# DIGITAL MANAGEMENT FOR THE RESTORATION PROJECT. THE CASE OF THE TEMPLE OF VENUS IN BAIA

P. D'Agostino[1]*, G. Antuono[1], E. Elefante[1], R. Amore[2]

[1] Dept. of Civil, Construction and Environmental Engineering, University of Naples Federico II, Naples, Italy – (pierpaolo.dagostino, giuseppe.antuono, erika.elefante)@unina.it
[2] Dept. of Architecture, University of Naples Federico II, Naples, Italy – raffaele.amore@unina.it

**KEY WORDS:** Archaeological heritage, 3D survey, segmentation, BIModeling, Roman Baths

**ABSTRACT:**

The work that is presented here shows the results of the survey and material characterization campaign, performed through digital information acquisition and management processes of the Temple of Venus in Baia, in the framework of the activities by the Departments of Civil, Building, and Environmental Engineering of the University of Naples Federico II, in agreement with the Archaeological Park of Campi Flegrei. The artifact stands as a deeply interesting example of an architectural palimpsest, which - despite being involved by significant structural reinforcement interventions - presents interesting technical solutions, to be further investigated in their singularity and specificity. Unfortunately, it cannot be currently visited, until the execution of works to guarantee its complete and safe accessibility, also in terms of structural safety. The use of digital methodologies for data acquisition, in the integration of range and image-based survey techniques, and their semantic de-discretization has allowed systematizing the developed knowledge into models that can be easily queried and implemented over time, where both the geometric and the information component are indispensable for orienting and elaborating a conscious and articulate restoration project, as required by this building.

## 1. INTRODUCTION

The work that is presented here shows the results of the survey and material characterization campaign, performed through digital information acquisition and management processes of the Temple of Venus in Baia. part of the wider Archaeological Park of Terme di Baia, managed by the abovementioned Archaeological Park of Campi Flegrei - an Institution of the Ministry of Culture with special autonomy - since 2016, together with the main archaeological sites and monuments of the Phlegrean territory (Fig. 1).

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Unfortunately, it cannot be currently visited, until the execution of works to guarantee its complete and safe accessibility, also in terms of structural safety.

Our work, following the essential historical, archival, documental, and iconographical investigations, focused on the survey of the artifact and its constructional interpretation, through procedures of characterization of architectural elements in - also parametric - modeling platforms. This was useful to establish the geometric data needs for the graphical update of the examined areas, and to produce an adequate technical - 2D and 3D - representation of non-documented areas (Fig. 2).

The following step was the individuation of the construction typologies of the various elements of the building body, classifying both ancient parts and those related in the following epochs, until the most recent ones, related to restoration interventions performed in the post-war period. The final phase was the definition of the present instability and decay phenomena.

### 1.1 Method notes: BIM and data enrichment for Cultural Heritage

The use of digital methodologies for the acquisition and management of geometric and construction data, aimed at defining a so-called digital twin consisting of the reference architectural building, allows to systematize the knowledge developed in models (Castagnetti et al., 2017; Diara and Rinaudo, 2018) that can be easily queried and implemented over time and are essential for the elaboration of a conscious and articulated restoration project, as required by this building. On the other hand, the issue of BIM-oriented parametric modeling in the management of knowledge and interventions on cultural heritage (Ding et al., 2023) has definitively led to the possibility - more appropriate to say the necessity - of a modus operandi aimed at an interdisciplinarity not only of a work process really "in parallel" in the operational phases, but above all of a hybridization and a characterization of the cultural models typical of each disciplinary field. However, the very concept of model requires that it be declined both in terms of design paradigm and of IT architecture within which to build and evolve the knowledge mediated by the digital tool.

In terms of design paradigm, it is perhaps good to remember how the reference regulatory context, certainly valid for the Italian case, but which in fact refers to the broader international context, is directing thought towards the use of digital tools - which today in fact they refer to the paradigm of parametric modeling - for the information management relating to the object of intervention.

* Corresponding autho

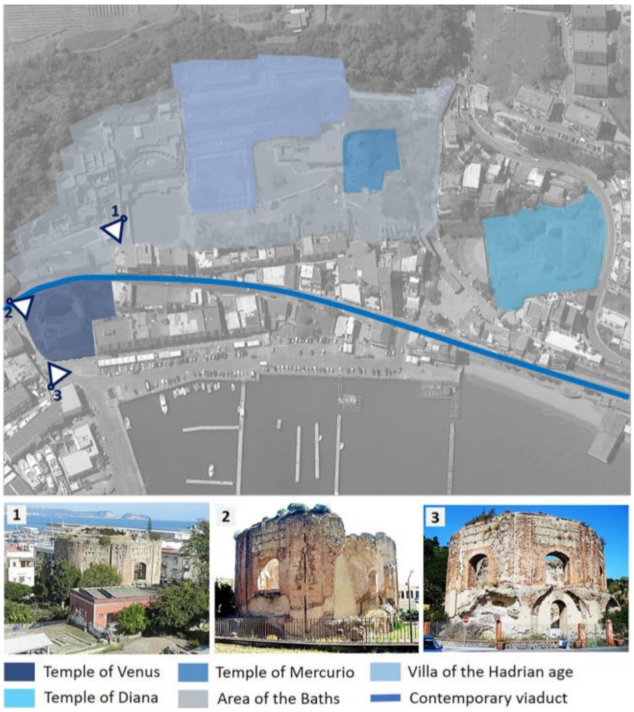


**Figure 1**. The area of the Archaeological Park of Baia (400,000 m²); the Temple of Venus, the object of the study, is located in the southern area straddling Via Lucullo, which interrupted its continuity with the park.

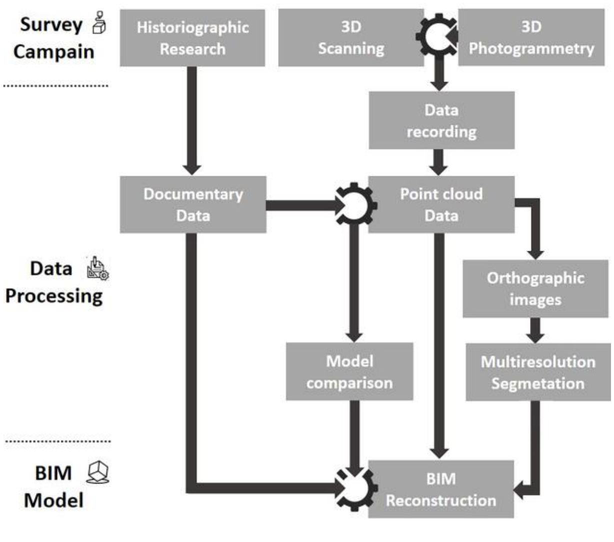


**Figure 2**. Methodological scheme of the process, between survey and parametric-informative modelling, for the digital documentation of the state of the temple of Venus at Baia.

Since 2016, when the Italian legislation, transposing the European directives of two years earlier, defined the progressive compulsory nature of IT tools to be used initially only in the case of construction and infrastructure, then extending, in fact, to every architectural work, with a broader and more generic reference to "digital information management for buildings" (Codice dei contratti Pubblici, 2016; 2023).

A regulation that will be imposed in prescriptive form starting from 2025 for projects over 1 million euros on a tender basis: if we take into account that in Italy, for new projects, spread throughout the national territory, including many of monumental and archaeological artifacts, the investment envisaged in the previous three-year Strategic Plan "Major Cultural Heritage Projects" of the Ministry of Culture, based on European structural funds, amounts to approximately 57.4 million euros, it is easy to understand how the defined time horizon will also require the use of specific digital infrastructures for similar works. The same regulatory reference, however, excludes cases in which the use of BIM-oriented technologies, i.e. those of defined ordinary and extraordinary maintenance works, unless "they do not concern works previously performed with the use of methods and tools of digital information management" (Spanò, 2022) Precisely these last regulatory cues suggest that, when approaching the restoration project, this will have to be declined through the definition of models that are fully configured as digital twins of real cases. Not only that, but also for it, therefore, it will be necessary to provide adequate information management, which passes, as known, through the structuring of digital sharing infrastructures, the so-called Common Data Environments (CDE).

If these infrastructures must be able, in addition to guaranteeing the principles of security and transparency, to provide, as is evident, robustness, to make information travel in interoperable forms both in the geometric component and in the more purely informational one.

A still significant problem precisely when one deviates from the essence of BIM as a tool naturally oriented towards new design, even in cases, such as the one under discussion, in which, on the one hand, in fact, the strength of BIM parametric modeling, through the rigorous and rigid object-oriented system does not adapt well to the definition of the variable geometries of the historical building. In this case, it is generally considered more convenient to invest in LOI (Level of Information) type information rather than LOG (Level of Information) type geometric characterization of Geometry) in accordance, moreover, with the vision defined by ISO 19650 and with the articulation of the LOINs (Level of Infomation Need) defined therein (Karlapudi et al., 2020). Secondly, then, the very need for data management in the BIM process, increasingly indispensable and specific in the recovery/restoration of existing buildings (Spanò, 2022), leads to deepening how to coherently integrate information often defined through diversified digital representations and for which the problems of so-called horizontal interoperability remain unresolved. Among these, if we have reached a definitive understanding of how to use the data obtainable through digital survey procedures, both range-based and image-based, it is also true that the scenario to refer to regarding the methods of data enrichment remain an open field of inquiry (Antuono et al., 2021; D'Agostino et al., 2022; Quattrini et al., 2017). In fact, the design applications that define the parametric HBIM intervention in order to trace on a digital model require that all the information on the state of the property and the improvement interventions regarding degradation, deterioration and wear of each part are integrated and available to anyone who requests their use without any loss of information and, above all, the boundary of reliability within which the data can be considered usable for technical purposes is made explicit.

The development of this paper therefore intends to describe a possible approach which, moving within the strictness imposed by the apparatus of rules and regulations as briefly described above, can constitute a useful tool in a case study in the archaeological field, on which testing procedures that can be validated between consolidated practice – typical of the restoration approach as we know it today – and the future wise and critical use of digital tools. In this sense, the workflow outlined above is aimed at defining an overall picture, hopefully integrable, as well as with data obtainable from the formal reconstruction of the building, with further diagnostic activities in the field.

## 2. THE CASE STUDY

### 2.1 The temple of Venus in Baia between the past and enhancement interventions

With the establishment in 2016 of the Parco archeologico dei Campi Flegrei, the site of the Terme of Baia became part of an autonomous institution of the Ministry of Culture, which includes the main archaeological areas and monuments of the Phlegraean territory: as many as twenty-six sites located in a particular natural context with significant landscape values, rich in historical stratifications, characterized by intense volcanic activity (Veronese, L., 2018).

This area, including the present municipalities of Bacoli, Monte di Procida, and Pozzuoli, is the setting for some of the most important myths of classical antiquity, the Gigantomachia, the *Cumaean Sibyl*, and the gateway to the underworld in Avernus. The fear and dismay caused by volcanic phenomena-which evoke death and threaten with their power-are intertwined with a nature of unique and mysterious beauty. Here was founded the city of *Cumae*, the oldest Greek colony in the Western Mediterranean, and, in Roman times the most important commercial port of *Urbe*, *Puteoli*. Baia constituted as early as the Republican age, an offshoot of Rome in Campania. Fronting the Gulf of Pozzuoli, it has been known since antiquity for its hot hydrothermal springs, which, rich in healing properties, gained increasing notoriety during the Republican age (Plinio il Vecchio N. H. 11,7; Orazio, Epistulae I, 1, 83). Between the 2nd and 1st centuries B.C. with the diffusion of Hellenistic culture in Rome and the great economic and social changes that consequently took place, *Aquae Cumanae* (this was the ancient name of Baia) was transformed from a place of healing into a place of *otium*. Here, away from the capital, the Roman aristocracy was free to follow less austere and rigorous lifestyle patterns. Important Roman political and military figures such as, Marius, Pompey, Caesar, Varro, and Cicero moved there and built luxurious residences. Meanwhile, scholars, scientists and philosophers of the time began to wonder about the therapeutic properties and origin of the thermal waters that rose from underground (Celso, De medicina II 17, 1-2). The thermal complex of Baia became the most important and renowned in the empire (Fronton, ad M. Caesarem I,3,5), the city of Baia an imperial residence. (Sirpettino, 1995).

Unlike *Pompeii and Herculaneum*, which were covered up by the eruption of Vesuvius in 79 A.D. and rediscovered only in the second half of the 18th century, the monumental remains of the *Phlegraean* area have for centuries characterized the landscape of the *'Terre ardenti*,' shaping the verses of the poets and geographers of antiquity. Beginning in the 15th century, architects, painters, and scholars represented and described what of the great complexes of antiquity had survived, contributing to enriching the millennial history of an area in which nature, artifice and myth have intertwined over the centuries (Di Liello, 2005).

In the early twentieth century, Phlegraean archaeological sites were in most cases, abandoned, hidden by vegetation.

The rediscovery of all archaeological site of the ancient Baiae started in the first decades of the 20th century after some relevant excavation works (Levi, 1921; 1922) for the realization of the Cumana railway to connect Campi Flegrei to the center of Naples (Fig. 3 e 4).

Starting from the ‘30s of the 20th century (Sgobbo, 1934), out-and-out archaeological research works were carried out, which were continued in the ‘50s through the excavations carried out by Amedeo Maiuri (Maiuri, 1931; 1951; 1958).

The archaeological complex of Terme di Baia has been conventionally subdivided by archaeologists into four main sectors: Mercurio, Ambulatio, Sosandra, and Venere (Venus) (Amalfitano et al., 1990). The Southern part of the Venus sector hosts the Hadrianic thermal complex (De Angelis d’Ossat, 1942; Rakob, 1961; Gullini, 1968), dating back to the 2nd century AD. It is constituted by a nymphaeum, ideally connected to the so-called Temple of Venus (the denomination of “temple” is improper and derives from the local antiquaries’ imagination that the structure was dedicated to the most important goddess of the area). The building is completely below ground level, due to bradyseismic phenomena that have characterized the whole area of Baiae. Despite the absence of archaeological excavations and studies related to the floor, it is deemed that the whole area was characterized by the presence of thermal baths (a *Calidarium*, presumably).

The building has a circular plan with a diameter of 26, 30 with four corner niches, inscribed in a square. On the side pointing toward the sea and on the opposite side there are two openings-crossed by the main axis of the building directed from east to west-, while additional secondary entrances were located at the apsidal parts that defined the main entrance, located toward the sea, and the adjacent exterior niches. The structure in elevation is octagonal in shape, with beveled corners, and reinforced by radial spurs; the surviving masonry, pierced by eight wide, low arched openings, constitutes a true windowed drum that supported the roof. Some scholars such as Kohte and Durm had envisioned a spherical type of roof (Koete, 1915, fig. 368; Durm, 1905, fig. 303).

As was noted by de Angelis D'ossat in 1942, however, the line of the dome's impost on the ambit wall is not horizontal-as it should geometrically be for a spherical vault-but appears to be interrupted by eight semicircles that raise the line of the impost at the windows. The vault, therefore, had, at the windows, as many rampant veloidic segments (spheroidal lunettes), which developed from the semicircular impost curves located above the large windows and was thus formed by 16 alternately spherical and veloidic 'spicchi'. This is an 'umbrella' or 'shell' type of covering vault, typologically similar to that covering the *Nymphaeum* of the *Horti Sallustiani* in Rome and the *Serapeum* of Villa Adriana in Tivoli. This also explains the presence of the corner pillars, which were made precisely at the spherical spindles of the vault, which were the most stressed demonstrating the 'skills' (of an intuitive kind, evidently) of the Roman builders of the Hadrianic period. The walls and vaults were made of cast masonry of local yellow tuff, with outer facing the brick bricks (bessali) divided as usual according to the diagonal, visible on the elevations with the long diagonal side of about 23 cm. and a thickness of 2.5 - 3.5 cm. yellow tuff masonry and pozzolanic mortar, with outer facing the brickwork (bessali) divided as usual according to the diagonal, visible on the elevations with the long diagonal side of about 23 cm. and a thickness of 2.5 to 3.5 cm. The arches are formed with bricks that have an average width of about 54 cm., which in some cases reaches up to 80 cm. On the outside of the wall structure, in addition to the described *opus latericium*, there are also parts of *opus reticulatum* formed of small 'tufelli' of 7.5 to 8 cm. sides, at the top of the building, interspersed with seven rows of bricks. Inside, most probably, all rooms were covered by marble

slabs, and the decoration of the dome consisted of a mosaic, of which very small traces have been preserved.
decades. They are clearly distinguishable because they were made of tuff masonry with regular ashlars, which did not, however, solve the building's critical conservative and structural. The particular environmental conditions and lack of maintenance have favoured the aggravation of certain forms of degradation, such as the presence of infested vegetation and surface erosion of the ashlars, resulting in the detachment of material. This triggers small limited collapses that, in addition to the inevitable loss of ancient material, may - in the medium term - undermine the overall stability of the building. It is, therefore, necessary to prepare an articulated plan of actions aimed at the implementation of a restoration project for the building.


**Figure 3**. From top to bottom: The Temple of Venus at Baia, J. P. Hackert, 1799; view of Baia with the Aragonese castle and the Temple of Venus, C. Bonavia, 1751-1758; Temple of Venus at Baia, postcard from the first half of the 20th century.

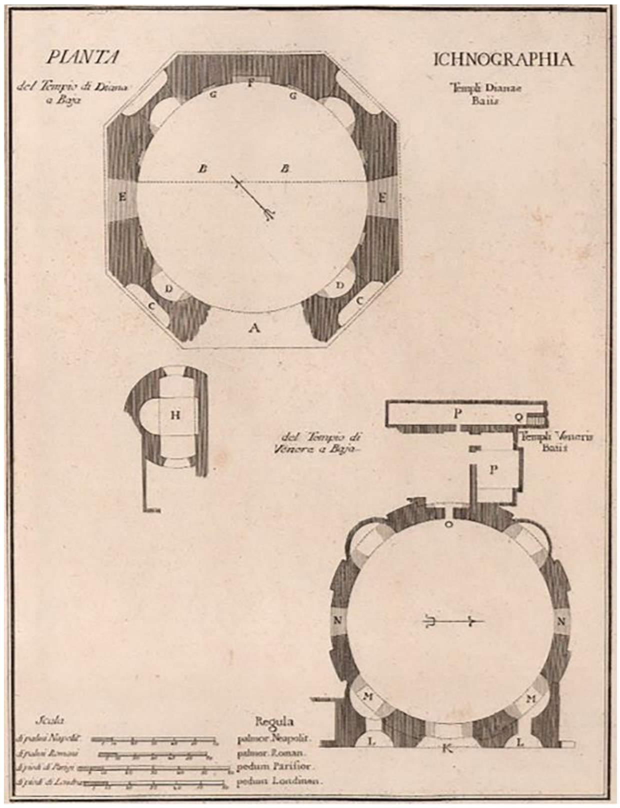


**Figure 4**. Plan of the Temple of Diana in Baja (above) and floor plan of the temple of Diana in the baths of Baiae (bottom), T. Rajola, 1768, (Paoli Paolo Antonius, 1768)

Localized consolidation works have been carried out in the past
The use of digital methodologies for data acquisition, in the integration of range and image-based survey techniques, and their semantic de-discretization has allowed systematizing the developed knowledge into models that can be easily queried and implemented over time, where both the geometric and the information component are indispensable for orienting and elaborating a conscious and articulate restoration project, as required by this building.

## 3. RESULTS OF THE EXPERIMENTATION

### 3.1 Data survey and segmentation

In order to describe the actual state of conversation of the site and update the documentation on the state of the site, as well as to verify and deepen the previous studies, an integrated digital survey campaign was carried out, using the most advanced technologies of data acquisition, data processing, and data restitution, to support a better knowledge of the artefact for a responsible and conscientious conservation project. In particular, to obtain a high level of metric-colorimetric accuracy of each architectural element (Bevilacqua et al., 2018), a range-based acquisition methodology (Terrestrial Laser Scanning - TLS) was integrated with an image-based data acquisition (terrestrial and aerial photogrammetry from SAPRs) (Hassan et al., 2020) (Fig. 5). Considering the relationship of the artefact with the surrounding space and the urban context, the TLS survey with BlK360 produced a close loop of 30 scans. The shooting points were chosen to achieve greater visibility between the shooting stations while assessing the variations in the density of points acquired from each position. This


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facilitated the merging of point clouds in the post-processing phase, which was carried out in Cyclone 360, to produce an overall point cloud that provided the metric reference with which to associate the radiometric accuracy of the photogrammetric survey. The digital photogrammetric survey was organized according to a preliminary subdivision of the artefact by area - interior and exterior - and by the continuous surface of the wall faces (e.g., following the octagonal composition for the exterior surfaces).

Images were acquired in both terrestrial and aerial modes, setting a Ground Sampling Distance (GSD) at 5 mm, with a maximum shooting distance of 19.50 m. The terrestrial photogrammetric acquisitions were acquired with a Nikon D7000 Reflex camera (with a 16-85mm f/3.5-5 lens) and processed in Metashape; the aerial shots were instead extracted from videos produced with a Dji Spark Drone (which has a 35mm, f/2.6 lens camera) and processed in Zephyr Aerial. In both cases, the exposure modes were precisely calibrated to the environmental conditions to maximize the uniformity between illuminated and shaded areas.

However, extensive post-processing of the images, in Adobe Lightroom, allowed the filtration of the necessary tonal parameters to recover information from areas that would otherwise have appeared underexposed or overexposed. As a consequence of the elaboration of the discrete models of the individual surveyed portions, the data were scaled and georeferenced from Ground-Control-Points (GCP), which were surveyed as a first approximation on the structured TLS data. The integration of the photogrammetric data with the laser scanner one produced a point cloud model from which the first drawings were obtained (plans, elevations, sections), useful for an accurate description of the actual state of the architectural work (Fig. 5); a documentary *corpus* that included both the photo-plans of the external walls, by an unwrapping operation of the external prismatic volume to an octagonal plan, as well as those describing the development of the internal cylindrical surface (Fig. 6).

The resulting drawings formed an essential basis for the thematic mapping of the informative characteristics of the architectural elements of the building (derived from historiographical research and field investigations), regarding the material characterization of the architectural elements, their state of preservation, surface deterioration or the description of restoration work carried out over time, as well as any other semantically aware source of information. Typically, such assessments are done qualitatively, with manual tracking, which is laborious and time-consuming.

However, in line with recent advances in image classification, the study tested a multi-resolution (MRS) approach to identify and quantify the contours of regions with specific characteristics from digital survey data. These characteristics include homogeneous material composition or recurring degradation types.

Referring to a prototypical surface portion of the outer octagonal volume, the process was tested in e-Cognition by exploiting the region growing MRS algorithm. This algorithm subdivides the image domain into similar segments (by consecutively grouping pixels with common characteristics) (Baatz and Schäpe, 2000) in the variation of scaling parameters, which affects the number of identified segments with homogeneous features - shape -, which changes the relationship between shape criteria and chromatic consistency, for segment optimization (Im et al., 2008) (Fig. 7). For the values of VAR_Shape (0.8), VAR_Compactness (0.6) and VAR_Scale (160), the approach has identified the empty regions from the solid ones, identifying the openings on the ground floor and the holes on the upper floors. The parameters of rectangularity and length/width ratio were used to identify the class of stone elements, although a greater fragmentation of segments has been achieved. This allowed the 20th century restoration to be distinguished from the openings and the second floor of the building. In addition, the regions associated with the densely vegetated areas were described by color channels, thus obtaining a classification that tends to minimize the heterogeneity of each polygon/seed generated.

The results obtained revealed some shortcomings and open challenges worth mentioning. Firstly, the framework produced mostly discontinuous segmentation results from which the class corresponding to the volcanic roof elements had to be deduced. The complexity and variability of the shapes and geometries of the dataset, the poor repeatability of the elements, which are often unique even within the same typological class, make it difficult to define unambiguous protocols aimed at optimizing the segmentation and classification procedures.

In fact, certain parts of the wall face, related to disintegration or surface erosion, lead to a morphological alteration of the stone elements, making the automatic recognition of the relative class rather convoluted. This led to an excessive processing of the groupable segments by visual recognition.

Moreover, in this case, the resolution of the aerial photogrammetric survey and the sharpness of the raster data set become fundamental, so that the greater accuracy of the segmentation procedures is directly proportional to the number of pixels to be analyzed per unit length.

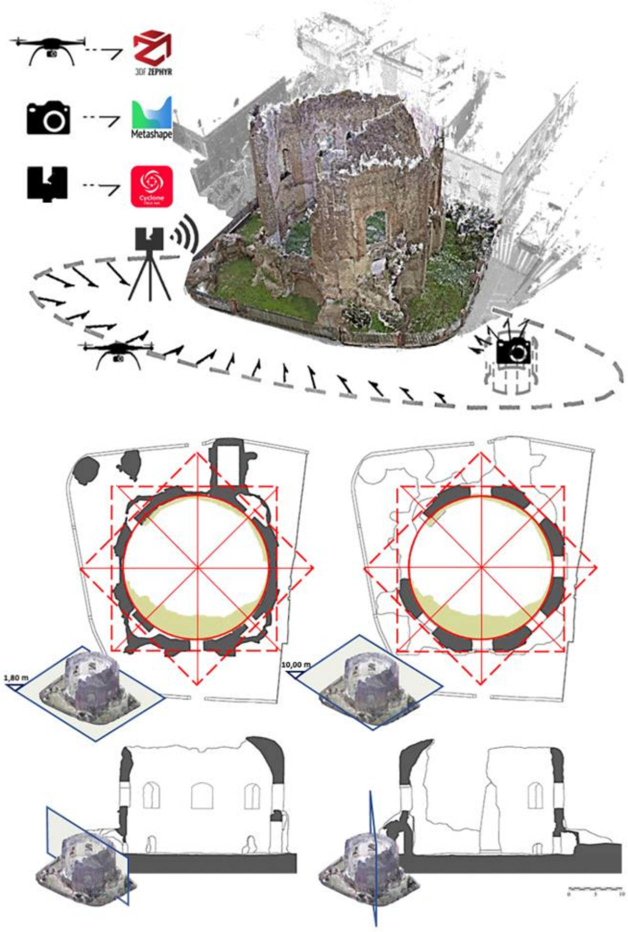


**Figure 5**. Data acquisition and integration of digital range and image-based survey, with the restitution of the plans and sections for the geometric-compositional analysis of the remains.

Nevertheless, the encouraging results favored the informative discretization of the wall surfaces in a semi-automatic approach that favored the parametric-informative documentation of a model in HBIM (Pocobelli et al., 2018). Indeed, the subsequent modelling phase was developed between different levels of abstraction and information enrichment of each element, depending on the dimensional sensitivity required for its assessment. This paves the way for the management and monitoring of the existing, as well as for the understanding of the existing relationships between different building elements (Bianchini, 2014).

From this point of view, the opportunities offered by the digital transition open up interesting perspectives for the innovation of processes for the digital management of information collected on existing cultural heritage. This leads to the optimization of workflows useful for the codification, archiving, and management of multidisciplinary data (Dell'Amico, 2020); to limit the ambiguity of workflows, the exchange of information, and the fragmentary nature of previous documentation. The latter can lead to errors, firstly in the assessment of the state of conservation and subsequently in the decision on intervention strategies.


**Figure 6**. Result of the semi-automatic thematization of the material characterization and degradation conditions of the artefact.

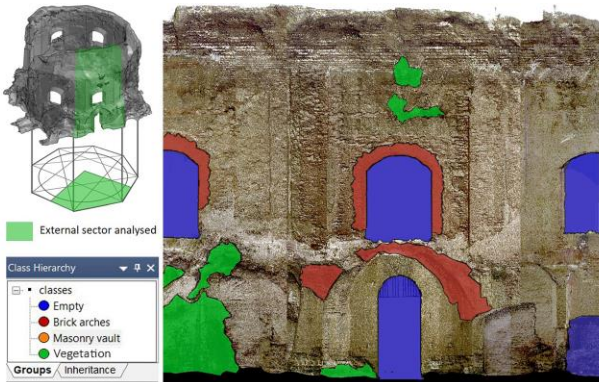


**Figure 7**. Outcome of multi-resolution segmentation and classification in e-Cognition of a prototypical surface portion of the outer octagonal volume.

### 3.2 The H-BIM model to inform the restoration project

The digitalization of archaeological heritage presents considerable obstacles due to the imperfection of forms corroded by time and the interpretation of surveys, which are not always unambiguous (Al-Sakkaf and Ahmed, 2019). The main objective of the study is to provide an information database linked to a multiscalar model, capable of collecting data and communicating it to workers promptly. The usefulness of a cloud-based system lies in the possibility of enabling and automating the continuous updating of the entire mass of information, making it available on a single platform, and knowing the exact positioning of each element in context.

The experiment defined a methodology for the EBIM digitalization of the actual state of the construction, describing the geometrically informative conformation, including the material and degradation components, shown here as an example for a section obtained from the base octagon (Fig. 8). Starting from the integrated data of the digital survey and the results of the documentary and thematic restitution, the modelling of the state of affairs was developed through a manual Cloud to BIM approach to interpret the geometric information and translate the elementary architectural units into their virtualizations.

For this purpose, the Autodesk Revit platform serves as an environment for the collection and coordination of information through a modelling by parametric elements, selected within families of objects, framed in a set of categorised semantic entities (Di Luggo and Scandurra, 2016). However, the heterogeneity and specificity of the constituent elements of the construction defines a geometric modelling process that maintains a high degree of complexity due to the high degree of typification of the elements, characterized by rules and parameters that are extremely linked to the specificity of the heritage (Campi and Cera, 2019). At the same time, the potential offered by interfacing with cultural heritage information, in accessible sharing environments, requires the verification of the effectiveness not only of the tools and methods related to the construction of digital twins of manufactured objects, but also of the ways to maximise and optimise the data enrichment of parametric instances (Antuono et al., 2021). This is the basis of object-oriented modelling, according to an interdisciplinary, coherent and interoperable data structure, which does not exclude the modelling of customised elements, but opens up the implementation of parameters for information management (Noronha Pinto de Oliveira and Sousa and Correa, 2023).

In fact, the geometric modelling process prepared for the Temple of Venus required a series of geometric approximations that significantly reduced the burden of punctual volumetric modelling, focusing mainly on the information aspect. This choice is in line with the recent overcoming of the LOD (Level of Development) concept in favor of the LOIN (Level of Information Need - UNI EN ISO 19650). While the first one classifies elements by implementing all their information aspects in parallel, the second one - the LOIN - allows objects to be encoded independently concerning the level of geometric detail and the level of information documentation, depending on the purpose of modelling (Abualdenien and Borrmann, 2022).

The recognition of the various parts to be modelled was the result of the previous semi-automatic surface segmentation process, which made it easy to reproduce the affected parts, integrating the information with that derived from the field surveys. The degradation map obtained in this way was reproduced from different modelling solutions in order to digitise the affected parts with a specific approach according to the required computational result and the relative parametric representation, in accordance with UNI 11182.

In particular, the gap identified as the absence of material has been filled thanks to the use of subtraction solids: the shapes have been properly simplified, but the operation guarantees both a graphical output in all views and an effective variation of the volume of the element concerned. In the case of vegetation, since it is an additional material to the basic elements, simplified geometries have been constructed according to two types of extrusions: a static one using the Local Model, and a dynamic one using the functionalities of the Adaptive Generic Metric Model. In both cases, it is possible to assign a thickness to the geometry in order to obtain a generated solid volume and to associate a material specifically created to describe the type of degradation referred to. The limitation of this method is that it can only be used on flat surfaces, requiring a reference plane for drawing the profile to be extruded orthogonally. Depending on the basic geometry, this problem can be overcome by using auxiliary reference planes that are as tangential as possible to the degraded surface, taking into account the possible volume compenetration. In this case, too, the procedure provides the desired result, as the volumetric dimensions of the individual degradations are parameterised in order to assess their impact and possible removal.

Surface degradation was then managed from within the elements themselves by modifying their outer layers using the Split Surface and Paint Surface tools. In this way, it is possible to distinguish the areas affected by the phenomena studied by determining their contours and then applying a material that does not affect the structure of the element. In this way, the information derived is reduced to the surface area, which is sufficient to identify and quantify these types of degradation. The choice of several methods for modelling degradation stems from the need to obtain different information depending on the classification, since each method reflects the effect of the attack on the element: manifested as an additional layer, as a subtraction of material or as a modification of the element itself.


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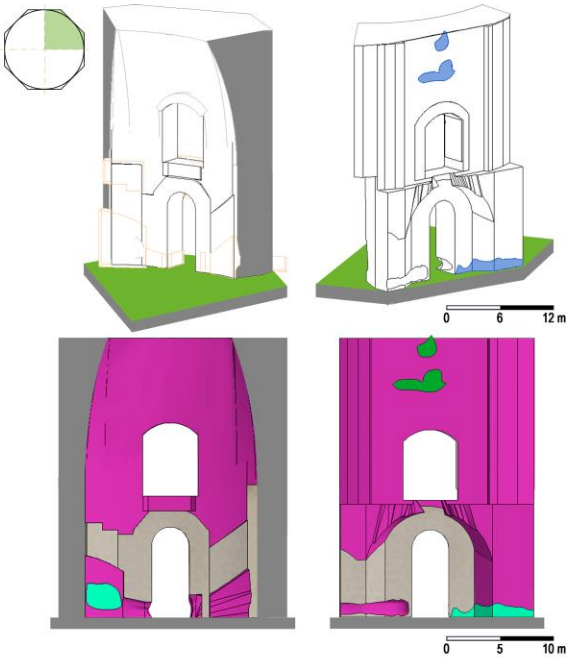


| Computo dei materiali | | |
|---|---|---|
| **Nome** | **Descrizione** | **Volume** |
| Laterizio | Brick listels | 1.86 m³ |
| Laterizio | Brick listels | 0.11 m³ |
| Tufo | Tuff strips | 578.60 m³ |

| Computo dei degradi | | | | |
|---|---|---|---|---|
| **Famiglia** | **Descrizione** | **Volume** | **Area totale** | **Area superficiale** |
| Parete | Alveolization, erosion, detachment | 0.00 m³ | 369.36 m² | 0.00 m² |
| Cupola parametrica | Alveolization, erosion, detachment | 0.00 m³ | 500.32 m² | 0.00 m² |
| Degrado esterno | Biological bath | 0.04 m³ | 8.57 m² | 4.20 m² |
| Degrado esterno | Vegetation | 0.04 m³ | 9.13 m² | 4.50 m² |
| Degrado interno | Biological bath | 0.28 m³ | 8.14 m² | 3.77 m² |

| Dati | |
|---|---|
| Area | 0.005 m² |
| Profondità del danno | 0.0300 |
| Tipo di degrado | Degrado interno |
| Intervento richiesto | Pulitura |
| Prova fotografica | IMG_20220720_100559.jpg |
| Rischio crollo | ☑ |
| Ultimo intervento | 1945 |
| Prossimo intervento | 27/06/2023 |

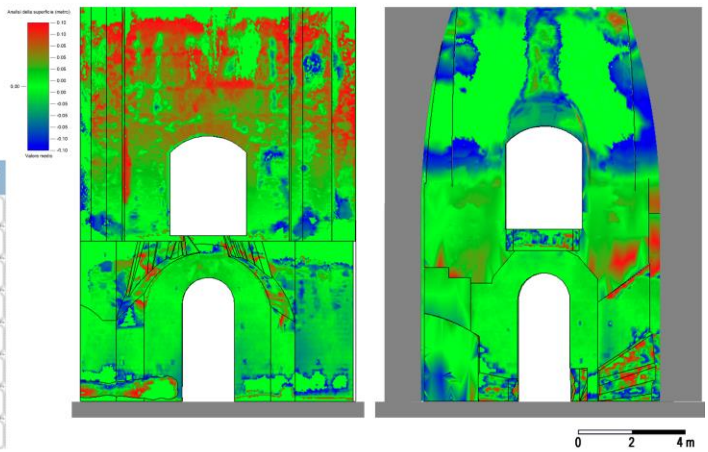


**Figure 8**. Outcome of the modelling of the decay elements of an exemplary portion of the artefact obtained by means of "Subtraction solid", "Local model", "Divide and paint surface" and relative parameters assigned in view of the maintenance phase.

A further check of the precision of the elements consisted in verifying the Level of Accuracy (LOA) in order to assess the model's deviations from the point cloud and possibly refine the modelling with a view to the artefact's information management. At the same time, this result was enriched with archival data organised in cloud-based systems in a multi-user logic, thus creating a multidisciplinary database useful for a description of the artefact for an extended knowledge that is both synchronous - more specifically designed for technical knowledge, to regulate and organise information for a desirable feasibility of design actions - and asynchronous - whose information base is purely aesthetic. This aspect is made explicit in the possibility of associating to each element a multiplicity of alphanumeric parameters that communicate different information necessary both for understanding the work in its various parts and for planning interventions. These parameters can then be catalogued in special tables, filtering the data according to the recipient of the processing (dos Santos et al., 2023).

Ultimately, an attempt was made to propose a hypothesis for the reconstruction of the roof, which had collapsed almost entirely. The volumes found, although incomplete in shape, suggest a segmented conformation, corroborating the thesis stated above.

The reconstructive proposal shown in Figure 9 offers an initial volumetric cue in the search for the lost conformation starting from the limited remaining portion of the ancient roof. The data obtained from the survey makes it possible to define the profiles along which the shapes develop, providing information regarding the height of the impost and the initial curvature. An attempt was made to offer a hypothesis that responded to the formal verifications in section and plan with respect to the point cloud, but that was also consistent with the visual perception found on site.

In particular, it was clear from an initial perceptual analysis that the shutter was not horizontal, but in the solid parts was arched, giving rise to the velodic lunettes alternating with the spherical ones in correspondence with the openings, which were reduced with respect to the former.

Verification of the Level of Accuracy revealed a series of deviations that were not surprising, as this is an ancient artefact with very irregular remains, but the results can be considered satisfactory with respect to this interpretation.

However, the study lends itself to further investigation, aiming to further refine the shapes in order to make them consistent with the shapes detected and the construction techniques of the time.

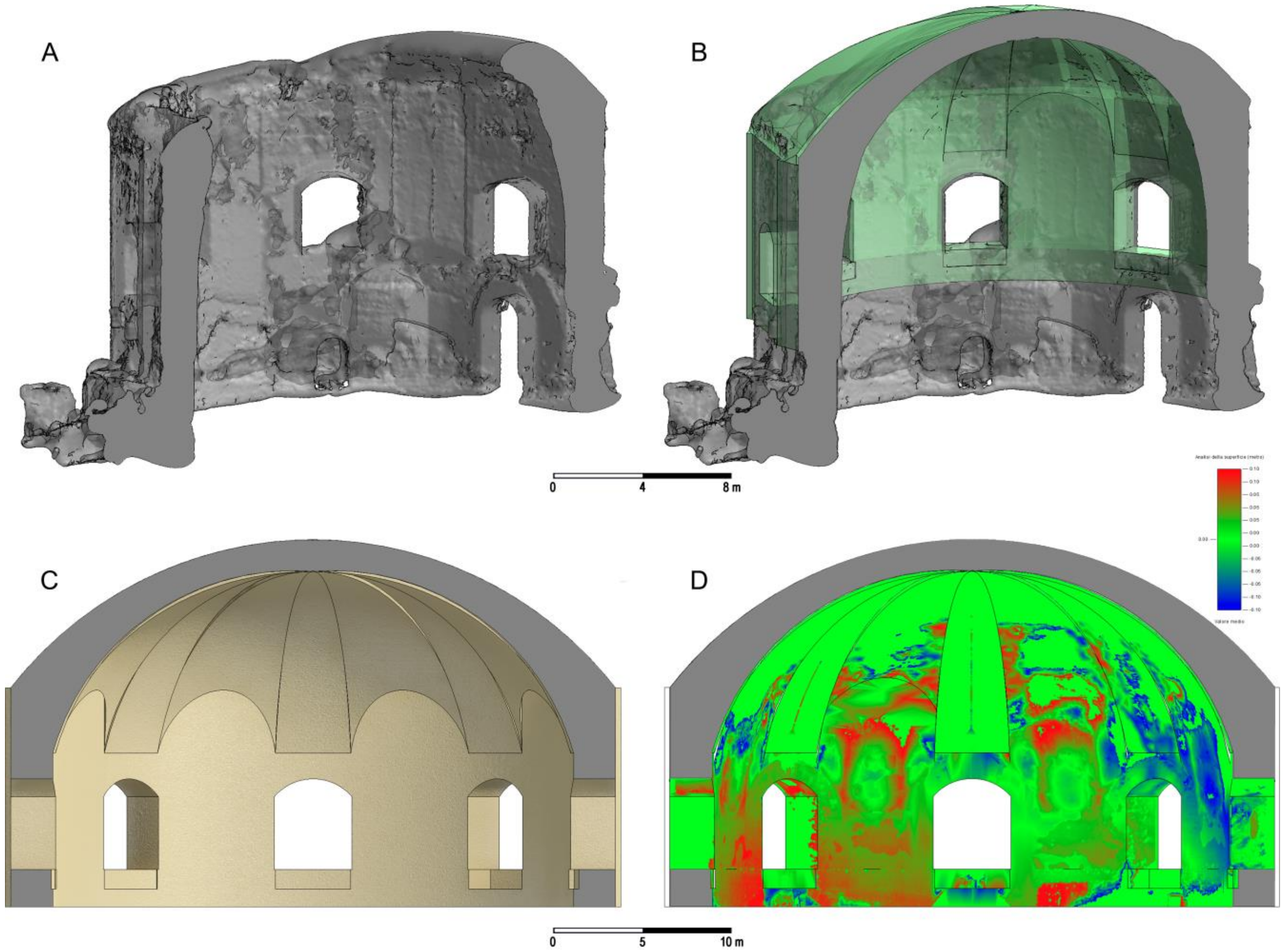


**Figure 9**. Hypothesis of the reconstruction of the vault from survey data. A: mesh of the state of the art; B: overlay of the reconstruction with the mesh; C: parametric hypothesis of reconstruction; D: outcome of LOA verification.

## 4. CONCLUSIONS

The digital-parametric approach to elements of an archaeological nature, while presenting a number of limitations, offers insights into the use of such means for the knowledge and monitoring of ancient artefacts. Starting from the survey operations, the data obtained, being highly reliable, provide a considerable information base for subsequent operations, whether they involve interventions or further study phases. Among these, the segmentation on the tested portion was successful in that it allowed the thematic mapping of the surfaces semi-automatically, facilitating the digitisation process also in the subsequent transposition into a parametric model. The latter, although approximate in form, returns a continuously implementable cloud storage, with a view to asset management.
The results obtained in the experimentation carried out constitute the first encouraging outcomes of a methodology that can be replicated on various building systems as well as opening the way to further future developments that promise even more accurate processing. We are moving, in this sense, towards the implementation of the flow through algorithmic modelling, imagining an interaction with the point cloud that allows the semi-automatic generation of volumes by associating to them the information deduced from the segmentation of surfaces.
It is with the spirit of providing a possible answer to these questions that the interdisciplinary research group intended to approach a workflow that, in architectural and archaeological value, could become a paradigmatic case study of a workflow that has the advantage of being able to be verified and intersected with practice and, therefore, validated as much with regard to the effectiveness of semi-automatic investigation procedures as to the expendability of data enrichment towards a full management of the data in the archaeological field as well.

## ACKNOWLEDGEMENTS

The contribution is based on the joint research of the authors. In particular, P. D'Agostino is the author of the paragraph "Method notes: BIM and data enrichment for Cultural Heritage"; R. Amore is the author of the paragraph "The temple of Venus in Baia between the past and enhancement interventions" ; G. Antuono is the author of the paragraph "Data survey and segmentation"; E. Elefante is the author of the paragraph "The H-BIM model to inform the restoration project". The paragraphs "Introduction" and "Conclusions" are shared by the authors.

## REFERENCES

Abualdenien, J., Borrmann, A., 2022. Levels of detail, development, definition, and information need: a critical literature review. *Journal of Information Technology in Construction*, 27(Special issue The Eastman Symposium, 363-392.

Al-Sakkaf, A., Ahmed, R., 2019. Applicability of BIM in Heritage Buildings: A Critical Review. *International Journal of Digital Innovation in the Built Environment (IJDIBE)*, 8(2), 20-37.

Antuono, G., D'Agostino, P., Maglio, A., 2021. Enrichment and sharing for historical architectures. A multidisciplinary HBIM approach. *Eikonocity*, 6(2), 40-65.

Baatz, M., Schäpe, A., 2000. Multiresolution segmentation: An optimization approach for high quality multi-scale image segmentation. *Angewandte geographische informations verarbeitung*, XII(58), 12–23.

Barba, S., Parrinello, S., Limongiello, M., Dell'Amico, A., 2020: *D-SITE, Drones - Systems of Information on cultural heritage. For a spatial and social investigation*. University Press, Pavia.

Bevilacqua, M. G., Caroti, G., Piemonte, A., Terranova, A. A., 2018. Digital technology and mecha- tronic systems for the architectural 3D metric survey. *Mechatronics for cultural heritage and civil engineering*, 92, 161-180. doi.org/10.1007/978-3-319-68646-2_7.

Bianchini, C., 2014. Survey, modeling, interpretation as multidisciplinary components of a Knowledge System. *SCIRES-IT: SCIentific RESearch and Information Technology*, 4/1, 15-24. doi.org/10.2423/i22394303v4n1p15.

Campi, M., Cera, V., 2019. Approcci H-BIM e Semantica: riflessioni e stato dell'arte sulla classificazione delle informazioni. *BIM VIEWS Esperienze e Scenari*, 12, 165-174.

Castagnetti, C., Dubbini, M., Ricci, P. C., Rivola, R., Giannini, M., Capra, A., 2017. Critical issues and key points from the survey to the creation of the Historical Building Information Model: the case of Santo Stefano Basilica. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, LII-2/W5, 467-474.

Celso, De medicina II 17, 1-2.

D'Agostino, P., Antuono, G., Elefante, E., 2022. Management and Dissemination for Dismissed Religious Architecture. An Approach Fusing HBIM and Gamification. *EGA: Congreso Internacional de Expresión Gráfica Arquitectónica 2022, Architectural Graphics*, 2, 399-407.

D'Ancora, G., 1792: *Guida ragionata per le antichità e per le curiosità naturali di Pozzuoli e de luoghi circonvicini di Gaetano D'Ancora*. Onofrio Zambraia, Napoli.

De Angelis d'Ossat, G., 1942: *Il 'Tempio di Venere' a Baia, in Bollettino del Museo dell'Impero Romano*. Carlo Colombo, Roma.

Dell'Amico, A., 2020. H-BIM: flussi informativi e processi di digitalizzazione del dato. *Dienne - Building Information Modeling, Data & Semantics*, 7, 54-67.

Diara, F., Rinaudo, F., 2018. Open source HBIM for cultural heritage: a project proposal. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2, 303–309.

Di Liello, S., 2005: *Il paesaggio dei Campi Flegrei*. Electa Napoli, Napoli.

Di Luggo, A., Scandurra, S., 2016. The knowledge of the architectural heritage in HBIM systems from the discrete model to the parametric model. *DISEGNARE- CON*, 9(16), 11.1-11.8.

Ding, J., Liang, M., Chen, W., 2023. Integration of BIM and Chinese Architectural Heritage: A Bibliometric Analysis Research. *Buildings*, 13(3), 593.

dos Santos, J. C. J., Almeida Santos, J. M., Rocha de Almeida Santos, M., 2023 (Preprint). Parametric Modeling Using the Bim Methodology for the Process of Pathology Identification in Buildings, *Journal of Building Pathology and Rehabilitation*. doi.org/10.21203/rs.3.rs-2815190/v1

Durm, J., 1905: *Die Baukunst der Römer*. Kröner, Stoccarda.

Fronton, ad M. Caesarem I,3,5.

Gazzetta Ufficiale della Repubblica Italiana. Codice dei Contratti Pubblici, Decreto Legislativo 18 aprile 2016, n. 50. https://www.gazzettaufficiale.it/sommario/codici/contrattiPubblici

Gazzetta Ufficiale della Repubblica Italiana. Codice dei Contratti Pubblici, Decreto Legislativo 31 marzo 2023, n. 36. https://www.gazzettaufficiale.it/eli/id/2023/03/31/23G00044/sg

Gullini, G., 1968. Apollodoro e Adriano: Ellenismo e classicismo nell'architettura romana. *Bollettino d'Arte*, V(II-III), 63-79.

Hassan, A. T., Fritsch, D., 2019. Integration of Laser Scanning and Photogrammetry in 3D/4D Cultural Heritage Preservation - A Review. *International Journal of Applied Science and Technology*, 9(4), 76-91.

Im, J., Jensen, J. R., Tullis, J. A., 2008. Object-based change detection using correlation image analysis and image segmentation. *International Journal of Remote Sensing*, 29(2), 399-423.

Karlapudi, J., Menzel, K., Törmä, S., Hryshchenko, A., Valluru, P., 2020. Enhancement of BIM Data Representation in Product-Process Modelling for Building Renovation. *Product Lifecycle Management Enabling Smart X. PLM 2020. IFIP Advances in Information and Communication Technology*, 594, 738-752.

Kohte, J., 1915: *Die Baukunst des Klassischen Altertums und ihre Entwicklung in der mittleren und neueren Zeit. Konstruktions- und Formenlehre*. Friedr, Braunschweig.

Levi, A., 1921: Baia. Ruderi di terme romane. *Notizie degli Scavi d'Antichità*, 10-11-12, 412-414.

Levi, A., 1922: Ruderi di terme romane trovati a Baja. *Monumenti Antichi*, 28, 129-154.

Maiuri, A., 1930: Il restauro di una sala termale a Baia. *Bollettino d’Arte*, II(VI), 253-264.

Maiuri, A., 1951: Terme di Baia, scavi, restauri e lavori di sistemazione. *Bollettino d’Arte*, IV(IV), 359-364.

Maiuri, A., 1958. *I Campi Flegrei, dal sepolcro di Virgilio all’antro di Cuma, quarta edizione riveduta e aggiornata*. Istituto Poligrafico dello Stato, Roma.

Noronha Pinto de Oliveira e Sousa, M., Correa, F. R., 2023. Towards digital twins for heritage buildings: A workflow proposal. *International Journal of Architectural Computing*. doi.org/10.1177/14780771231168226

Paoli Paolo Antonius, 1768: *Avanzi delle antichita esistenti a Pozzuoli Cuma e Baja*. Napoli.

Plinio il Vecchio N. H. 11,7; Orazio, Epistulae I, 1, 83.

Pocobelli, D. P., Boehm, J., Bryan, P., Still, J., Grau-Bové, J., 2018. Building Information Models for monitoring and simulation data in heritage buildings. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2, 909–916.

Quattrini, R., Pierdicca, R., Morbidoni, C., 2017. Knowledge-based data enrichment for HBIM: Exploring high-quality models using the semantic-web. *Journal of Cultural Heritage*, 28, 129-139.

Rakob, F., 1961: Litus beatae Veneris aureum. Untersuchungen am ‘Venustemplel’ in Baiae. *Mitteilungen des Deutschen Archäologischen Instituts. Römische Abteilung*, 68, 114-149.

Sgobbo, I., 1934. I nuclei monumentali delle terme romane di Baia per la prima volta riconosciuti. *Atti del III Congresso Nazionale di Studi Romani*, 294-309.

Sirpettino, M., 1995: *Le seduzioni di Baia imperiale*. Edizioni Scientifiche italiane, Napoli.

Spanò, D., 2022. Workflow HBIM: dalla modellazione e gestione dei dati di restauro alla cantierizzazione dell’intervento. https://www.ingenio-web.it/articoli/workflow-hbim-dalla-modellazione-e-gestione-dei-dati-di-restauro-alla-cantierizzazione-dell-intervento/ (last accessed 29/04/2023).

Veronese, L., 2018: Alle origini di una difficile tutela: Amedeo Maiuri e i restauri al Parco archeologico delle Terme di Baia. *Restauro Archeologico*, 26, 20-43.