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HBIM IN ARCHAEOLOGY, BETWEEN RESEARCH AND VALORIZATION. DATA AND PERSPECTIVES FOR *THUBURBO MAIUS* (TUNISIA)

1. Introduction

A century after the anastylosis intervention that affected its SW portico (Merlin 1915; Poinssot 1915), the so-called Palestra dei *Petronii* of *Thuburbo Maius* (Henkir el Kasbat, El Fahs) (Figs. 1-2) was chosen as the object of a research axis of the Tunisian-Italian cooperation program that links the Institut National du Patrimoine and the Université de La Manouba to the University of Bologna, in partnership with Sapienza University of Rome[1]. In the framework of that collaboration, the archaeological and architectural study of the monument was also aimed at creating a dossier on which to base the design of a new restoration and a new layout. In this perspective, the Palestra of *Petronii* has become the case study for the experimentation of an HBIM approach, functional both for research and for valorization.

H.B.R., An.C.

2. Palestra of *Petronii*: from the old excavations to the new documentation

The investigation of the sector to the E of the Summer Baths led, in 1914, to the identification of a large porticoed quadrangular square (Fig. 3), with a conspicuous quantity of remains of architectural elements still *in situ*, although in collapse: marble columns from the quarries of Jebel Oust, Corinthian capitals and several fragments of an architrave, with the inscription dating the monument to 225 and attributing its construction to *P. Petronius Felix* and his sons (Merlin 1915; Poinssot 1915) (Fig. 2). Very soon an anastylosis operation affected the northern porticus, which had already been rebuilt in 1916. Ever since its rediscovery the notable similarity, in size and shape, between this space and the one to the S of the Baths, later identified as the enclosure of the Temple of *Caelestis*, did not go unnoticed. Up to the present, the porticoed square has often been identified as the gymnasium of the Summer Baths, albeit doubtfully. This uncertainty is also reflected in the names adopted in literature, which in most cases prefer to qualify the

[1] This research was developed as a part of a Tunisian-Italian project, linking Institut National du Patrimoine (INP) and the Faculty of Letters, Arts and Humanities at La Manouba (Tunisia) with the University of Bologna (Italy) and Sapienza University of Rome (Italy). On this project and its first results can be found in Ben Romdhane, Coralini *et al.* 2024.

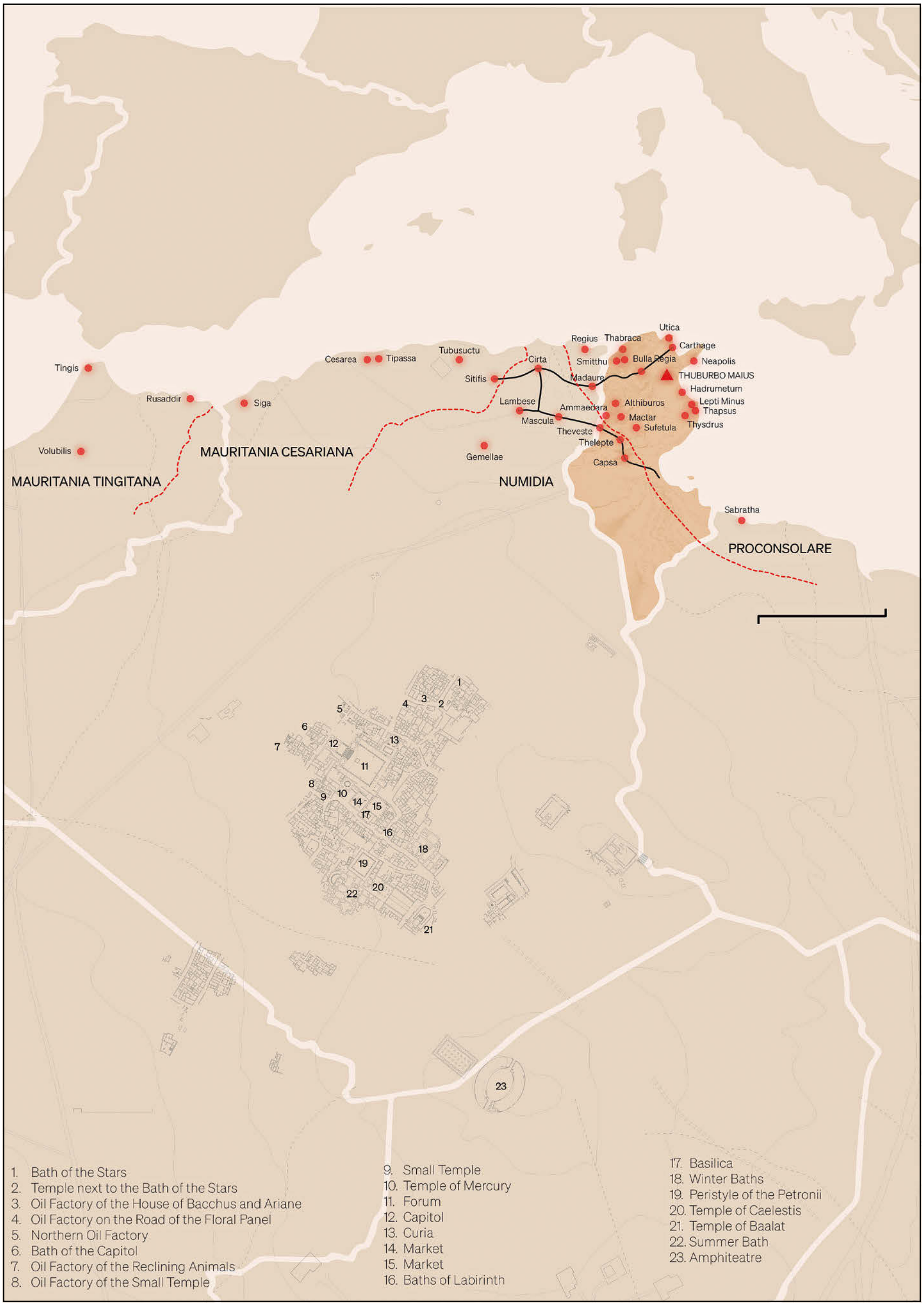

Fig. 1 – *Thuburbo Maius* in the Roman colonies of North Africa.

Fig. 2 – Aerial view of the *Palestra Petronii* and the Summer Thermal Bath of *Thuburbo Maius*.

architectural form, from the 'portique' of Louis Poinssot (1915), Alfred Merlin (1916, 1919), Louis Drappier (1920) and Alexandre Lézine (1961) to the 'peristyle' of the *Corpus des Mosaïques de Tunisie* (1985).

Drappier (1920) had already opposed the thesis of the thermal gymnasium, due to the absence of direct relations, in the structures and routes, between the two complexes. Merlin came to different conclusions in his more recent works, who in his reflections on the municipal statute of *Thuburbo Maius* (1933) proposed to see in the porticoed square of the *Petronii* «probably a gymnasium annexed to the summer thermal baths» (Merlin 1933). Pietro Romanelli (1940) held a similar position, seeing it as a «quadrangular gymnasium with a portico», as did Alexandre Lézine (1961) and Walid Ben Akacha (2011), as well as the authors of the main syntheses on the baths in the Roman world, such as Fikret Yegul (1992) and Yvon Thébert (2003). It is true that, as also highlighted by the authors of the *Corpus des Mosaïques* no direct architectural connection has been identified to date between the porticoed square and the Summer Baths, above all due to a lack

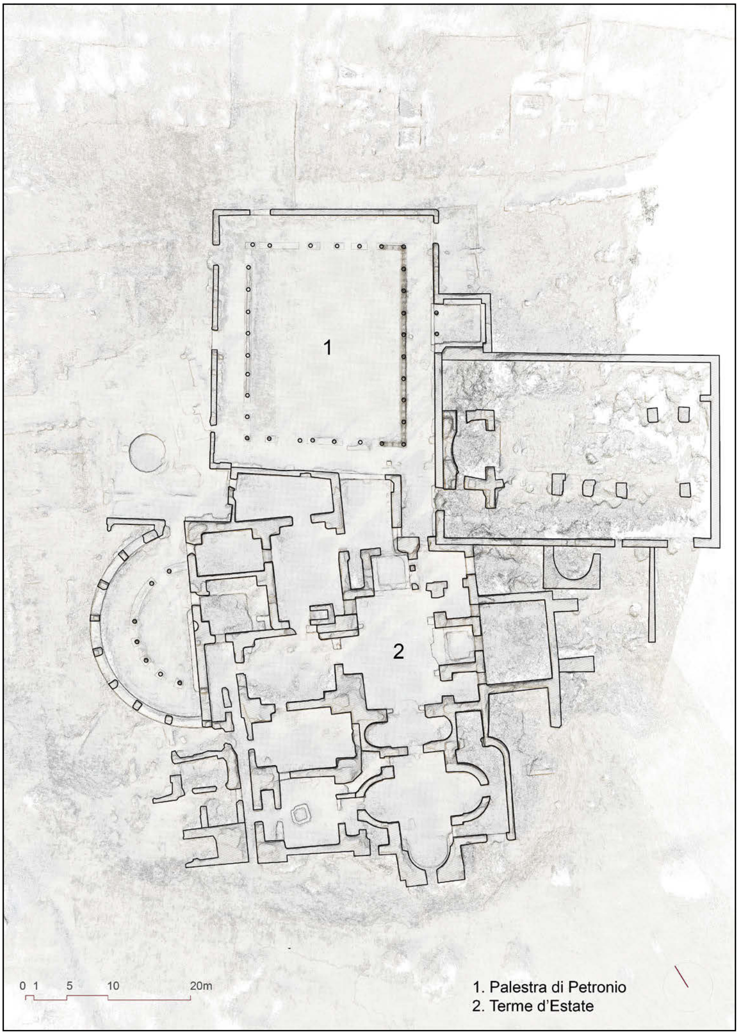

Fig. 3 – Plan of the *Palestra Petronii* and the Summer Thermal Bath of *Thuburbo Maius*.

of stratigraphic samples below the levels of the mid-imperial age reached by the old excavations.

Drappier's (1920) mention of surveys carried out in the arm of the portico adjacent to the Summer Baths, and of the discovery on that occasion of the remains of structures pertaining to a previous phase of the thermal complex, remains, in fact, an isolated testimony with no supporting documentation.

The contiguity and spatial coordination between the two complexes seem, however, sufficient to suggest that, even in the absence of data relating to the existence of a structural connection, the baths and the quadriportico were nevertheless linked by a functional relationship. It seems likely, in fact, that the porticoed quadrangular square built by the *Petronii* could have been – if not a thermal gymnasium in the strict sense – one of those spaces for aggregation that the Roman cities of North Africa equipped themselves with at different times and in different forms, as recently demonstrated by Paul SCHEDING (2019). In particular, the *Porticus* of *Thuburbo Maius* could be included in the group of structures added to the thermal installations characterised by a structure open towards the outside, so as not to limit their function to an exclusive relationship with those, but to qualify them, instead, as multipurpose spaces (TEATINI 2020). As already highlighted by LÉZINE (1961), the *Petronii* square, with its three entrances that faced three public streets, was a «place accessible à tout venant».

As regards its building history, the most successfull theory in scientific literature is its contemporaneously with the Summer Baths: as stated by Yvon THÉBERT (2003), and then taken up again by BEN AKACHA (2011), the two complexes would have been part of the same urban intervention, and of the same project, implemented in the first quarter of the third century, between 200 and 225[2]. The authors of the *Corpus des Mosaïques* (1985) believe, instead, as DRAPPIER (1920) did, that the construction of the Porticus was subsequent to that one of the Baths: the construction of the *Petronii* Square would have coincided with the first important restructuring of the thermal complex, which would have affected the eastern sector, adjacent to the new space. Also, for this topic, the results of the stratigraphic analysis of the building, possibly integrated with those of specific verification surveys, will be able to provide valuable data.

The relationship between the Porticus and the exedra at the centre of its south-eastern side is very interesting: the exedra is a square-shaped room, raised above the usable level of the quadriportico and paved with large slabs of local marble, of the same type used at *Thuburbo Maius* also in the exedras of the Forum, in the *sectilia* of the Summer Baths and in the central carpet of the court of the temple of *Caelestis* (LÉZINE 1961). In this exedra, also following the discovery in the Summer Baths of an inscription relating to the rules of the cult of Asclepius and a head of the god, Alfred MERLIN (1933) proposed to recognize the *Asclepieia* of *Thuburbo Maius*. LÉZINE (1961), on the other hand, had a different opinion, both on the intended use and on

[2] According to our working hypothesis, the Winter Baths would also have been part of the same urban planning project, the conditions of which would have been set by Caracalla's intervention in favour of the city, with the construction of the *exceptoria Antoniniana*.

the genesis of that space, attributing to the exedra the role of *apodyterium*/changing room, in relation to the function – of gymnasium – performed by the peristyle square, and who recognized at least two phases, one of which preceded the construction of the quadriportico and the other the result of a restructuring connected to the new construction. The presence of regular incisions on the threshold of the room (for a thickness of 4.5-6.5 cm and a length of 12-13 cm) testifies to the existence of a metal gate (Lézine 1961).

As regards the elevations and architectural elements, the *Petroni Porticus* is characterised by an equal ratio between the frieze and the architrave, both 41 cm high, a peculiarity of the Roman architecture of North Africa (Lézine 1961). Among its Corinthian capitals, there is also an example of a typology peculiar to the Trajan period, which is distinguished from those also by the traces of an ancient repair intervention. Its use in a more recent monument of no less than two centuries can be explained as the result of a reuse, but the possibility that it is the outcome of a modern restoration intervention cannot be excluded (Lézine 1961).

As highlighted by this state of the art, there are many open questions for the so-called Palaestra *Petronii* of *Thuburbo Maius*, from the times and methods of its construction to its functional destination. On an urban scale, it seems undeniable that the porticus was inserted organically into the neighborhood of the large baths brought to light by the excavations conducted between 1914 and 1917. Even if the existence of a connection in spatial syntax does not necessarily imply functional complementarity, this seems to remain the most convincing hypothesis. The greatest difficulties in reading and interpretation are determined by the absence of a monographic dossier for the monument. Filling this gap (verifying the *vulgata*, acquiring new data, relating all the information for a new exegesis) is the objective of the research axis dedicated to it in the *Thuburbo Maius* project: the use of HBIM promises to optimize the analysis work. In this direction, during the 2022 campaign, the new photogrammetric and three-dimensional documentation of the structures was integrated with the mapping of the state of conservation carried out with a thermal camera by Nicola Santopuoli (University of Bologna). The survey using laser scanner and drone has allowed us to obtain the essential basis for finally creating that scientific edition of the monument that has been hoped for since the first season of excavations (Merlin 1919).

H.b.R., An.C.

3. State of art of BIM applied to archaeological site

BIM was declined in Heritage Building Information Modeling (HBIM) in 2009, when it was first applied to historical heritage (Murphy *et al.* 2012). This methodology starts from the inverse assumption to the traditional one:

at the beginning of the process there isn't the information related to the design ideas but the data that can be collected to scientifically reconstruct the construction genesis of the artefact (Garagnani *et al.* 2016; Doria *et al.* 2024). In this context, archaeological assets represent a further challenge with the goal of building, through BIM language, virtuous processes that enable the management of the entire procedure, from the campaigning phase to the management and valorisation of an archaeological site (Carpentiero 2020; Doria *et al.* 2024). It is due to Garagnani *et al.* (2016, 2021) to have systematised in 2016 a new methodology for archaeological areas, starting from the previous research of Scianna *et al.* (2015), called ArcheoBIM.

This procedure differs from BIM and HBIM by attempting to reconstruct the building on the basis of archaeological data, reconfiguring a pre-existing condition. The outcome is an informed and interoperable three-dimensional digital repository mainly oriented to the documentation of the heritage, to the planning of conscious restoration interventions (Murphy *et al.* 2013; Empler 2021), and to valorisation. Through the model, the various professionals can validate their observations and hypotheses in a virtuous process that underlines each time the criticalities and problems of the proposed reconstruction, leading to the identification of the reconstruction that is architecturally most convincing and, therefore, most plausible. For these reasons the main difficulty is the very low conservation status of the artefacts, which makes the traditional use of software difficult, and therefore also requires reliable reconstruction of the site. The second one is the presence of non-exhaustive information in order to semantically characterise the elements to be modelled, thus limiting the historical reliability of the result.

An example are the activities started in 2016 for the excavation, study and virtual graphic reconstruction of the Etruscan city of Marzabotto (Gaucci *et al.* 2015; Garagnani *et al.* 2021), where Garagnani, taking up the work of Scianna *et al.* (2015), brings to systematisation what can be defined as ArcheoBIM (Garagnani *et al.* 2016; Bosco *et al.* 2019; Diara *et al.* 2021; Mancuso 2023). Other examples are Altino (Del Pozzo, Balletti 2023), Massaciuccoli (Sala 2023), Pompeii (Biancardo *et al.* 2023), the Roman Forum of *Liternum* (Cangiano 2019) and *Paestum* (Bosco *et al.* 2020, 2021).

The common denominator in these cases is the degree of uncertainty in the data, which is higher as one deals with objects that are distant in time and poorly witnessed, and which consequently involve a largely interpretive reconstruction phase. The informed and interoperable model thus also stands in this methodology as the tool to identify critical reconstruction choices through metadata, which can be updated according to the developments of the research.

E.P.

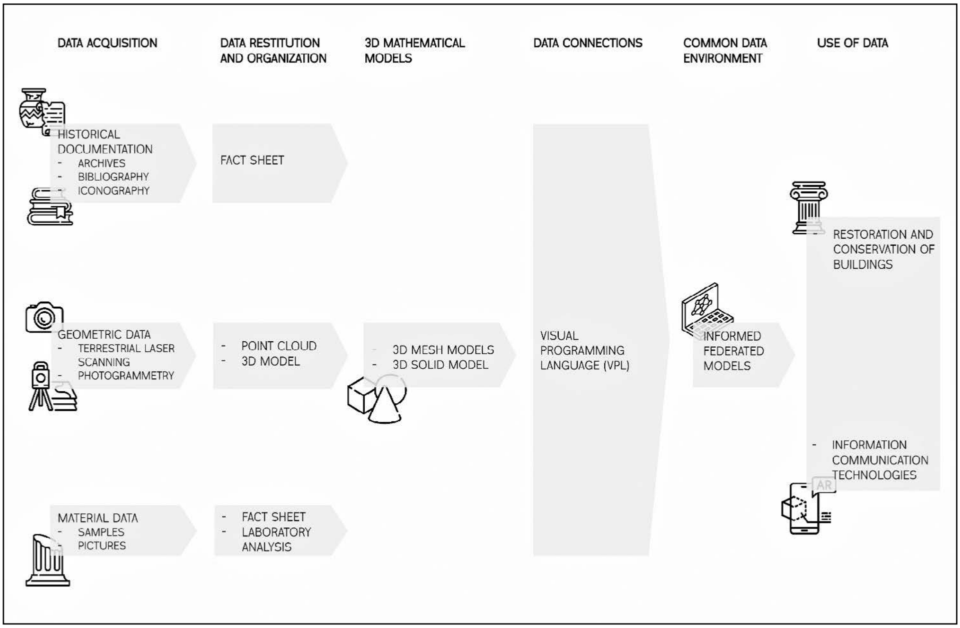

Fig. 4 – Methodological outline.

4. Methodology

4.1 *Knowledge framework*

A careful reading of the existing knowledge framework requires the definition of methods and strategies that promote a deep and integrated understanding of the *Palestra Petronii*. This understanding should encompass historical analysis, the study of past events and interventions, the state of conservation, the nature of materials, archaeological components, conservation status, and geometric and proportional studies. In this research, we apply an operational methodology developed by an interdisciplinary team, which integrates several tools, procedures, and experiences to address the complexities of protecting the archaeological site in a holistic and multi-scale manner. This approach aims to overcome previous methodological approaches characterized by sectoral and fragmented analysis (Fig. 4).

A.C.

4.1.1 Terrestrial Laser Scanning (TLS)

An integrated digital survey of the structure was conducted, employing both terrestrial laser scanning equipment and aerial image-based systems (drone photogrammetry). The resulting digital numerical model provides an accurate and detailed virtual representation of the real object, serving as a robust and reliable foundation for graphical restitution. This model enables in-depth critical analysis of the artifact, allowing for the reconstruction of its history from construction to its current state, facilitated by geometric and formal analysis. The data acquisition process involved the use of a Faro Focus 3D CAM 70 laser scanner and spherical targets as reference or control points. The morphology of the artifact dictated the planning of the acquisition campaign and the positioning of data capture points to ensure data completeness without redundancy. All scans were performed by positioning the instrument at fixed locations along the vertices of an open traverse. Scans requiring high metric accuracy of the acquired data were carried out to produce a three-dimensional digital model with an instrumental resolution set for a sphere with a 10 m radius, resulting in an average point distance of 1.2 cm at that specific distance. This instrumental setting does not yield a homogeneous real resolution, as it is necessary, during subsequent processing phases, to decimate the number of acquired points that overlap during the registration process. For these same scans, HDR panoramic images were captured using an integrated camera, to obtain colorimetric (RGB) values.

Particular attention was given to surveying the artifact in relation to its context, aiming to investigate potential contiguity between the *Palestra Petronii* and the Summer Baths to explore structural and/or functional connections between the two. Moreover, emphasis was placed on acquiring detailed data regarding the planimetric connection between the porticoed square and the distillation exedra, providing a solid basis for analysing the spatial relationships between the two environments and reconstructing their genesis. The scans were acquired and subsequently automatically aligned into a single 3D model using SCENE software. The data processing phase in SCENE involved registering the single scans into a unified coordinate system. Following the automatic registration method, most results were favourable. In the few instances where automatic homologous point recognition was insufficient to achieve an optimal result, manual registration was performed. Upon completion of the process, a processing report was generated, which identifies optimal registration quality when the average deviation between homologous points is less than 4 mm, medium quality registration when the deviation is between 4 mm and 8 mm, and low-quality registration when the deviation is greater than 8 mm. The average deviation identified by the software is approximately 3 mm. To integrate metric, colorimetric, and material information, a second point cloud was acquired using aerial photogrammetry systems.

A.C.

4.1.2 Photogrammetry

Unmanned Aerial Vehicle (UAV) integrated with range-based technology, commonly known as drone photogrammetry, enables a digital photogrammetric survey that combines data accuracy with reduced field work time compared to traditional methods. Given the nature of the *Palestra Petronii* and the need to understand its position within the context of the ancient city, UAV surveying required a variable level of accuracy, ranging from detail scale to architectural scale and urban scale (extending to the city of Thuburbo itself).

Aerial images were acquired using a DJI MAVIC PLATINUM PRO aircraft equipped with a stabilized 4K camera. Several flights were conducted, each executed using a series of flight lines flown parallel and perpendicular to the direction of the site's maximum slope. The first flight was performed at a nominal altitude of approximately 120 m AGL (above ground level), corresponding to a GSD (ground sample distance) of about 2 cm. The second flight occurred at a nominal altitude of roughly 60 m, resulting in a GSD of approximately 0,5 cm. Both survey sessions included nadir (vertical) and oblique flights at a 45° angle to the horizontal. To provide redundancy and enhance the quality of the restitution, the longitudinal and transverse overlap between photographs was set to 75%. Particular attention was paid to capturing the black and white targets distributed throughout the area, so they could serve as homologous points for the merging of the two-point clouds derived from Terrestrial Laser Scanning and UAV data respectively. Images from different flight were then processed using Metashape software and then join to generate an unstructured point cloud that was, however, not yet correctly scaled or oriented.

To generate a unified numerical model, it is essential that the reference systems of the two point clouds (structured and unstructured) are congruent. This alignment is achieved through a process that involves identifying a set of control points common to both clouds. These control points, materialized on the ground using black and white targets, were previously identified during the acquisition phase and within the structured point cloud. Subsequently, the corresponding points in the unstructured cloud are identified. By setting the coordinates of the control points as constraints in the registration process, the geometric transformation (scale, rotation, translation) necessary to align the unstructured cloud is determined, ensuring the correct integration of the data.

The point clouds acquired using laser scanning and drone, previously aligned in terms of position and scale, were integrated within the Recap Pro software. The fusion of these two datasets generated a high-density point cloud, essentially void-free but affected by a high level of noise. Therefore, it was necessary to apply a series of post-processing algorithms for decimation and removal of anomalous points (Fig. 5). After this processing phase, it

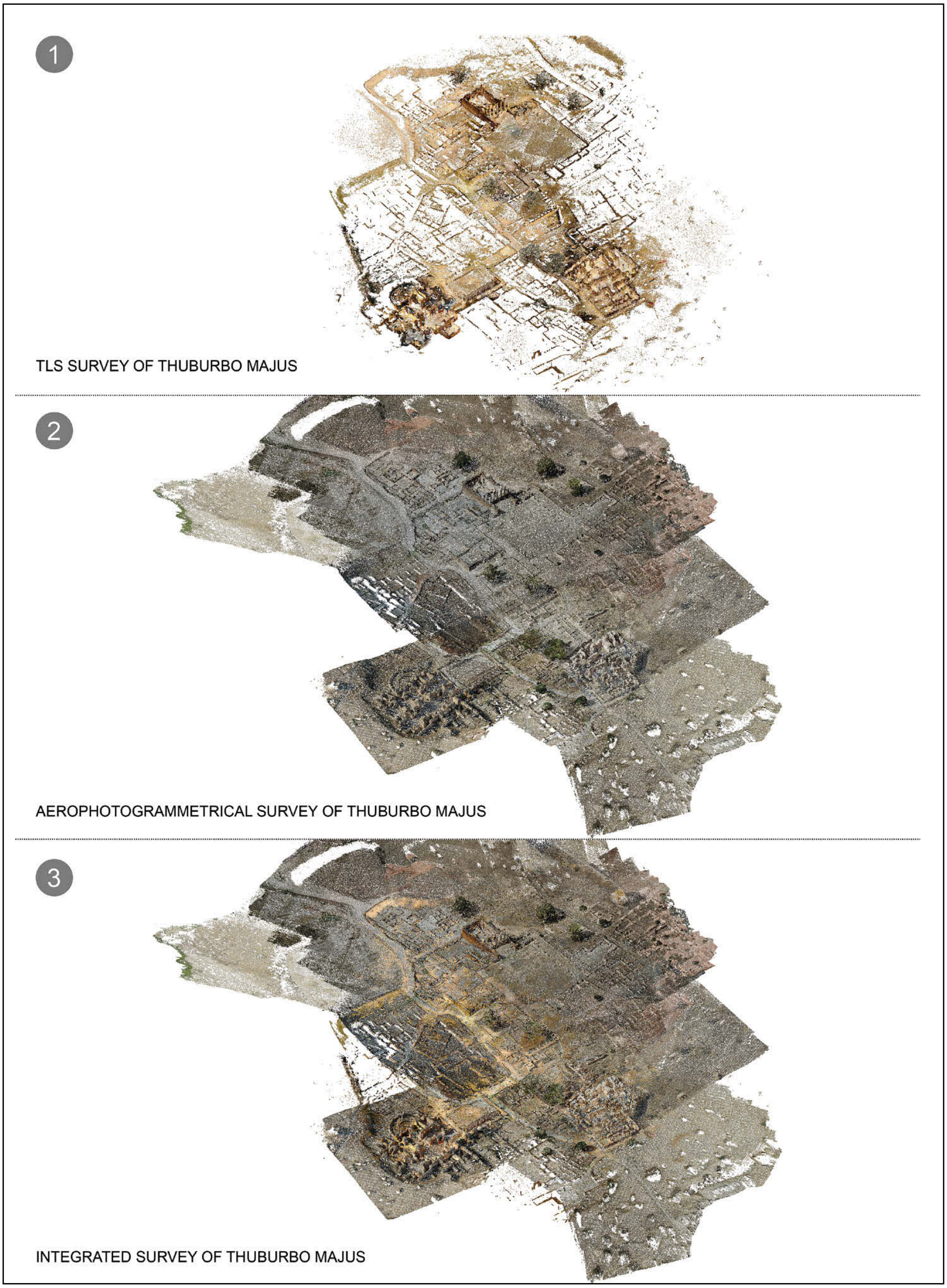

Fig. 5 – Data acquisition methods: TLS, photogrammetry, and integrated survey (TLS+photogrammetry).

was possible to start the data interpretation phase through critical-technical evaluations, cross-comparisons, and Building Information Modeling (BIM) of the *Palestra Petronii*.

A.C.

4.1.3 USM

The roof system of Petronius's gymnasium leans, on one side, on the colonnade, and on the other, on masonry partitions. Only the basement part of the wall remains, but where the *opus Africanum* masonry type is still clearly legible (Fig. 6). This frame technique is characterised using different elements according to their static function. The larger ones, arranged according to five different possible laying schemes, generally made of stronger materials, behave like a structural frame, interspersed with 'infills' of lesser quality and load-bearing capacity and faster execution (Camporeale 2013). The name is a neologism that has been used since the mid-twentieth century, appearing for the first time in Lézine's (1956) study of the *Domus* des chapiteaux historiés in Carthage, but is probably already a common expression in the archaeological field (Camporeale 2013).

It is a masonry technique used above all, in Roman times, in the provinces of North Africa, probably due to its Phoenician or Punic origins, but can also be found in the Iberian Peninsula and Italy. Camporeale (2013) proposes a typological cataloguing that considers the equipment of the pillars not only according to their position, but also their construction procedure and static mechanism, a system that proves to be very functional for the subsequent semantization and modelling of the site in HBIM language. Based on Camporeale's cataloguing into five typologies, the *opus Africanum* present in the Palestra di Petronio falls into the fourth scheme, having the stone blocks arranged vertically. This specific construction method, also used by the Phoenicians in Carthage (Lancel 1992) before its destruction, spread throughout North Africa in the imperial period, being found in other urban settlements besides Thuburbo, such as Thamugadi, Tiddis and Cuicul.

Along the perimeter of the *gymnasium*, the masonry presents pillars of vertically superimposed squared blocks of varying length, made of stone, travertine or pinkish limestone, interposed by *opus mixtum* of the same lithic type and white mortar with inclusions of limestone, quartz and calcite. The construction of the 'pillars', not being mortared by the interposed paraments, is therefore independent and denotes a different hierarchical importance of the components, which is then reproposed within the model through two different families, one for the vertical stone elements, the other for the statically and constructively independent irregular masonry.

E.P.

UNITA' STRATIGRAFICA MURARIA 01 - USM01

CARATTERISTICHE GENERICHE
n° del campione: USM1
paramento interno/esterno: esterno
individuazione dell'alzato (nord/sud/ovest/est) o dell'ambiente interno: Nord-Est
tipologia/tecnica costruttiva: opus africanum – parti in opus coementicium

CARATTERISTICHE DELLA MURATURA
materiale elementi verticali: travertino, calcare rosato
materiale elementi muratura interposta: calcare
apparecchiatura muraria: elementi lapidei squadrati verticali con muratura in opus coementicium interposta
altezza dei filari [m]: -
dimensione degli elementi in travertino [m]: 1.18- 1.41 x 0.62 - 0.72
dimensione degli elementi in calcare rosato [m]: 0.61 x 0.86
dimensione degli elementi in calcare [m]: 0.05 - 0.12 x 0.15 - 0.30

CARATTERISTICHE DELLA MALTA - PARAMENTO
composizione: malta bianca con inclusi di calcare, quarzo e calcite
consistenza: non rilevabile
spessore [m]: -

Fig. 6 – *Opus africanum* USM analysis.

4.1.4 Conservation state and the macroscopic characterization of stone materials

The portico, as it appears today with its NW colonnade fully reconstructed and two sides only partially outlined, was rebuilt through anastylosis in the 1920s. This reconstruction was carried out following principles later reaffirmed in the Athens Charter (1930). The portico consists of twelve slender and elegant columns, approximately 400 cm in height and 40 cm in diameter. The Attic base of the columns features the characteristic sequence of *torus-scotia-torus*, while the capitals are of the Corinthian order with hooked leaves. The entablature comprises an architrave and a frieze bearing an inscription. The reconstruction efforts at the site of *Thuburbo Maius* were influenced by the cultural context of the early 20th century, marked by debates on archaeological restoration and the controversies surrounding the anastylosis of monuments on the Athenian acropolis, which elicited both praise and criticism (Mallouchou Tufano 1988; Carbonara 1997). The anastylosis was carried out using the principles, materials, and knowledge available in the 1920s. Today, it inevitably shows the effects of time, and approximately ten years ago, provisional support structures made of pipes and joints were installed.

Preliminary investigations at the site, particularly on the *Palestra Petronii*, have examined materials, construction techniques, and forms of deterioration, enabling a detailed assessment of the conservation state. The stone material of the column shafts, largely composed of a single block in a gray-violet color with yellow-pink streaks and patches, is likely a veined sedimentary limestone potentially containing shell fragments. Indeed, the ancient city of *Thuburbo Maius* is home to quarries of 'lumachella limestone' from which this rock was extracted. This type of stone was referred to by Roman stonemasons as 'oriental lumachella' (Lazzarini 2004). The capitals, column bases, and entablature are also likely made of sedimentary limestone. The columns themselves are composed of calcarenite, a lower-quality stone that was coated with a layer of stucco to simulate marble and then carefully worked to achieve the desired aesthetic effect. Regarding its conservation state, the colonnade exhibits both widespread and localized degradation, including surface and structural issues. The stone blocks of the entablature, some of which are fractured, have undergone restoration interventions over time, including the insertion of metal clamps. Moreover, macroscopic observations, diagnostic investigations, and specifically thermographic surveys, moisture content measurements, and spectrophotometric analyses, have identified the presence of iron rods and cement within the third capital, connecting it to the corresponding entablature block.

N.S.

4.2 *Modelling*

4.2.1 From point cloud to parametric modelling

The inherent challenges of applying BIM procedures to existing structures are well-known: accurately modelling a structure requires a deep understanding of construction techniques and structural configurations. Moreover, the modeler must have a thorough spatial understanding, derived from reliable surveys and the ability to identify underlying geometries and proportions within the building. The complexity is particularly evident in archaeological contexts. Due to the partial preservation of remains, archaeological sites often have information gaps. Creating a model requires specific methodologies to interpolate missing parts, allowing for a comprehensive understanding of the artifact and its historical phases. Therefore, the focus is not only on the *Palestra Petronii* in its current state, but also on all available documents and interpretations related to the structure. The model is based on a dual structure: an information management system organized hierarchically to store

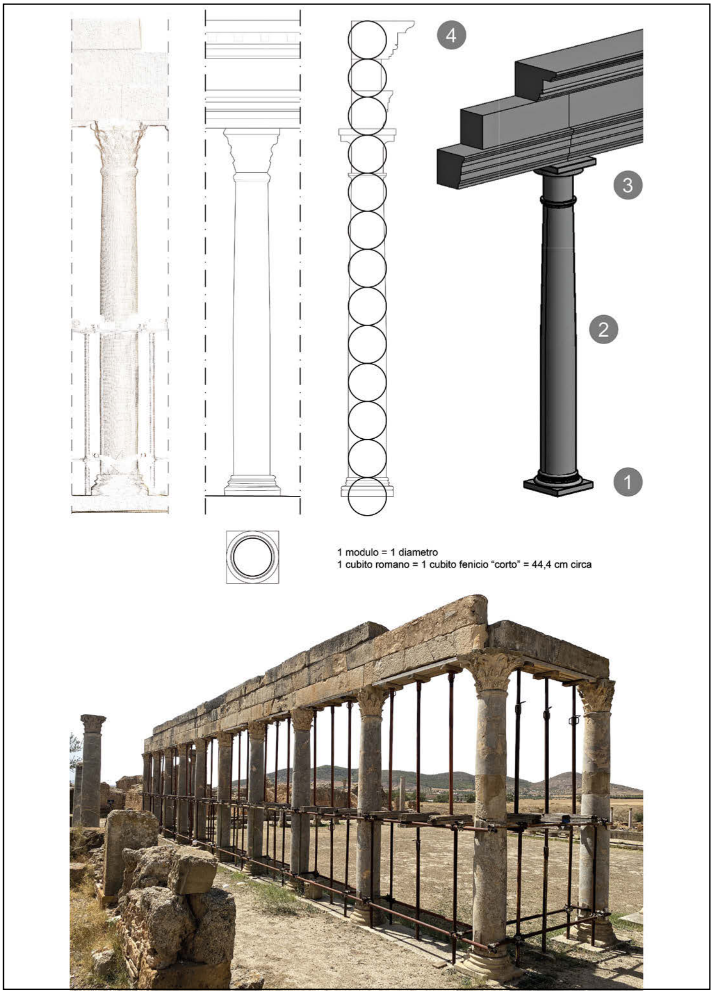

Fig. 7 – Column analysis and segmentation.

and retrieve data associated with digital objects, and a geometric study that serves as the foundation for subsequent historical and conservation analyses.

A key aspect is the potential information (geometric and otherwise) contained within the point cloud. However, this data requires 'semantization' to reconstruct the recognizable characteristics of classical architecture while adapting them to the specific features of the *Palestra Petronii* (Fig. 7). Several studies have explored the parameterization of classical architectural orders within a BIM environment (Bianconi *et al.* 2019; Rossi 2019; Potestà 2021), highlighting the importance of modules, series, repetition, and proportional systems in both the construction of the order and the parameterization underpinning BIM.

Unlike Roman buildings in Rome, which can be referenced against the codifications of classical treatises on architectural orders (e.g., Vignola 1562), public structures in African provinces exhibit proportions that can deviate significantly from traditional canons. As previous studies have shown (Ferchiou 1975; Pensabene 1986; Ward-Perkins 1993), the ratio between the base diameter and the height of shafts in African columns differs from that of typical Roman buildings. This necessitates a recalibration of geometric parameters and a more flexible approach to the parameterization of architectural orders in this specific context. However, by comparing these studies, a reliable framework can be established to reconstruct the object under examination.

Following a metric-proportional analysis of the elements, based on the point cloud, they were modeled digitally. By selecting appropriate categories, families, and architectural types, the geometric and typological characteristics of each component can be accurately represented. The level of detail in the modeling is determined by the project's specific objectives, namely the conservation and valorization of the cultural heritage. The hypothetical reconstruction of elements in archaeology always contains a degree of uncertainty. Within the HBIM model, in fact, the creation of a new parameter is foreseen, already addressed in literature, although within the context of non-archaeological built heritage (Bianchini, Nicastro 2018). This parameter is called Level of Reliability and considers both the geometric correspondence and the ontological and informative reliability of the model with respect to the reality it wants to describe.

A.C.

4.2.2 Visual Programming Language

Software using the HBIM language was created for modelling new buildings and, although highly performing in this sector, has considerable limitations in the field of archaeological heritage. The strong irregularities and uniqueness of the objects that must be inserted clash with the logic of the algorithms that provide for the input of elements that are often necessarily connected to others and that have characteristics that guarantee certain quality standards typical of new buildings (Garagnani *et al.* 2021). Such problems are also experienced in the modelling of the Petronio Gymnasium, leading to the search for the integration of several modelling methods. The result is a procedure that, from the specific context of application, can be adapted to the different case histories of archaeological sites.

The constraints of HBIM modelling can be overcome using Visual Programming Language (VPL), a modelling methodology that is based on the use of strings and textual encodings for the graphic manipulation of objects. Using a BIM methodology does not aim to perfectly model the irregularities

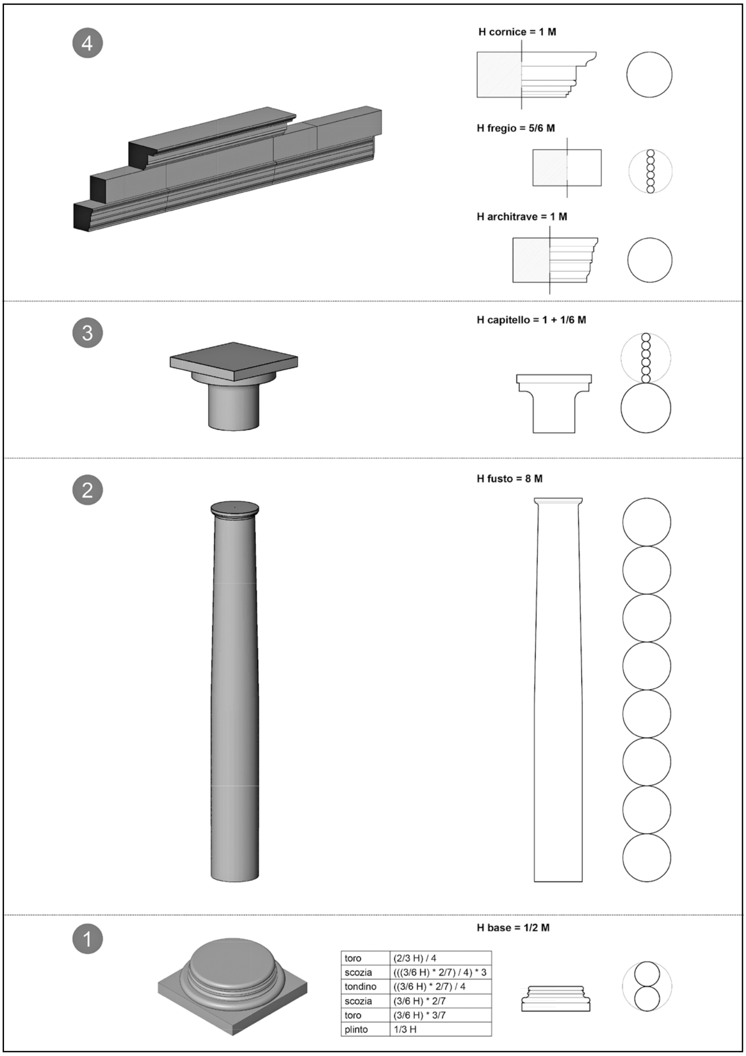

Fig. 8 – Parameterisation of the morphological elements of the portico.

of the artefact. These features can be read more clearly from the point cloud or a photogrammetric model, both of which can be integrated into the model, segmented by areas of interest. The aim of the research was to obtain a model for the management of the site from the point of view of conservation and to be the basis for possible communicative outputs. For example, according to these objectives, a simplification on the order of a centimetre is expected and required for irregularities in the three dimensions of wall ridges. However, even semantically more defined elements such as the columns, whole or partial, of the arcade constitute obstacles within the BIM modeler. These elements have a rather complex parameterisation of the mouldings and the decorative system that characterises them, making them very easy to manage within mathematical modellers supported by visual programming tools, less so within BIM modellers where surfaces with a curvilinear character, such as entasis and Corinthian capitals, in the case of the Palestra di Petronio, are difficult to parameterise.

Within the research, VPL is used on an object that lends itself particularly well to parameterisation due to its proportional logic, the Corinthian order of the Palestra's portico. At the basis of the modelling is the investigation of its formal genesis, which begins with the decomposition according to the nine characteristic lines, then going on to reconstruct the sequence of mouldings that characterise it, and from the identification of the module understood as the diameter of the column at the imoscape. At this point, going down in scale, it is possible to read all the proportional rules that relate the parts to each other and to the module.

These identified relationships are the parameters on which the modelling rests and which allow, as the module varies, the dimensional control of the entire column. By means of integration with special plug-ins, the parts, modelled using VPL, can be imported into the HBIM modeler, generating a nested family according to the classical order decomposition (Fig. 8). Care is taken in the management of the decorative apparatus: the details of the Corinthian capitals are imported into the family ensuring that they are only displayed in the detailed mode of the model. In this way, it is possible to control the dimensions of each object through the variation of the module, enriching it with the collected metadata system that justifies its construction genesis. The integration of the VPL thus makes it possible to guarantee the characteristics of parameterisation, interoperability, proper to an HBIM model, and at the same time a more faithful and detailed representation of objects that in their conservative partiality and uniqueness describe their cultural value.

E.P.

4.3 *Common Data Environment (CDE)*

HBIM places in the middle of the process the importance of accurate, transparent and collaborative information management, which is essential to support effective decisions, reduce errors and increase operational efficiency. The vision of 'better information management' represents a fundamental step to ensure that each phase of the process is aligned with quality, transparency and sustainability criteria, elements that are increasingly playing a decisive role in current archaeological and architectural practices.

4.3.1 Role of the Common Data Environment

Key element of HBIM process is the Common Data Environment (CDE), a collaborative platform organized as a centralized repository that collects, manages and distributes all the information relevant to a BIM procedure (Fig. 9). CDE is more than a simple archive: it is configured to be a secure and dynamic environment where information can be uploaded, updated and consulted in real time by all stakeholders involved. Its role is essential to ensure that all participants in the process – from archaeologists, to surveyors, to restorers, to facility managers – can access updated and reliable information, thus reducing the risks of errors, misunderstandings or duplication of data.

Through the CDE, information flows are managed in a centralized and structured way, ensuring fluid and continuous communication. This not only facilitates collaboration, but also ensures that all informations are shared in a standardized format and accessible to each professionalism involved. Such uniformity is particularly important for complex processes, such as that of the Palestra di Petronio, where a multiplicity of scholars and disciplines are called upon to collaborate without a centralized and well-structured system such as the CDE, information would risk being lost or being difficult to use, compromising the overall efficiency of the process followed.

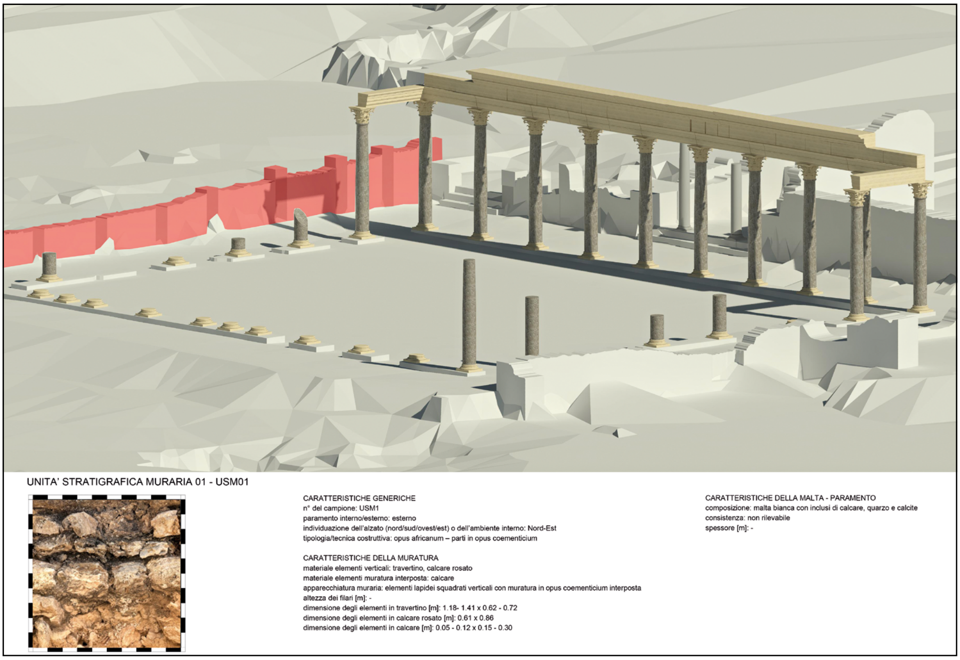

Fig. 9 – HBIM: informed model of *Palestra Petronii*.

4.3.2 Key features of information in CDE Environment

Efficiency of CDE depends on the quality and optimal management of the data entered into it. Informations contained in CDE must have specific characteristics to effectively support the design and operational process within *Thuburbo Maius*. Among these characteristics we find real-time updateability, which allows each part of data to be constantly aligned with the latest changes; interoperability, which allows data to be shared and used on different platforms (including software) without loss of content or quality; traceability, which makes it possible to monitor and historicize each change made to the data, offering a clear view of the evolution of the project and the decisions taken throughout the life cycle. Furthermore, CDE makes the information easily accessible to each participant in the process based on their needs, thus promoting a personalized and targeted use of the data, an essential element in a context where the timeliness and precision of the information are crucial for the effectiveness of the procedure.

4.3.3 CDE management tools and platforms

To implement and manage a CDE, according to the HBIM specifications, there are several platforms designed to meet the needs of various participants in the process. These tools not only allows to organize and store information, but also provide advanced functionality for workflow management, data security and access control, ensuring that information is used safely and compliant with current regulations. The choice of the most suitable platform depends on the specific needs of the project and the stakeholders involved, and must take into account factors such as scalability, ease of use and compatibility with industry standards.

4.3.4 Importance of data quality and typology in CDE

Technology is only part of the effectiveness of a CDE. Quality and type of data entered into the system are crucial to ensure truly optimized information management. Data must be accurate, relevant and structured to support each phase of the process and facilitate interoperability between the various systems and actors. This means that, before being loaded into the CDE, data must be validated and conformed to needs of the work group, to ensure that they are actually useful and usable by all stakeholders. The evaluation of data quality therefore becomes an essential phase of the process, since a well-populated and managed CDE is the key to efficient, sustainable and resilient management. The evolution of HBIM towards ArcheoBIM underlines the importance of an approach oriented to advanced information management. CDE, as a centralized and collaborative repository, plays a fundamental role in ensuring transparency, efficiency and collaboration in each phase of the project, with a direct impact on the quality and sustainability of the processes. Optimized CDE management enables stakeholders to access accurate and up-to-date information, facilitating better decision making and increasing resilience and efficiency throughout the project lifecycle.

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4.4 *Output and use of the model*

4.4.1 Conservation process

It is essential to always remember that any restoration intervention must be based on prior and thorough knowledge of the monument. A comprehensive study of the Palestra must precede any proposal for intervention, encompassing key aspects such as archaeological research, geometric surveys, and material analysis. Based on investigations conducted during the 2022, 2023, and 2024 missions, a technical-economic feasibility project has been initiated. This project adheres to the fundamental principles of restoration and proposes establishing a pilot site to remove the temporary structural supports from the colonnade (Fig. 10). This allows addressing, as a priority, issues related to structural restoration, with a clear understanding of the monument's historical phases and the primary risk factors. Special attention must be given to: 1) the treatment of stone surfaces, as they represent the monument's antiquity and authenticity, with planned cleaning and conservation-focused restoration; 2) the metallic elements used during previous anastylosis and maintenance operations, which must be appropriately treated. Case-by-case evaluations are necessary for potential integration using mimetic mortars to compensate for gaps caused by the removal of improper cementitious mortars encasing the metal elements.

Similarly, it is deemed appropriate to remove the incongruous mortars present on the columns and the trabeation blocks, followed by an assessment for filling gaps with appropriately formulated mimetic mortars. Regarding the essential aspect of structural restoration, a static intervention is planned that respects the current conditions of the colonnade as much as possible, aiming to: 1) avoid altering the behavior of the trabeation; 2) realign the weight of broken blocks onto the vertical axis of the columns; 3) prevent the rotation of blocks on the capitals, thereby preserving the abacus of the capitals.

Without delving into specifics, a key element of the static intervention involves stainless steel tie rods (Jurina 2014), designed and installed to accommodate the monument's global and local structural framework while maintaining its expressive authenticity. These operational procedures are integrated into the HBIM model developed in earlier phases, enabling professionals in the field to carry out restoration swiftly and with precise action monitoring. Moreover, it is important to underline again the growing relevance of the use of digital tools for the applications in the archaeological field. Here we cite only an interesting case study in the site of the ancient urban centre of Nineveh (Marchetti 2023), where in-depth archaeological excavations

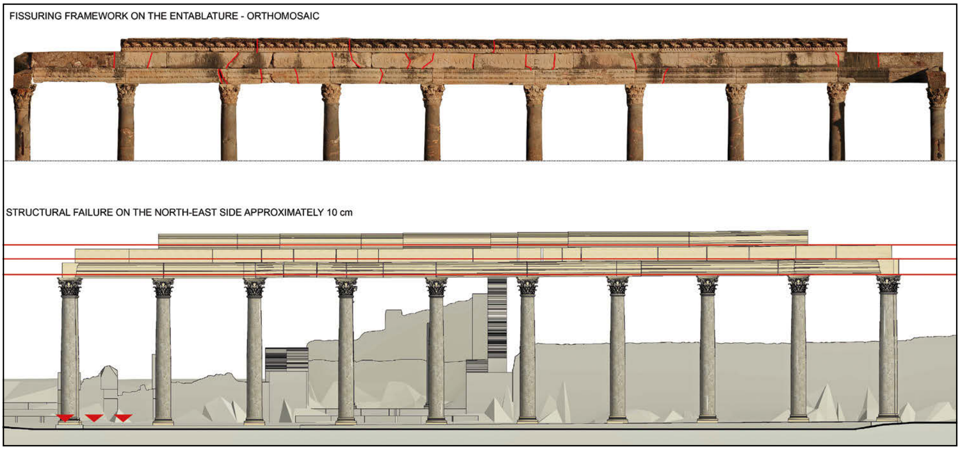

Fig. 10 – HBIM model for the restoration of the porch of *Palestra Petronii*.

and restorations activities, together with an archaeological park opening, have been properly supplemented by digital tools and also two recent review papers on this subject (Moullou *et al.* 2024; Sylaiou *et al.* 2025).

N.S.

4.4.2 Dissemination and valorization

Data contained in the CDE environment can also be used, but not yet developed for Thuburbo Maius, to activate a process of valorization and dissemination of the Palestra, through methods linked to the use of Information and Communication Technology (ICT). The model created with the HBIM Modeler is enriched with information relating to the visual aspect (texture) and the most accredited reconstruction hypotheses by archaeologists (Empler *et al.* 2022). The outputs are:

– a model for viewing in VR (Virtual Reality), through the use of head mount viewers provided at the entrance to the archaeological area, in which there are visualizations of both the current state of the Palestra and the reconstruction hypothesis, with the possibility of interrogating the parts present in the two models;
– a model for viewing AR (Augmented Reality) with the use of visitors' portable devices, where the reconstruction of the Palestra is displayed in overlay on the device screen;
– APP for mobile devices with the possibility of having thematic itineraries calibrated on the different historical phases of the city and the transformations that have occurred, specifically, on the Palestra.

T.E.

5. Conclusions

The application of HBIM to archaeology can be referred to as ArcheoBIM, introducing a new and pivotal role for the informed modeling of archaeological sites and structures. Central to this approach is the CDE, which serves as a repository for heterogeneous data collected through analyses and evaluations conducted by experts from various disciplines. This interdisciplinary integration enables a more comprehensive understanding of the object of study, supported by a flexible and continuously updatable system. Collected data facilitate the generation of different outputs, ranging from site preservation to its enhancement and promotion. This underscores how the digitization process serves as an essential and transformative tool for the management authorities overseeing areas subject to such investigations. ArcheoBIM not only ensures the safeguarding of cultural heritage but also enhances its accessibility and potential for broader engagement, demonstrating the critical role of digital methodologies in modern archaeological practices.

H.B.R., An.C., T.E.

Hamdem Ben Romdhane
Institut National du Patrimoine (INP)
hamdenbenromdhane@gmail.com

Antonella Coralini, Nicola Santopuoli
Dipartimento di Storia Culture Civiltà
Alma Mater Studiorum Università di Bologna
antonella.coralini@unibo.it, nicola.santopuoli@unibo.it

Tommaso Empler, Adriana Caldarone, Esterletizia Pompeo
Dipartimento Storia Disegno e Restauro dell'Architettura
Sapienza Università di Roma
tommaso.empler@uniroma1.it, adriana.caldarone@uniroma1.it
esterletizia.pompeo@uniroma1.it

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ABSTRACT

HBIM represents one of the new frontiers in the digitalization process applied to archaeological sites. This paper illustrates a methodological procedure applied to the Palestra of *Petronius*, located in the archaeological site of *Thuburbo Maius* in Tunisia. The Palestra faces structural and restoration issues, which are investigated using an HBIM procedure. A key element in this context is the Common Data Environment (CDE), a collaborative platform designed as a centralized repository that collects, manages, and distributes all relevant information for a BIM process. CDE serves as a secure and dynamic environment where information can be uploaded, updated, and consulted in real time by all the researchers involved. Its role is essential to ensure that all participants in the process – including archaeologists, surveyors, restorers, and site managers – have access to up-to-date and reliable information, thereby reducing the risks of errors, misunderstandings, or data duplication. These data also enable the configuration of various outputs, ranging from site preservation to its valorization, confirming that digitalization is a crucial and fundamental tool for the management entities overseeing areas subject to this type of investigation.