

HBIM and Extended Matrix for the archaeological reconstruction of the excavated medieval contexts: the case of the castle of Monteforte Irpino (AV).

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Abstract – This paper aims to propose an Extended Matrix approach to the medieval castle of Monteforte Irpino (Avellino, Campania, Italy), for the reconstruction and understanding of archaeological contexts after excavation and documentation activities. Extended Matrix (EM) is a particular approach to HBIM (Heritage Building Information Model) mainly based on the reconstruction of archaeological context starting from several type of data, such as: archaeological data, survey data, stratigraphic evidences, bibliographic sources, comparison. Thanks to the use of three-dimensional photogrammetry from UAS and from the ground, and thanks to the use of an extended matrix tool completely open source, Archaeologists have been able to reconstruct the archaeological context of the site and propose considerations based on the three-dimensional data produced, which find reliable comparisons in other similar Italian contexts.

I. INTRODUCTION

The last two decades of the 20th century and the first years of the 21st century have been strongly characterised by the impact of technologies on human life and, in particular, by their unprecedented and widespread vertical and horizontal entry into collective everyday life. This impact has obviously occurred in all human activities and archaeology, as well as all practices related to it, has not been exempt. While archaeological excavation has been little influenced by technology, a massive technological revolution has taken place in the techniques related to documentation (i) before, (ii) during, and (iii) after excavation[1]. The development of new tools applied to

cultural heritage has had a significant impact on all phases of archaeological research activities, such as (i) documentation and (ii) virtual planning and reconstruction [2]–[5].

Great emphasis has been placed on HBIM (Heritage Building Information Model) in recent years. The methodology aims at recording and digitising the archaeological record (reality based) and formulating reconstructive hypotheses supported by different degrees of reliability depending on (i) input data, (ii) stratigraphic evidence, (iii) bibliographic sources, (iv) comparisons with other sites (source based) [6]–[8].

There are several successful experiences in the literature: (i) the reconstruction of the House of *Caecilius Lucundus* in Pompeii, in which a laser scanning acquisition of insula V of Regio I was used to reconstruct the rooms of the Domus together with a careful analysis of the rooms and its phases using the Extended Matrix method [9]; (ii) the reconstruction of a workshop in Montesa (Valencia), in which an excellent virtual reconstruction was accompanied by an excellent documentation during excavation. During the excavation of this modern-age brick kiln, in addition to the acquisition of the structures by combining laser scanning and photogrammetry, the stratigraphic units removed during the excavation phase were reconstructed directly during the excavation of the kiln [10].

Extended Matrix (EM) is a particular approach to HBIM, as explained by [7].

The main conceptual differences between the EM method and a traditional HBIM are that the latter is (i) predominantly used for the knowledge of a single architectural monument, (ii) is a tool primarily aimed at architects, and (iii) the object of interest is crystallised in a

single life phase that contains the information it seeks to convey [7].

This paper aims to propose an EM approach to the medieval castle of Monteforte Irpino (Avellino, Campania, Italy), for the reconstruction and understanding of archaeological contexts after excavation and documentation activities.

II. MATERIALS AND METHODS

A. Case Study

The archaeological site is located in southern Italy, in the municipality of Monteforte Irpino (lat. 40.896311°, long. 14.706968°), 630 m above sea level approx. (Fig. 1).

The first records of the settlement date back to the beginning of the 12th century and testify to the castle's link with the Benedictine abbey of Montevergine. The site has a pseudo-elliptical plan, with a NW-SE orientation. The escarpment wall preserves the Angevin donjon at the N-W end and the palatium to the S-E with a large room with niches and is interrupted by three towers on the eastern front. South of the donjon, several rooms can be distinguished that were subject to archaeological excavations in the 1980s. Research activities, which began in 2019 and intensified in 2021 as part of a restoration project, have made it possible to highlight at least three building phases from the 12th to the 14th century, in addition to the later phases of occupation of the service rooms on the west front. These, originally intercommunicating, are organised on two levels (given the presence of a stairwell and conspicuous collapses), are equipped with residential comforts (ovens, fireplaces, storage niches) and, as attested by the ceramic material, were probably used as a dump between the 15th and mid-18th-19th centuries, i.e. well after 1531, the date reported in a Spanish document, which describes the castle as ruined and abandoned [11].

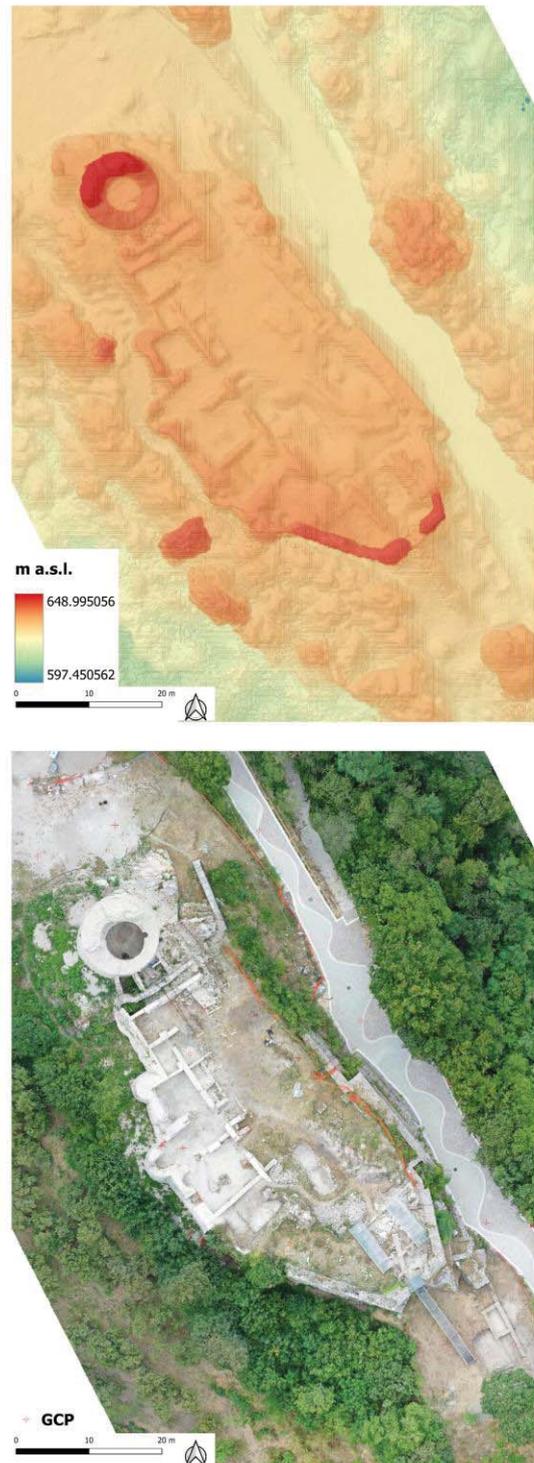


Fig. 1. Study area.

B. Data and EM method

Excavation campaigns carried out by LATEM (Suor Orsola Benincasa University) in 2019 and 2021 allowed

archaeologists to divide the chronology of the site into at least three phases.

The reconstructive process focused on the third phase.

The work was divided into two phases: (i) acquisition of the data for the creation of the three-dimensional model at the end of the 2019-2021 excavation campaign, and (ii) then the Harris matrix relating to the stratigraphic units (SU) and masonry stratigraphic units (MSU) was created and reported in yEd graph. At the same time the virtual stratigraphic units (VSU) useful for the validation of the reconstructive hypotheses were inserted in the tool, according to their level of reliability, indicated by RGB colour code.

The three-dimensional data used as the basis for the EM tool were acquired through photogrammetric processing. The acquisition involved the use of (i) a UAS (DJI Mavic2Pro), equipped with a 20MP RGB camera, for the aerial photos, and (ii) an SLR camera (CanonEOS1000D), for the integration of the ground photos.

Acquisition was done using Pix4D Capture autonomous flight software in (i) dual grid mode and (ii) orbit mode. Photogrammetric acquisition involved an 80% lateral and frontal overlap of the photographs, with the camera tilted at 75 degrees, and covered an area larger than that occupied by the castle, so as to obtain photographic coverage of the preserved masonry. In addition, to improve the rendering of the wall surfaces, photographs were acquired in circular orbit mode, rotating around the castle and using the center of the parade ground as the focal point.

The acquired photographs were processed within photogrammetry software to create a three-dimensional model of the entire fortified site, georeferenced to ground-acquired GNSS points, to be used as the basis for EM [5], [12]–[15].

Photogrammetric acquisition produced (i) a high-density point cloud, filtered for confidence to remove noisy points; (ii) a high-resolution three-dimensional model; and (iii) a textured three-dimensional model.

The tools used for EM were (i) Blender (3D modelling software) for the reconstructive and three-dimensional modelling aspect, and (ii) YeD graph for the EM representation, to which the data were linked. The programmes communicate and interface with each other any changes in YeD also occur in Blender.

The validation of reconstructive hypotheses takes place entirely in YeD graph. A formal language is used to divide the matrix into (i) source based and (ii) reality based. Other nodes indicate the information that can be extracted from the document, which can be 'extractor' and 'combiner' nodes. Extractor is used to report which information has been used (e.g. height, material, shape, colour). This information is then reported in the property node. The combine node, on the other hand, is used where several Documents cross each other to reconstruct the same property. Then an Excel catalog has been created

containing all the Documents and make them easily accessible [7].

The native functions of Blender allowed (i) to import the three-dimensional photogrammetric model, (ii) to process a three-dimensional reconstruction, and (iii) to process the textures, while the development of the EM tool was obtained by adding additional modules to the Blender software.

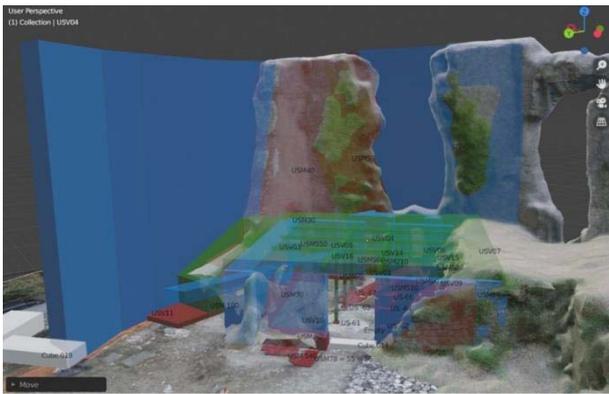
In addition, the use of this system made it possible to use a scientific reconstructive approach based on the evidence identified during archaeological study and excavation. The reconstruction is done on an analytical basis since each data is reported within the system, on Blender. Finally, the reconstructed model is then textured using textures produced from photographs or material catalogues (e.g., Substance Materials, Blender Material add-on library).

III. RESULTS AND CONCLUSIONS

The result of the EM method applied to the archaeological heritage and in particular to the reconstruction of the archaeological excavation contexts stratigraphically investigated has allowed to have a greater understanding of the reconstructed area. In particular, an important result was achieved in the first room overlooking the entrance of the site which, due to the poor conservation of the structures, was difficult to understand.

It is a rectangular space made by carving where possible the rocky bench, characterized by the presence of a series of niches along the sides. The room was probably built on at least two levels. The first one, of which traces have remained, probably carried out the function of basement warehouse, an hypothesis corroborated by the presence of the niches and the absence of lights inside the environment. The second level of the structure was accessed through the masonry staircase partially found during the excavation campaigns, leaning against the perimeter walls. Similar structures articulated on several levels are present in others at other sites such as the settlements of Montoro, Mercato San Severino, Avella, and San Niceto [16]. Such structures are commonly identified as palatium, places to house the lord of the castle or sometimes the garrison.

The room was identified as a front for a garrison or guard at the entrance. The excavation phase has returned no relevant findings to this function but the EM method has allowed comparisons to be made with other similar structures and to observe the context as a whole (Figs. 2-3).



Node	Definition	Description	Col
US	Extant structures	In situ archaeological evidences	Red
USV/s	Structural virtual reconstruction	Based on in situ archaeological evidences	Blue
USV/n	Non structural virtual reconstruction	Based on sources and comparisons	Green
SF	Fragmental virtual anastylosis	Repositioning of non in situ architectural fragments	Yellow
VSF	Fragmental virtual reconstruction	Completion of repositioned fragments	Brown

Fig. 2. Preliminary phase of EM with characterization of different SU, MSU, and VSU.

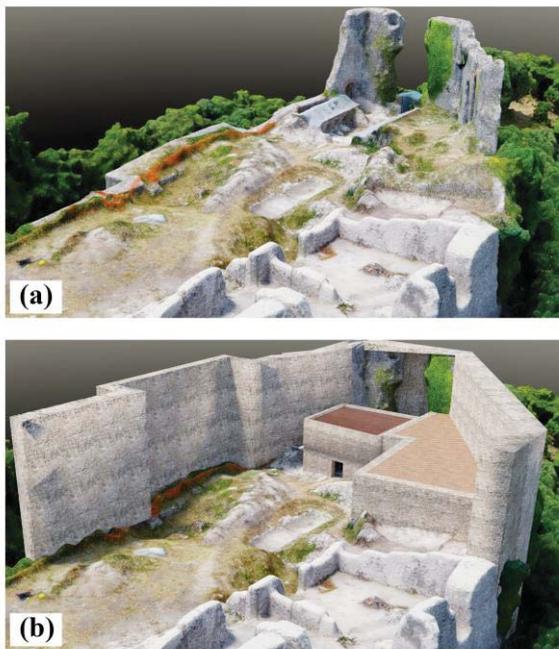


Fig. 3. (a) Three-dimensional survey of Monteforte Irpino castle, (b) reconstruction based on data obtained from studies conducted..

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