pro main specifications

UAS are nowadays considered consolidated platforms for the 3D metric documentation of archaeological sites (Adami et al., 2019; Adamopoulos & Rinaudo, 2020) and they can be used to deploy several sensors as payload. In archaeology, they offer a cost-effective solution for 3D mapping compared to traditional techniques. Depending on the dimensions and characteristics of the archaeological area to be documented, both fixed-wing and multi-rotor platforms can be deployed. Both solutions offer nowadays high levels of automatization in data acquisition and are thus easy to deploy in the field.
A similar evolution can be observed in the development of terrestrial photogrammetry: the deployment of Structure from Motion (SfM) algorithms and the availability of high-resolution digital cameras on the market at a fair price allowed the wide diffusion of these approaches in the archaeological documentation practice.
Especially in Building Archaeology, the possibilities offered by these techniques can be successfully adopted (e.g., stratigraphical analysis, materials and building techniques identification, restoration, etc.).
UAV data were acquired with manual flights, ensuring a sufficient overlap (more than 80%) between images, flight altitude 15 m above the take-off point, and projected Ground Sampling Distance (GSD) of 0.01 m. Both nadiral and oblique images were acquired with interlaced flight lines (north-south and east-west).
Terrestrial data were acquired by performing a circular acquisition around the Arab Bath and using the center of the building as POI (Point of Interest). As for the aerial images, both nadiral and oblique images were acquired (lens axis perpendicular and oblique with respect to the building's main facades). The acquisition schemes of both aerial and terrestrial datasets are reported in Figure 4.

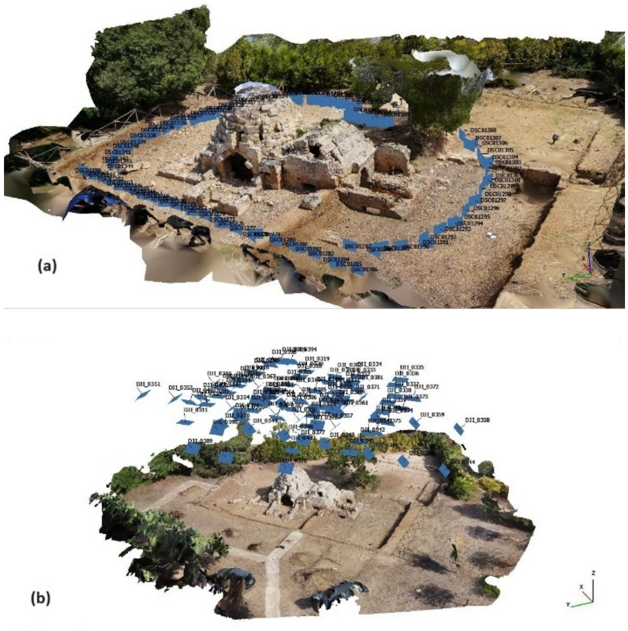

Figure 4. Scheme of image acquisitions. Terrestrial (a) and UAV (b).

The data were processed following consolidated pipelines (image matching, tie points extraction, Bundle Block Adjustment, etc.), leading to the typical accuracies needed for the architectural/archaeological documentation (Table 5). The software used for the photogrammetric processing was the commercial solution Agisoft Metashape (v.2.0.3).

UAS + terrestrial photogrammetry	
GCPs RMSe (14 GCPs)	0.011 m
CPs RMSe (8CPs)	0.012 m

Table 5. Photogrammetric data processing results

3. GENERATION OF THE FINAL PRODUCTS. FROM POINT CLOUD TO HBIM

The following section is dedicated to the description and comment of the phases that brought to the generation of the added-value metric products that can help the archaeological investigation, as well as several actions connected to the protection and dissemination of this type of heritage.
The first step consisted in the generation of the traditional 2D drawings of the building, starting from integrating the previously processed data. The generated 2D drawings (some examples are reported in Figure 5) represent a fundamental step in the process of knowledge for this type of heritage and can serve different purposes: building archaeology analyses, decay identification and support to the restoration activities, etc..
Finally, a step further in this process was achieved via the creation of an HBIM model starting from the survey data. This operation was completed via a Scan2BIM approach (Brumana et al., 2022), testing different modelling strategies.
For example, one of the possible strategies that will be discussed is the one that foresees the point cloud to NURBS approach together with more traditional approaches starting from the 2D drawings.

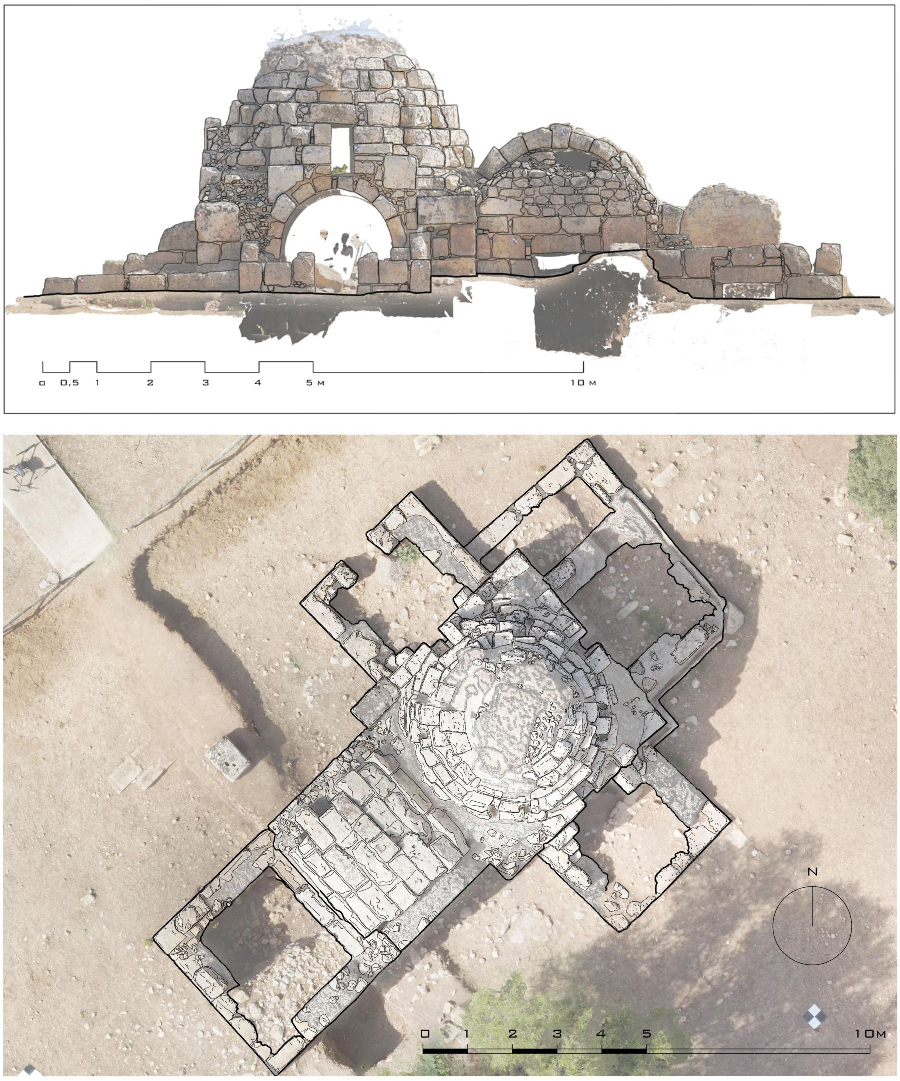

Figure 5. Example of 2D drawings of the Arab Bath of Mezzagnone

3.1 2D drawings

One of the practices that is still widely diffused and fundamental in the archaeological documentation is the generation of traditional 2D drawings, making the drawing phase a crucial step of the whole interpretative process. For this research, the data derived from the survey were used to create the traditional CAD representation. Both 3D and 2D data were used for this purpose. With a mean GSD (Ground Sampling Distance) of around 0.01 m the orthoimages derived from the photogrammetric data processing were a fundamental support for creating the 2D drawings of the overall complex and the individual facades.
The point clouds derived from the TLS survey were also used for the generation of the drawings by means of the PointCab software Origins which allows the creation of floorplans and cross sections of the point clouds that can be imported into a CAD environment aiding the drawing process.

3.2 3D modelling. Testing different modelling strategies

The HBIM process has been chosen for its incredible benefits in the archaeological domain: this informative 3D database is a key point for documentation and monitoring operations. In fact, the main goal of this work is to efficiently test a workflow that goes from the survey on the field to the semantic parametric and informative model for a complex archaeological context.
The preservation of archaeological sites also depends on data fragmentation of traditional 2D studies as well as innovative 3D analyses. Through the HBIM method, important and sensitive information is semantically linked to the 3D database, creating a common environment to implement documentation and perform further analyses.

3.3 HBIM: Parametric and NURBS modelling

The parametric modelling of the Arab bath was planned in order to achieve a simplified HBIM model, having a medium level of detail (LOD3-4), coupled with a NURBS modelling of covering parts (dome and barrel vault).
For this project, two modelling strategies were adopted to achieve the established level of detail and to test how two different methodologies can be adapted to metric survey data. The former is based on the parametric smart extrusion of wall masonries starting from 2D data (archaeological plan and sections), and the latter relies on adapted NURBS geometries on 3D point clouds referred to the covering parts of the Arab bath.
The extrusion method was chosen to generate vertical masonries and related openings in the simplest way possible, according to desired LODs. On the other hand, the free-form modelling for the

dome and the barrel vault was selected because of its non-rigid tools for creating surfaces and solids. Then, the complexity of covering parts of the building required more modelling control since interpolated curves and surfaces were adapted to point clouds.
FreeCAD open-source software was selected as HBIM environment, especially for its flexibility and possibility of editing and adapting to archaeological purposes (Diara & Rinaudo, 2020). Moreover, the solution of using an open-source platform for the BIM modelling is particularly interesting for the archaeological community that is historically connected to the use of free and open software solutions.
The first step of the modelling phase was related to the parametric generation of the Arab bath wall structure. . To achieve the final results a more standard approach was tested starting from a 2D representation of the plan to be vertically extruded depending on real measurements extrapolated from 2D sections, drawings and LiDAR data Figure 6.

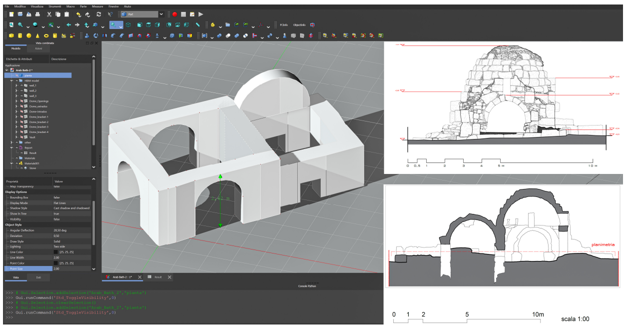

Figure 6. Parametric modelling of masonries (adapted extrusion) starting from 2D plan and sections

The archaeological plan derived from the 2D drawings previously generated was imported in FreeCAD, and, based on some hypotheses derived from the observation of remains and foundation evidence, a parametric extrusion was performed. Starting from 2D data and with the help of 3D point clouds, all the main structural features of the building (especially wall thickness, the openings, and their positions) were retrieved. The openings were obtained with modelled objects to be cut off from the wall models with Boolean operations. At this point, the main wall structure was completed and classified as ifcWall.
The covering parts of the Arab bath, related to the dome and the barrel vault, were modeled in Rhinoceros by using NURBS surfaces, following a different strategy from the one already presented. This approach was followed due to the more complex geometries of these elements. Starting directly from the point clouds data, the barrel vault (intrados) was modelled by interpolating adaptive curves on the covering and creating a NURBS surface. The extrados was created applying a solid offset depending on the real thickness given by the stone blocks: between 0.26 and 0.32 m.
Continuing the NURBS modelling, the intrados of the dome was modelled by adapting a half sphere to the point clouds, while the extrados was obtained via a terraced sphere adapted to stone blocks, even if an important simplification of shapes was applied due to stone blocks leaking out irregularly as well as due to lack of dome components Figure 7 and Figure 8.

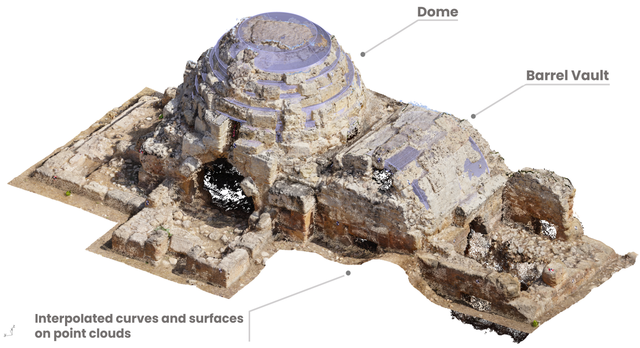

Figure 7. Interpolation of NURBS curves and surface directly on point clouds: the dome and barrel vault of the Arab bath.

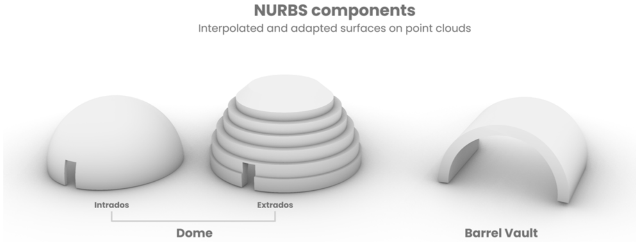

Figure 8. NURBS components related to coverings

Once finished the NURBS modelling, the covering parts were imported inside FreeCAD (Figure 9) via a georeferenced STEP file and metrically matched and parametrized by using FreeCAD tools and addons (Diara, 2022).

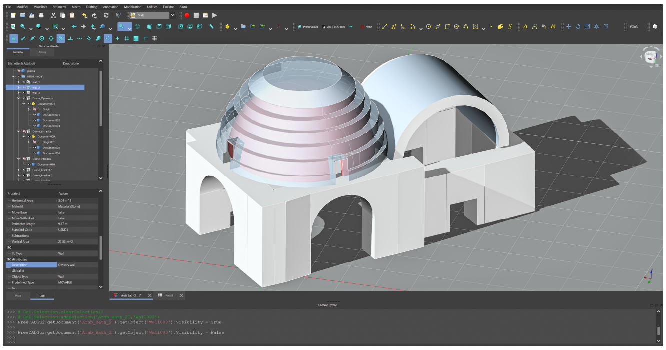

Figure 9. HBIM model of the Arab bath

3.4 Deviation analysis

Finally, a metric evaluation of this second approach was necessary in order to metrically validate NURBS and parametric components and the overall procedure. In this regard, NURBS geometries and surfaces were compared with TLS and aerial point clouds for understanding metric differences among different 3D data using the so-called cloud2model analysis: this approach was adopted for the covering system of the Arab Bath (the dome and the barrel vault).
Using the open-source software CloudCompare, the NURBS modelled dome was compared with the dense point clouds from terrestrial and aerial data (for having homogenous metric data). The cloud-to-mesh distance was computed by setting a distance range between 0.00 and 0.20 m to deal with possible outliers.
The obtained mean distance was 0.031m, the standard deviation was 0.044 m and the RMSe (root-mean-square error) was 0.054 m. The point coverage of this analysis is here estimated: between 0.00 m and 0.05 m, the coverage is 58%; between 0.05 m and

0.10 m, the coverage is 38%; between 0.10 m and 0.15 m, the coverage is 3%, between 0.15 m and 0.2 m, the coverage is 1%.
A graphical representation of the analysis is shown in Figure 10 in while the point coverage is reported in Table 6.

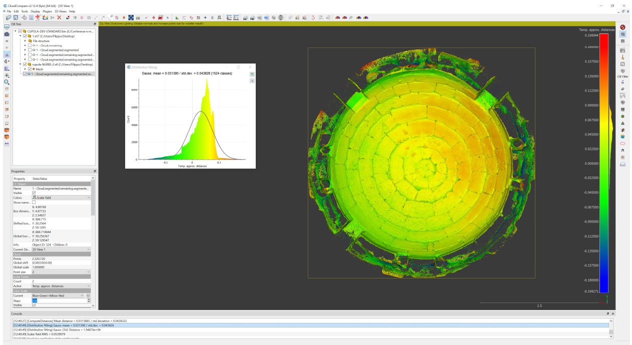

Figure 10. Standard deviation analysis of the dome

Range (m)	Point Coverage
0.00 – 0.05	58%
0.05 – 0.10	38%
0.10 – 0.15	3%
0.15 – 0.20	1%

Table 6. Deviation analysis of the dome: Point coverage for metric range

The same operation was performed for the barrel vault of the Arab bath. Concerning the NURBS model and point clouds the distance range for the analysis was set between 0.00 and 0.15 m. The computation has returned these values: mean distance 0.018m, the standard deviation 0.035 m and the RMSe 0.039 m. The point coverage of this analysis is here estimated: between 0.00 m and 0.05 m, the coverage is 79%; between 0.05 m and 0.10 m, the coverage is 19%; between 0.10 m and 0.15 m, the coverage is 2%.
A graphical representation of the analysis is shown in Figure 11, while the point coverage is reported in Table 7.

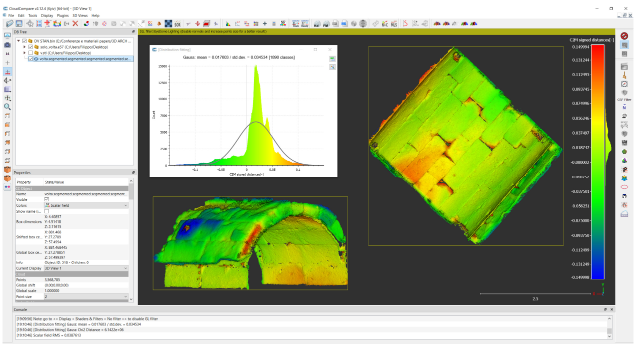

Figure 11. Standard deviation analysis of the barrel vault

Range (m)	Point Coverage
0.00 – 0.05	79%
0.05 – 0.10	19%
0.10 – 0.15	2%

Table 7. Deviation analysis of the barrel vault: Point coverage for metric range

As expected, these two analyses show evident metric distances related to stone blocks leaking out of the main dome/vault. Because of simplification on modelling, metric discrepancies are also associated with this choice, even if the 58% (dome) and the 79% (vault) of point coverage are inscribed into the standard deviation value. Nevertheless, they meet the criteria for the LoD chosen for this project.
Finally, the cloud-to-mesh distance was computed concerning parametric masonries of the main bath room (modelled in FreeCAD) by setting a distance range between 0.00 and 0.30m. The obtained mean distance was 0.011m, the standard deviation was 0.089 m and the RMSe (root-mean-square error) was 0.090 m. The point coverage of this analysis is here estimated: between 0.00 m and 0.10 m, the coverage is 72%; between 0.10 m and 0.15 m, the coverage is 20%; between 0.15 m and 0.30 m, the coverage is 8%.
A graphical representation of the analysis is shown in Figure 10 in while the point coverage is reported in Table 6.

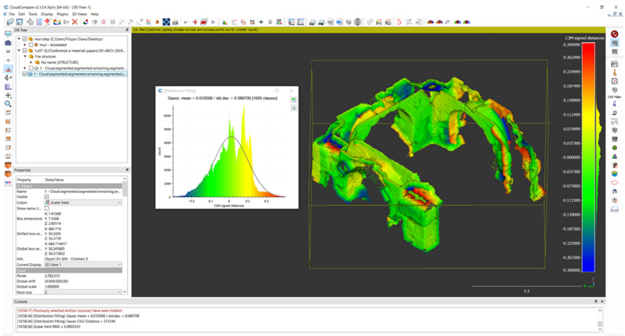

Figure 12. Standard deviation analysis of masonries

Range (m)	Point Coverage
0.00 - 0.10	72%
0.10 - 0.15	20%
0.30 - 0.15	8%

Table 8. Deviation analysis of the parametric masonries of the main room: Point coverage for metric range

3.5 HBIM: Semantic data

One of the most important aspects of adopting an HBIM platform for the archaeological documentation is the possibility of adding different information of the Arab bath. The informative platform was implemented with the material database (stone related to wall masonries; concrete related to past maintenance interventions; cocciopesto material), bibliographic references, past studies, photographic references, and 2D drawings.

Furthermore, the semantic sphere includes the initial draft version of the stratigraphic analysis of the archaeological site: stratigraphic units (US) and masonry stratigraphic units (USM) related to both the excavation and the construction site of the building Figure 13. In creating an HBIM environment, the inclusion of stratigraphic information and other historical data is therefore possible, obtaining a 3D database depending on specific research goals. Acting in this way, a complete and homogenous documentation of the archaeological site can be designed especially for data security and exchange, keeping traditional studies and 3D data enclosed in the same platform.

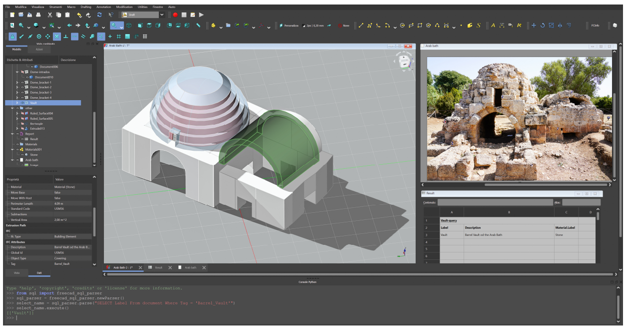

Figure 13. HBIM platform. The parametric model of the Arab bath with semantic information: active SQL query and image reference.

This essential data becomes fundamental for two main reasons: the former refers to keeping safe semantic and sensitive information in a unique platform, breaking barriers of data fragmentation generated from different sources; the latter concerns the possibility of investigating this data through relational and custom queries designed for further archaeological analyses and for maintenance.

4. CONCLUSION AND FUTURE PERSPECTIVES

The aim of the research presented in this paper was to achieve a complete documentation of the Arab Bath, exploiting different geomatics techniques. Moreover, the contribution and the possibilities offered by each of these techniques have been underlined and discussed in the work. The final objective of the research was also the generation of metric added-value products to support the archaeological practice in the documentation process. The first added-value products that were generated are the 2D drawings, that were produced at different representational scales. Two different plans of the sites were created: a plan in scale 1:200 to cover a wider portion of the area and a more detailed one in 1:50 to represent the architectural consistency of the building. To achieve a complete representation of the complex both terrestrial and aerial data were integrated. The TLS data were crucial to define the geometry of the vertical surfaces; the UAS data were used to complete the higher an horizontal portion of the masonries; both terrestrial and aerial photogrammetric data were used also for their high quality RGB information to support the drawing and modelling phases.
Finally, also the four main facades (NE, NW, SE and SW) and two cross-sections of the building were generated.
The second aim of the research was testing different strategies for the modelling and creation of the HBIM model. The pros and cons of the two tested approach has been highlighted and their metric accuracy have been evaluated as well.
The proposed HBIM model could become a starting point for further analyses on stratigraphy and for formulating an updated reconstruction hypothesis of the initial building conformation. In this regard, could be interesting analysing the archaeological context through the Extended Matrix methodology (Demetrescu, 2018) , to have a complete 3D vision of the Arab bath depending on real stratigraphy and virtual ones.
The usage of FreeCAD open-source software allowed to process a model to be implemented with information concerning the building stratigraphy and its history; to easily get an integrated database concerning resources, materials, and IFC entity classifications. Furthermore, the possibility of setting up semantic queries (designed for archaeological purposes) is extremely useful for monitoring and conservation purposes (Figure 14).

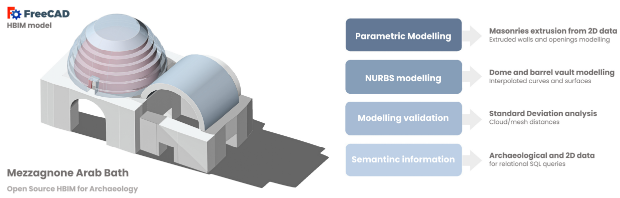

Figure 14. Summary of HBIM creation of the Mezzagnone Arab Bath.

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