Proceedings of the 8th International Congress on Archaeology, Computer Graphics, Cultural Heritage and Innovation 'ARQUEOLÓGICA 2.0' in Valencia (Spain), Sept. 5 – 7, 2016

ARCHAEOBIM: AN INNOVATIVE METHOD FOR ARCHAEOLOGICAL ANALYSIS OF AN ETRUSCAN TEMPLE IN MARZABOTTO

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Abstract:

The digital reconstruction of the recently discovered Tuscanic temple of *Uni* in Marzabotto gave the chance to test the application of the *Building Information Modeling* (BIM) process to the combined fields of Archaeology and Engineering. In addition to the traditional historic and archaeological analysis, a new methodology in Experimental Archaeology is proposed; it proved to be original and innovative in the examination of the buried building, taking advantage of technologies focused on the architectural reliability validated by inferred digital models.

Key words: Building Information Modeling, Etruscan temple, Digital model, Marzabotto, ArchaeoBIM, Digital archaeology

1. Preface

The preliminary results of the Project FIR 2013 titled "*KAINUA. Reconstructing, perceiving, disseminating the lost reality. Transmedial technologies for the Etruscan city of Marzabotto"* were presented at the Digital Heritage 2015 Conference in Granada (Gaucci *et al.* 2015) as they represent some achievement in the application of new methods and technologies to the analysis of ancient structures. The aim of the project is the development of a virtual model of the entire Etruscan town of Marzabotto near Bologna, that visitors can enjoy directly on site, through Augmented Reality devices. In this perspective, the virtual reconstruction of some Etruscan buildings allowed to experiment new applications of informative computer modelling. The extensive use of digital models followed an emerging approach that properly mimic the building process in contemporary engineering, referred to as *BIM* (*Building Information Modeling*). Digital models produced in a BIM environment are also 3D archives with a considerable potential in terms of conservation, research and dissemination. Therefore, the models generated in this work lead to the virtual reconstruction proposal for those buildings that have no more existing elevations, with hypothetical elements justified by the numerical simulation analysis. In addition to the traditional and historical studies, the highly innovative aspect of this research is the application of technologies that enable reflections on the architectural credibility of the model; a new method for virtual Experimental Archeology was started beginning from the building's remains, following an approach that was defined *ArchaeoBIM*. This method fosters a virtuous cycle, controlling all the development stages starting from the data used to author the model until the simulation and final postfiguration, which is the virtual conjectural restitution of how the building actually existed in the past.

During the 2013-2015 excavations in *Regio* I, 4, the team of Bologna University, directed by Elisabetta Govi, discovered a new urban Tuscanic temple sacred to *Uni* (Roman *Iuno*). This is a significant discovery, both for the scientific relevance of the building itself and for new reflections on the issues about the urban plan and the history of the town (Govi in press). Therefore the temple has been elected as Case Study. The *ArchaeoBIM* method granted a deep analysis based on the archaeological record and information about elevations, inferred from ancient sources. Then, the architectural remains, mainly the roof elements, were digitally acquired in order to get a more definite quantification of shapes and loads to model. The last phase was the production of the whole model of the temple, following a specific *ArchaeoBIM* approach later described in this contribution. The primary aim was to establish credibility of architectural and engineering criteria expressed by a virtual building process.

2. Archaeological Analysis

The archaeological record of the temple is limited broadly to massive foundations made of pebbles, mostly taken away by peasants during the past centuries (Fig. 1). Nothing was found to describe the original building as

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it was standing on the ancient ground level. It can be assumed that the temple followed the Tuscanic order, as described by Vitruvius in *De Architectura* (IV 7, 1-5). However, the plan proportions do not follow exactly the famous Vitruvius' *tuscanicae dispositiones*, although they do not differ so much. These are some of the initial reflections that guided the preliminary archaeological analysis, taking into account some critical issues to be solved in order to build up a believable model, which had to properly consider building materials, the reconstructive hypothesis for elevations and the roof, based on ancient sources and scientific literature.

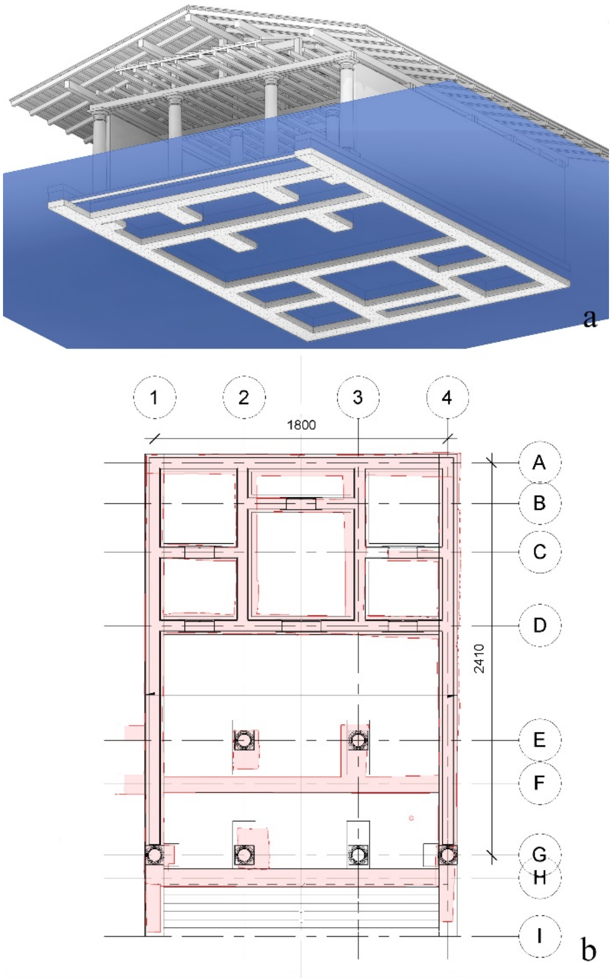

Figure 1: The ArchaeoBIM digital model (a) produced beginning from the real foundation plan (represented in red color, b).

Materials used for the elevation walls were not discovered during the excavations, as well as in the entire town. They would have been mudbricks walls, eventually supported by wooden beams, as hypothesized for the dwellings. Columns could be made of straight trunks or, less likely, by stone; the bases and the capitals could be made of local travertine. Coming to the wood (this consideration is also valid later, for the roof), a prevalent use of the deciduous oak can be presumed, due to the medium-hill environment, as confirmed by the paleoenvironmental studies conducted by M.L. Carra.

The Vitruvian criteria were parametrically translated into digital models, even if conscious of the historical limits of his work compared to the archaeological records. Therefore, the height of the elevation was modelled following the *dispositiones tuscanicae* given by Vitruvius.

The wooden structure of the roof has been generated following Vitruvius descriptions (IV 7, 4-5). The oak allows the use of great supporting beams but ancient sources testified a maximum lenght of 7-8 m. Beams of such length are essential to support loads, especially considering that in the Etruscan (but also Roman) architectural technology the roof system ignores the use of the truss. It has yet to be investigated the connection system among the wooden elements: various solutions can be found in the Greek world, as witnessed by the ancient sources (Orlandos 1966, pp. 45-49; hypothesis of grappa, nails and ties for the Temple II dell'Ara della Regina, Bonghi 2012, p. 38). The roof was covered with *tegulae* and *imbrices*. These elements, mainly similar to modules destined to house roofs (Pizzirani and Pozzi 2010), were found during excavations of the areas around the temple, in contexts intended as a late walkway around the sacred building. A few fragments of palmette antefixes, according to a decorative scheme well known in the acropolis sacred buildings, were found as well. The excavation of the temple *temenos* is not ended, thus it is not possible to establish if greater *tegulae* were used for the slopes. At the present state of the excavation, it is plausible to speculate a roof composed by elements in special modules, considering the use of the house modules for the small front roof only. It seems not methodologically correct to place on the temple other decorative elements not yet found beyond palmette antefixes.

3. The digital acquisition of artifacts' datasets

By starting the FIRB 2013 project, it was possible to apply and test directly on the site under investigation some of the latest 3D digital acquisition techniques. In recent years systems based on passive sensors, such as digital photogrammetry and computer vision algorythms, were progressively optimized (Buscemi *et al.* 2014). From the combination of digital photogrammetry and computer vision techniques, algorithms like *Structure from Motion* were implemented into software, like Agisoft PhotoScan, which allows reconstructing 3D models from photographs following a typical automated process, as experimented in this research work.

During the excavations at Marzabotto in 2014, it was decided to take advantage of these methodologies using PhotoScan, combined to total station's data acquisitions in the field: the aim was the production of referenced three-dimensional models related to the various digging stages.

The metric accuracy of measurements and models made during the excavation led to the use of the same technology aimed at the digital acquisition of materials related to the temple of *Uni*'s roof system, including roof tiles and, in particular, brim gutters with palm-shaped antefixes.

Several tile fragments hypothetically attributable to the roof structure were found in stratigraphic units 1119 and 1142. Because of the fragmentary state of conservation of these materials, we proceeded to a measurement aimed at the estimation of modules and most of them can be identified as simple elements, just like the ones found for common settlements around the town. The only exception was represented by a couple of well preserved palm-shaped antefixes similar to the ones belonging to the *Kainua*'s acropolis and some tile fragments that, according to their thickness, appear to be more similar to the covering elements discovered nearby the close Temple of *Tinia* (Sassatelli 2009, p. 332, fig. 13).

The presence of both shapes leads to believe preliminarily that the simple module was used for the small front roof slab, the greater for the wide temple coverage instead. The temple of *Uni* takes up an area of 492 square meters, slightly larger than the Temple C in the Acropolis. These sacred buildings, both Tuscanic, had probably similar coverage.

Once verified the right module to use, artifacts in good state of conservation were digitally acquired. Then, roof tiles, shingles and antefixes were processed in order to evaluate their shape, volume and weight for the accurate reconstruction performed using computer models (Fig. 2).

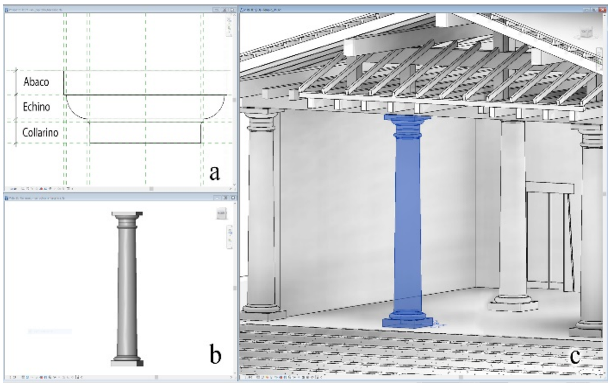

Figure 2: Detail of the parametric column generated as a custom family in Autodesk Revit (a, b). All the Tuscanic elements were modelled using a parametric approach then assembled into the final ArchaeoBIM model (c).

4. *ArchaeoBIM*: digital semantics for archaeological investigations

Over the past years the field of contemporary architecture and building engineering have been affected by a major change in design methodology, following an approach called *Building Information Modeling* (BIM), aimed at a better fulfillment of the requirements that apply to the construction industry (Eastman *et al.* 2008). One of the main features of the BIM approach is the interoperability among disciplines, which share information during all the different stages of the building process. BIM models are three-dimensional representations of facilities based on assembled objects including information about their physical properties and their mutual relationships (Fai *et al.* 2011). Even if BIM was developed for new constructions at the industrial level, some works dealing with the process application to existing buildings and monumental sites were published over the years, with the acronym of HBIM (*Historic Building Information Modeling*). HBIM was originally proposed as a modeling system for historic structures surveyed using laser scanning combined with digital photogrammetry, in order to generate parametric 3D models by comparing real elements to already prepared digital libraries (Dore and Murphy 2012). Since the HBIM's goals and methodologies are based on different premises, the term *ArchaeoBIM* was chosen to distinguish this research scenario and to identify the workflow developed to inflect the common BIM matrix to the archaeological virtual reconstruction. The temple of *Uni*'s *ArchaeoBIM* model was produced investigating semantics and morphology largely following Vitruvian rules, even if the only element that could be acquired with surveys was the foundation plan (Fig. 1). A hypothetical reconstruction, consisting of precise metrics for the elevations and sections, was generated beginning from groundwork's extents. The original *ArchaeoBIM* process consists of digital elements that have to be combined just like in the real building assembly: the reliable parametric engine of Autodesk Revit software was chosen to create these smart components. Like in BIM semantics, the individual elements retain memory of data associated to them, so the overall geometric reconstruction is supposed a visual index for various contents (Garagnani 2015). Walls were traced following the foundations path, built on top of the podium with plastered, sun-dried clay bricks about 1 meter on the ground line. Also the Tuscan order columns, digitized with a parametric schema based on the shaft diameter (Fig. 2), were created as custom Revit families considering weights and materials, since some structural analysis are still in progress in order to validate elements' dimensions and their stress behavior. The preliminary results of this methodology suggested some further explanations for the actual position of some plinths close to the linear foundations. On the top of *pars antica* and *pars postica*, an impressive frame made of oak timber would have been erected as a roof, covered in tiles that were mostly found during previous excavations in Marzabotto. The different oak beams, probably 8 meters long, were placed in the *ArchaeoBIM* model following a well-known diagram in the scientific literature: a horizontal sequence of beams (*mutuli*) were placed on the top of the walls to allow coupled transversal girders (*trabes compactiles*) to be sustained. Other layers of sloped frames, made of crossed beams (*cantherii* and *templa*), were modeled according to 16° declivity to arrange roof tiles and decorations (*antefisse*) (Fig. 3).

5. Conclusion

Archaeology often needs to reconstruct ancient buildings or monumental sites in order to study and preserve the cultural heritage they represent. That is why *ArchaeoBIM* was chosen as the name of a proposed methodology that applies the BIM-based modeling to no more existing architectural domains that cannot be directly investigated. The authors of this research work believe that the *ArchaeoBIM* process can really represent a versatile and profitable approach to the documentation of the archaeological heritage, by standing as a complete knowledge management system, as useful for the consultation of the materials contained as for the deepen study of ancient building technologies, which lead to possible conscious reconstructions.

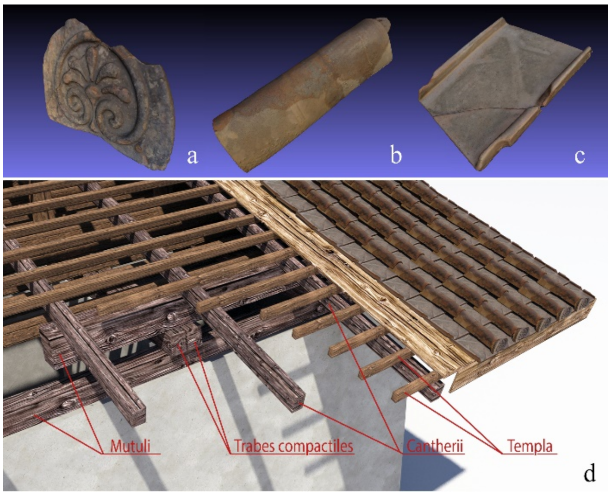

Figure 3: Detail of the ArchaeoBIM model for the temple of Uni's roof. The original elements were acquired using digital photogrammetry (a, b, c) then they were assembled in the final 3D model, following a real building sequence (d).

Acknowledgements

This work was supported by the Italian Ministry of University and Research (MIUR) concerning the "Future in Research" program FIRB 2013, under Grant RBFR13X8CN.

The authors would like to thank Giuseppe Sassatelli and Elisabetta Govi, respectively former and current director of the University of Bologna excavations in Marzabotto, and the Superintendence for Archaeological Heritage of Emilia-Romagna.

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