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A parametric model to manage archaeological data

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Abstract – **The paper focuses on the work carried out in the *insula* 4-6 of Paestum (Italy), in the framework of a collaboration between the Archaeological Park of Paestum and the University of Naples "L'Orientale"; the contribution shows the "drone to BIM" solution applied for the study of the *insula* and the related methodological approach. The combination of the digital survey with the parametric reconstruction of the structures, which characterizes the so-called ABIM (Archaeological Building Information Modelling), provides a complete information system useful for different purposes, from documentation to interpretation and management. To systematize the incomplete archive documentation of the *insula* and to integrate the dwg file supplied by the Park, an aerial digital survey has been carried out to provide a detailed map of all the structures still visible on the area. The three-dimensional information, derived from the UAV, constitutes the basis for the construction of the BIM model.**

I. INTRODUCTION

The increasingly use of 3D survey methods in archaeology, has modified the typical graphic documentation approach. Unfortunately, 3D information is often disconnected from the rest of the archaeological data (e.g. reports, images, drawings from previous excavation campaigns, old maps). The 3D dataset is generally used just to post-produce 2D vectorial information, to generate orthophotos or to extract measures.

Even if this workflow allows to obtain accurate and high-resolution replicas of whatever archaeological object, ranging from small finding to big monument, most of the 3D information is still underused: to manage a large dataset of heterogeneous data, coming from archaeological research, is a task still hard to be faced with a traditional approach. More broadly, researchers attempt to identify, at the beginning of their approach, the best solutions (hardware + software) for the most correct 3D data-acquisition and elaboration process; at the end they are obliged to optimize the dataset according to the used software and, mainly, according to their different needs, e.g. research, exploitation and conservation.

Even if GIS has made easier to perform complex spatial analyses, especially in the field of reconstruction of the ancient landscape, for the analysis of the composite archaeological architectures are necessary new tools and approaches fully 3D; probably for this target the best solution is the BIM [1][2].

II. BIM, HBIM, ABIM

Since the 1970s, BIM methodology has progressively expanded its field of application. BIM has been designed as integrate system for the planning and management of the modern civil infrastructures [3], but very soon it has become an innovative tool for the analysis of archaeological and architectural heritage. In particular, the HBIM (Historical BIM) offers advanced suggestions for the application of the BIM methodology to the processes of management, maintenance and enhancement of the cultural heritage [4].

As the BIM has been not designed for the archaeological research, one of the main challenges is how to adapt this approach to the needs of historical analysis and, first of all, how to optimize the 3D dataset in order to allow a fast and accurate 3D modelling process.

The ABIM is characterized by the combination of the digital survey with the parametric reconstruction of archaeological structures, with their peculiar and often unique elements; it represents a big opportunity to make available, in a virtual environment, all the data related to a single monument. The ABIM can contain not only spatial data, but also other detailed information (photos, drawings, descriptions, annotations) concerning the monument or single part of it [2][4][5]. For the archaeological research, the ABIM represents a big repository or an information system allows to link whatever type of data, particularly useful to manage complex architectures or buildings. It constitutes the base of a reasonable, transparent and verifiable reconstruction of whatever archaeological evidences.

The strength of a BIM approach lies in the ability to verify the accuracy of all recorded information and in the ability to manage the life cycle of the object. BIM supports a typically interdisciplinary approach by offering specialists updated, accessible and shared information; by making heterogeneous and multidisciplinary data available, the system facilitates collaboration. The BIM model, therefore, does not represent a method for managing and displaying three-dimensional data, but it is a searchable information system in which the quantity and quality of the information guarantees its reliability.

The idea of implementing a BIM system for an archaeological context, stems from the need to create a complete and accessible data container in which every single aspect of the asset can be immediately made available for different purposes, as safeguard, fruition, maintenance enhancement and protection activities, and for future investigations. The goal is to obtain a management system able to guide any restorations or valorization process.

As already mentioned, the BIM has been implemented in the context of the most recent engineering practice and only in the last decade it has been applied to historical buildings; this field of interest, so called HBIM, has concentrated any effort and scientific considerations on the issue's method, that is how to apply this approach to the architectural heritage.

Frequently the analysis of historical buildings, integrated with the study of ancient constructive techniques and the comparison of coeval edifices, provides information allowing to reconstruct, more or less precisely, the original project of the designer or of the architect. In the HBIM approach the 3D survey represents an objective starting point for any further interpretation of the monument.

In the archaeological field, often, the structures are stored only for few centimeters or at foundation level; therefore, the simulation or the virtual reconstruction are approaches used to hypothesize the shape, the sizes and the extension of the building. From this point of view ABIM is a container collecting all available data making more transparent any reconstructive hypothesis. To reach this result it is important to define correctly a methodological approach and a precise workflow, also according to the chosen software.

To classify the complexity of the archaeological evidence within a three-dimensional representation, it is necessary to identify every single element that composes it; this process allows to recognize the structure, the function and the level of detail to be achieved in the modeling parametric phase. The archaeological reality must be re-created in BIM, through the definition of the objects. Therefore, before starting the modelling, it must be established what is a BIM object, in what terms of modeling and information it can be obtained, and at what level of detail it must be codified. The context is thus divided into its constitutive elements, organized into categories and types and assigned to a chronological phase. At the end of the semantics phase the modeling step can be started.

III. THE CASE STUDY: THE *INSULA* 4-6 OF PAESTUM

Starting from these premises, in 2018 has begun a collaboration between the Archaeological Park of Paestum and the University of Naples "L'Orientale", to re-examine the *insula* 4-6 of Paestum. Unfortunately, this area has been excavated several times, but there was no documentation (photos, drawings, stratigraphic reports) available for these investigations. Furthermore, the majority of the walls are preserved for few centimetres and the sizes of the rooms are not always clear. Therefore, to better investigate the chronology, the extension and the organisation of the inner public and private buildings of the *insula*, a new approach, based on the ABIM, has been set up. The aim was to deepen the knowledge of the walls stratigraphy in order to elaborate reconstructive hypotheses and define chronological phases.

The *insula* 4-6 dates back to the late-republican period with several remakes at the end of republican age and the beginning of imperial age. The area has a North / South orientation and it is about 273m long and 35m width, i.e. 120 roman *actus*. The *insula* is marked to the North by the *decumanus* Bo and to the South by the Bo2 road axis. In the northern part there is a large *domus* with a double atrium and peristyle and, after a slight variation in altitude, there are the rooms of a *thermae* built on the edge of a large open space, identifiable as the *palestra*; toward South, there is another house, with the atrium and the peristyle clearly visible, while the limits of another possible *domus*, located in the southern strip of the block, appear less precise. This area has never been studied and published, except for minor restoration and maintenance operations [6].

As mentioned, the documentation of the excavations is mostly lost, and this makes it impossible to reconstruct the life of this part of the ancient city. In the absence of whatever stratigraphical data, which could provide useful information about the great transformations occurred in the area between the Roman and Late Ancient periods, an innovative method has been tested.

To combine all possible information coming from the *insula,* an ABIM application has been considered; the approach has been divided in different steps, first of all, a drone-survey for the acquisition and processing of geo-referred bi- and three-dimensional data, essential for the successive parametric modelling phase. Then, according to a traditional approach, all the different constructive techniques documented in the *insula* were identified thanks to the bibliography and to the comparison with the masonries existing in other part of the site.

IV. DATA ACQUISITION AND METHODOLOGICAL APPROACH

In the last decade archaeological research has begun to take advantage of new remote-sensing methodologies and tools as UAV (Unmanned Aerial Vehicles). In particular, the applications of aerial photogrammetry are evolving thanks to the quick development of UAV technology for documentation and site mapping [7] [8].

Since the Archaeological Park of Paestum had for the area only a digital map, revised and geo-referred in 2008, a drone-based photogrammetry survey of the *insula* was planned during the summer and the autumn of 2018; the survey had to allow the updating of the map of all the structures still visible in the area and to implement the ABIM application.
The *insula* 4-6 is approximately extended 12.000 sqm and it is located in an area of the park relatively marginal to the visit route and, for this reason, often completely covered by vegetation. By considering the management, the cure of the archaeological paths made by the Park and the variable flow of visitors, the survey phase was not continuous; for this reason, the flights were performed in different periods of the year.
From May to October 2018 several flights were carried out in order to test the best sensor, altitude and resolution. From the different dataset acquired with a DJI Phantom 4 two projects were chosen, aligned and overlapped with Pix4Dmapper.
To scale and roto-translate the projects several Ground Control Points, easily detectable in the aerial photos, were measured, with a Total Station. Among them there were two points with known coordinates from the GPS network supplied by the Park; by connecting our GCPs with the Park network, it was possible to geo-refer the aerial survey and check the accuracy of the measurements. At the end of the process, a coloured point cloud of 3.897.284 million points was generated._
From the final geo-referenced model, a high-resolution orthophoto has been extracted to draw the structures visible in the last survey, but not recorded in the map provided by the Park. The aerial survey was followed by a terrestrial photographic campaign, aimed at the cataloguing of the main buildings of the *insula*; the photographic acquisition has been functional to the annotation of some fundamental information such as composition, level of degradation and preservation of the walls.

V. THE ABIM IMPLEMENTATION

For the creation of the ABIM of the *insula* 4-6 of Paestum, it was chosen Autodesk Revit. The point cloud, generated by the UAV, was imported into the software to check the geometries in comparison with the DWG file provided by the Park. For the creation of the topographic surface, the cloud was simplified in Cloud Compare, saved in .txt format and, then, loaded into the project through the “Create Surface from Import” command. (fig. 1). The data provided by the topographic surface, together with the point cloud and the information acquired through archaeological research and analysis, allow the definition of “reference levels”. These levels are fundamental constraints within which the software works and through which it is able to project plan and section views.

As Autodesk Revit is a software based on libraries of contemporary construction objects, the use of the ABIM in the archaeological field requires, first of all, the creation of specific libraries of old architectural elements. This phase, traditionally called Scan to BIM, is not automated nor simple since it involves the definition of the semantics underlying the buildings and its constructive techniques [9].

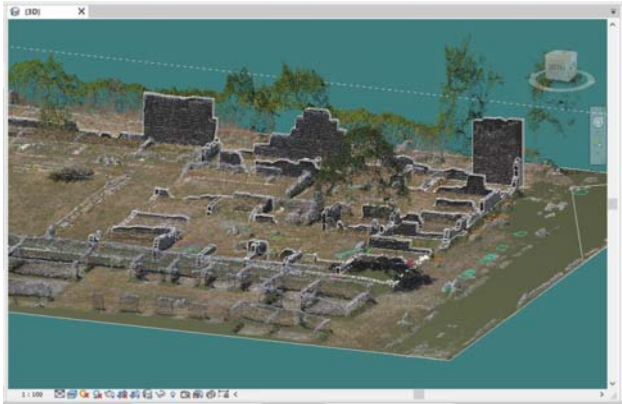

Fig 1 – Point cloud, terrain model and DWG graphic base of the insula in a 3D view of Revit.

One of the main challenges in the application of BIM to archaeological site is the identification of the objects to be parametrize, that is the single “brick” or base-unit on which to build the hierarchy of the different architectural elements. In this way it is possible to define the semantic of the built and, in the same time, the Level of Detail (LOD) of the archaeological analysis.
In the case-study, “wall” objects have been identified to represent, in parametric modeling, the entire wall of a room as it is in current state. The characteristics of the different interventions/phases of life of the object/wall are distinct thanks to the information structure. The chronology is annotated in a field dedicated to temporal references; this value can express the chronological period of the construction of the entity and its de-functionalization. The single stratigraphic units, the analysis of degradation or the reconstruction of decorative systems, just to give a few examples, are distinguished and annotated in special "views" linked to the specific object and, therefore, easily recalled for inspection and updating.
On the basis of the point cloud, single architectural elements (walls, doorsteps, pavements, columns, pipelines, etc.) were modelled and assigned to specific “families” according to the Revit categories; these objects were parameterized by defining their dimensions and their variation based on specified measurements obtained by the study of local techniques (fig. 2).

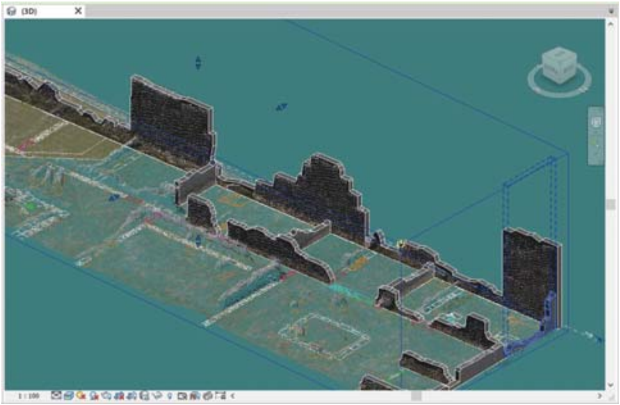

Fig 2 – Masonry in blocks built as a BIM object and textured

The software associates the modelling of parametric objects with the drafting of tables that explain the specific properties of the elements in the model; these tables can be modified by adding parameters and each parameter can be filtered. Moreover, the Properties tab of each model object can be enriched with information, through external links, e.g. photos about degradation analysis, archive material, texts, databases of different nature and even detailed 3D surveys (fig. 3, 4).

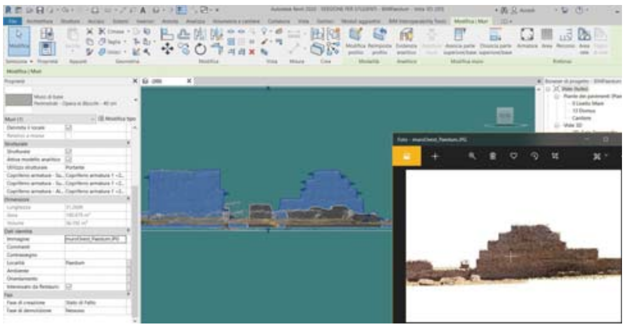

Fig 3 – Photogrammetric image linked to the BIM object

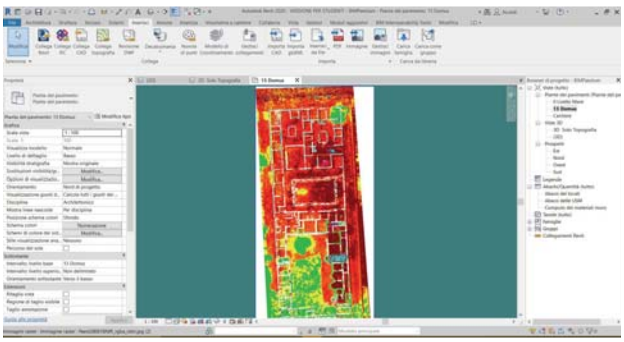

Fig 4 – Thermal photoplan of the insula inserted on the terrain model, below the point cloud and the graphic base in DWG, in a 3D view of Revit

VI. RESULTS

The archaeological context of the *insula* 4-6 of Paestum allowed to test a methodological workflow that start from a 3D data acquisition by drone and ended to the parametric modelling with the definition of an integrated database for information management.
The work pipeline can be divided into three main phases:
1 - pre-modelling phase, that involved the definition and cataloguing of archaeological objects, construction techniques and materials;
2 - the modelling phase, that concerned the creation, into Revit software, of archaeological parametric families, whose geometric accuracy was constantly checked through the point cloud provide by 3D surveys;
3 – the phase of the attachment of analyses information about the wall's composition, state of conservation and typology, generally providing from external reports (e.g. photogrammetry, masonry and degradation sheets).
The result is a queryable and flexible data container, that can be used by different users for the typical archaeological research or for the management and valorisation of the archaeological site.
During the elaboration phases, the issue of LODs, i.e. Development Levels or Levels of Detail, based on American or Italian legislation, has been addressed. LODs, which establish the degrees of accuracy in the virtual rendering of the object in BIM, must be redesigned for the archaeological context.
In the archaeological field, indeed, the level of detail of an ancient object is linked to its chronological phase and its state of conservation, which in virtual reproduction are often difficult to classify as real levels of detail for modeling. In our case we have chosen to enhance the information side of the BIM system and identify increasing degrees of detail in the rendering of BIM objects based on the information related to them (masonry stratigraphic units cards, analyzes carried out on the walls, archive documents, photographic survey, etc.).
In the "architecture" section of the software new "families" have been set, associated with existing wall types available in Revit's libraries. Then these families have been associated with their own specific characteristics; the construction materials were inserted in the Structure tab, as well as the internal composition of the wall was recreated (fig. 5). The modelling involved the constant support of the point cloud for the precise recreation of the profiles of the individual walls.

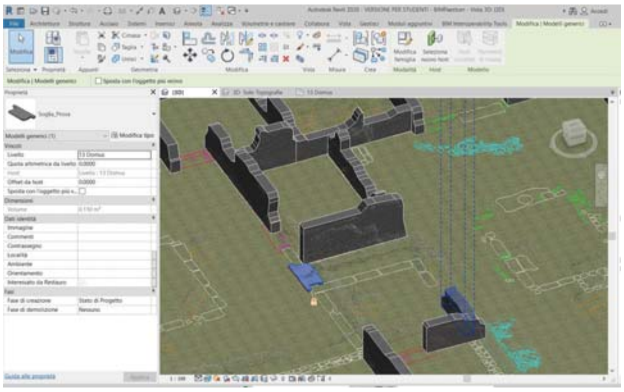

Fig 5 – Parametric modelling of decorative object: the creation of a marble threshold

VII. CONCLUSIONS

Archaeological excavations that took place in this area left scarce and inaccurate documentation. This caused the loss of the stratigraphic information as well as of the removed late-roman structures. This particular condition required a detailed analysis of the walls to identify the relationships among the buildings, useful to provide a reconstruction of the *insula* life and its changes over time.
Contrarily from the traditional HBIM case-studies in the archaeological contexts, like the *insula* 4-6 of Paestum, the creation of standard libraries has to be based on the existing architectural elements and masonries. This approach makes the modelling phases particularly complex since the geometrical features are linked to a verifiable and reliable measurements and parameters.
The paper, through the case study of Paestum, has highlighted how it is possible to apply a BIM approach to an archaeological context, by starting from the creation of archaeological families related to the well-known construction types of Roman and Late Ancient times. The great versatility of the database interfaces of the software allows to customize the cards by inserting, moreover, documentation standards of archaeological research. It optimizes the modelling of the structures to an intermediate LoD, leaving the most detailed documentation to the annotative functions of the single instance, allowing the connection of multiple data extensions. This parametric system becomes an interactive and interoperable container of archaeological, 3D geometric and environmental information, much more powerful of a 3D GIS application.
Testing the BIM system in an archaeological context moves the Building Information Modelling methodology beyond its design limits. The experimentation has as its aim the creation of guidelines for application in the archaeological field.
The setting up of families of archaeological objects allows the operator to deepen the knowledge of the single parts of the structure, to organize and plan the documentation to be produced and to attach it to the single element (instance); the whole model can be used by the different specialists working for the management and enhancement of the asset. BIM modelling allows the setting of reconstructive hypotheses on the real masonry, allowing the creation of real feasibility studies.
The rules and standards so far produced for the BIM and HBIM models do not take into account the complexity of the archaeological reality. The assessment of the Level of Reliability, which takes into account both the geometric conformity and the ontological accuracy of the model with reference to the reality that is being described, may be a solution [10]. It is necessary a system of evaluation of archaeological objects and models in BIM environment, LOD for archaeology, that takes into account the specificity of objects whose specific function is closely related to the chronological reference context.
The challenge for the future application of BIM to archaeological sites will be mainly based on the reuse of the semantics and the libraries.

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