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FROM THE ARCHAEOLOGICAL RECORD TO ARCHAEOBIM*:* THE CASE STUDY OF THE ETRUSCAN TEMPLE OF UNI IN MARZABOTTO

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Abstract:

The digital reconstruction of the recently discovered Tuscanic temple of Uni in the archaeological site of Marzabotto, the Etruscan town of Kainua, 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, the case study was mainly approached considering findings and rules based on the *dispositiones tuscanicae* by Vitruvius; given these premises, a new methodology in experimental archaeology is proposed; it proved to be original and innovative in the examination of buried buildings, taking advantage of technologies focused on the architectural and structural reliability, validated by inferred digital models. The peculiar aspect of this research involves the elements at the beginning of the process, which consist of foundations or negative archaeological evidences only, supported by the clues and the rules that can be found in the historic and scientific literature. The case study presents the steps in the process, beginning from the analysis of the archaeological remains and the ancient sources. The digital acquisition of the roof tiles and the paleobotanical detailed study allowed to virtually reconstruct the physical behaviour of materials, considering their own structural properties. Finally, the BIM enviroment proves how successfully it mimics the building process of the temple. To better define this distinctive working process, the expression ArchaeoBIM was proposed, which highlights the common BIM matrix used for the data management through one or more analytical models, applied to the peculiar aspects of the archaeological discipline.

Key words: Building Information Modeling (BIM), 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, Garagnani, & Manferdini, 2015) as they represent some achievement in the application of new methods and technologies to the analysis of ancient structures. The field of investigation and experimentation is the entire Etruscan town of Marzabotto, the ancient Kainua (Fig. 1), a prosperous center founded around 500 B.C. along the Reno Valley, about 30 km south of Bologna (Govi, 2014, pp. 87-109). The aim of the project is the development of a virtual model of the entire town that visitors can enjoy directly on site, through augmented reality devices. In this perspective, the virtual reconstruction of some Etruscan buildings allowed scholars and researchers to experiment new applications of informative computer modelling, in order to foster the knowledge exchange across different disciplines (from Archaeology to History of Architecture, from Engineering to the study of materials). The extensive use of digital models followed an emerging approach that properly mimics the building process in contemporary engineering, referred to as BIM. Digital models produced in a BIM environment are also 3D archives (Scianna, Serlorenzi, Gristina, Filippi, & Pallaga, 2015) 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 archaeology was started beginning from the building’s remains, following an approach that was defined as ArchaeoBIM. This method fosters a virtuous cycle, controlling all the development stages starting from the data used to produce the model until the simulation and final postfiguration, which is the virtual conjectural restitution of how the building actually existed

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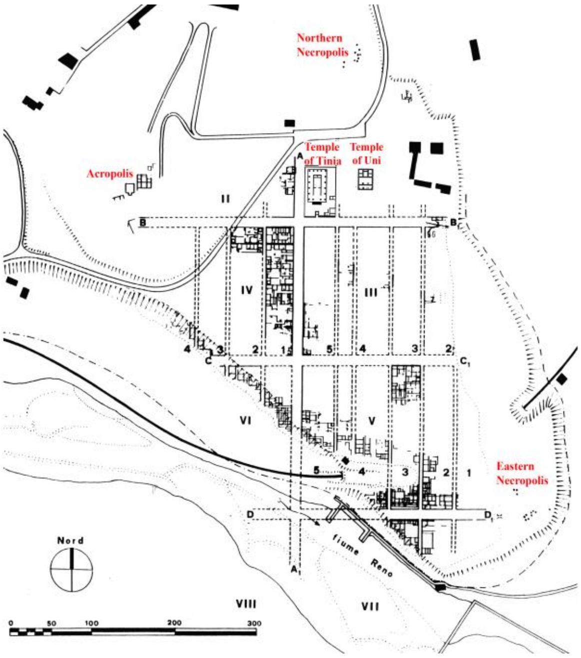

Figure 1: Plan of the Etruscan town of Marzabotto (the ancient Kainua): Regiones are designed with Roman numbers and Insulae with Arabic ones.

in the past. These data can be subject of discussion because of more or less complex problems that the BIM process highlights, leading eventually to some hypothesis that are most likely plausible from different points of view.

2. Introducing the case study

On-site excavations, conducted by the University of Bologna since 1988, have always pursued the aim of a virtual reconstruction of the buildings investigated. The most significant example are the House 1 of Regio IV, 2 (Govi & Sassatelli, 2010), and the urban Temple of Tinia, Regio I, 5, whose models are the result of considerations inferred from different fields of study (Sassatelli & Govi, 2005a; Baronio, 2012). Recently, the houses of the so-called *Isolato Mansuelli* (Regio IV, 1) have been systematically reviewed to prepare their virtual reconstruction (Gaucci, 2016).

During the 2013-2015 excavations in Regio I, 4, the team at the Bologna University, directed by Giuseppe Sassatelli until 2014 and by Elisabetta Govi at a later time, discovered a new urban Tuscanic temple sacred to Uni (Roman Iuno), the wife of Tinia (Roman Iuppiter), whose peripteral temple is close, on the west side. 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, which increasingly appears to be of primary importance in the context of the Etruscan culture of the Po Valley. Elisabetta Govi has presented a report to the scientific community about the Temple of Uni (Govi, in press).

The reconstruction of the temple began from the BIM technology. This process 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.

However, a reflection on the Etruscan temple as a three-dimensional (3D) building in and of itself, with all related morphological issues, is not common in literature. The study of the archaic Temple II of Ara della Regina in Tarquinia, for example, is a reference case (Bonghi Jovino, 2012b).

3. Archaeological analysis of the Temple of Uni

The presence of a monumental building in Regio I, 4a, was already known, due to geophysical prospections and archaeological surveys conducted in the 1990s by Superintendence for Archaeological Heritage of Emilia Romagna (Lippolis, 2005). However, the excavations conducted by the University of Bologna in 2013-2015 allowed us to clearly define the plan, the sacred nature and the chronology of the building itself, while the relationship of the temple with the surrounding space has still to be investigated and it will be the purpose of the next excavations (Govi, in press). 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. 2). Nothing was found to describe the original building as 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), while the datation proposed by Elisabetta Govi, the end of the 6th century B.C., makes the building one of the most ancient of its kind. However, the plan proportions do not follow exactly the famous Vitruvius' *tuscanicae dispositiones*, although they do not differ so much. In the forepart (*pars antica*) the temple, with its open front, should have had four forelined columns and two in the middle of the backline, surrounded by sidewalls. The backside (*pars postica*) was closed on all sides and divided into three parts (*cellae*), a common distribution for this type of temple. According to sacred rules regulating the construction, the main entrance was southbound and should have had a podium (F. Melis in Colonna, 1985, p. 60). 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 the podium extension, building materials, the reconstructive hypothesis for elevations and the roof, based on ancient sources and scientific literature.

There are not remains of the podium, although it was supposed to be part of the foundation walls above the ground, which formed a raised platform upon which the temple was erected. A possibile comparison should be made with the well-preserved podium of the Temple C in the Acropolis of the town, even if its height is still *sub iudice*. As a matter of fact, critics claim that the effective height is about 0.3 m above the ground, according to the internal walls, even if the perimetral ones are more than 1.5 m high (Vitali, 2001, p. 40). The variability in height of other cases (Potts, 2011, pp. 42-43, Tab. 1; Bonghi Jovino 2012a) does not help to elaborate a tangible hypothesis. However, if the two spoliation trenches not entirely discovered during the 2015 excavations can be read as restraints of a staircase running along the front, the comparison with the staircases of the buildings of Acropolis, mainly with the podium-altar B and the most monumental podium-altar D, is possible. The podium-altar B and the podium-altar D count respectively 6 and 3 steps (h. 0.17-0.2 m; tread respectively 0.25 and 0.35 m). Therefore, we can suppose that the Temple of Uni had at least 7 steps and a height of the podium of 1.4 m. According to Vitruvius (III 4, 4), the staircase of a temple podium must provide for an odd number of steps: this way, when starting the climb with the right foot it is possible to arrive at the top with the same foot. At the moment, it is not possible (even if reasonable) to attribute travertine molded coverings to the podium, such as those found in the great cistern-well of the closed Temple of Tinia and related to it (Sassatelli, 2009, p. 332, Fig. 11), or those belonging to the monumental podium-altar D in the Acropolis.

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 (Govi, 2010, pp. 213-218). Columns could be made of straight trunks or, less likely, by stones (Sassatelli & Govi, 2005b, p. 26); the bases and the capitals could be made of local travertine (Sassatelli & Govi, 2005b, p. 26; Sassatelli, 2009, p. 332, Fig. 12). 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 and based on the paleobotanic remains found in the archaeological contexts during the excavations. The oak is one of the most used wood in the ancient Greek and Greek-colonial world, as testified by ancient sources (Orlandos, 1966, pp. 13-14); this kind of wood is hypothesized also for the Temple II of Ara della Regina in Tarquinia (Chiesa & Binda, 2009, pp. 67-69), while for the Temple A in Pyrgi was probably used cypress, as recognized in the remain of a beam found in a well, next to the building (Colonna, 1988-1989, p. 111, Fig. 88).

The Vitruvian criteria were parametrically translated into digital models, even if we are 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 proportions expressed by the Latin author are the only data available to properly assume the height of the columns. Basing the calculations on the width of the building, which had to be slightly less than the width of the foundations (19.14 m), we would have columns about 6.4 m high, characterized by an *imoscapus* of 0.9 m in diameter (*summoscapus*: 0.67 m). The same parameters were considered for the reconstructive hypotheses of other Tuscanic temples (often characterized by a more significant conservation of architectural elements); the Temple of Uni could have been similar to the Temple of Portonaccio in Veio, as it is constituted by a similar side closure in the *pars antica* (Colonna, 2008, pp. 59, 61).

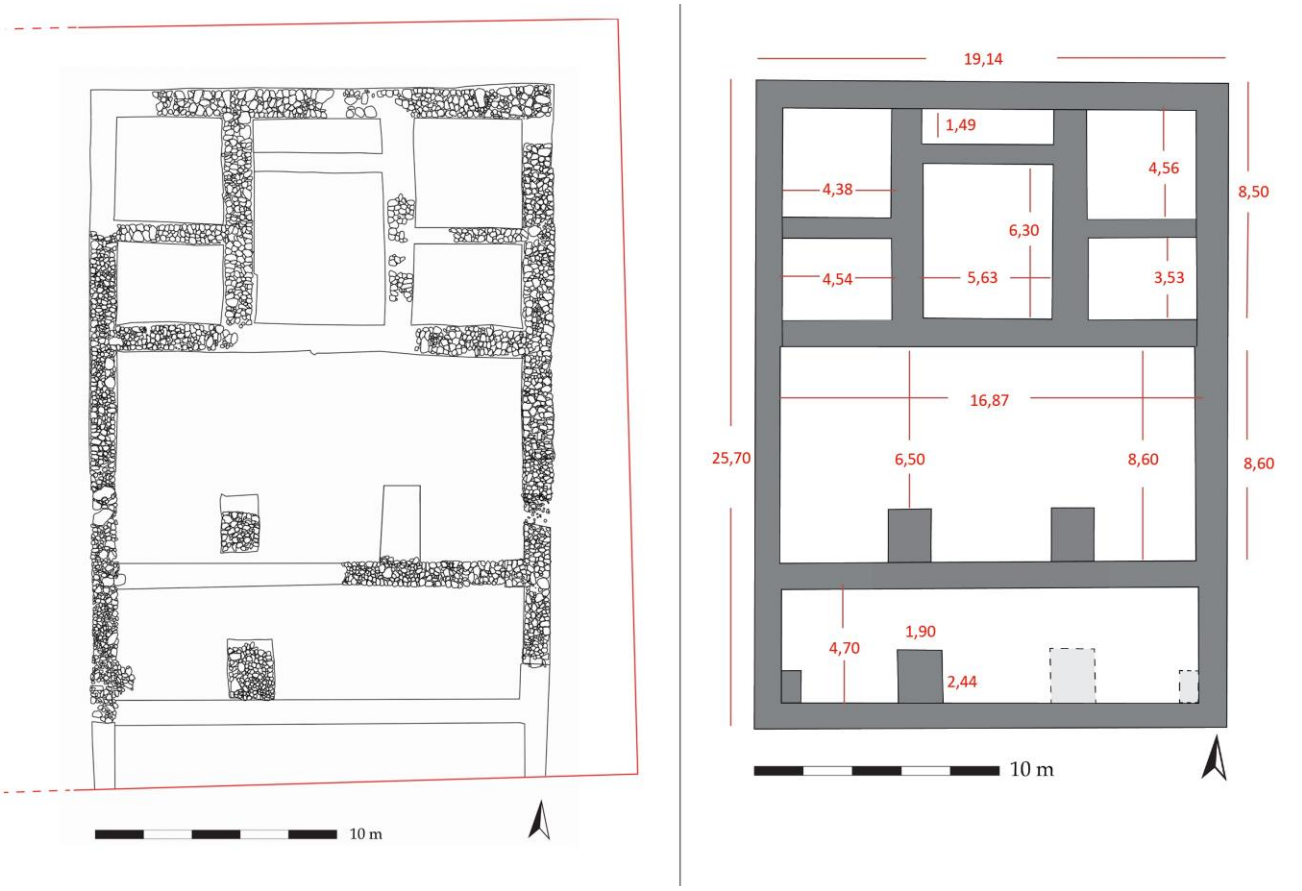

Figure 2: The excavation plan for the Temple of Uni found in Regio I, 4 (the excavation boundaries are represented in red color) and the schematic plan of the building with dimensions expressed in meters.

The wooden structure of the roof, in fact, has been generated following Vitruvius descriptions (IV 7, 4-5), which are limited and ambiguous (Andrén, 1940, pp. LV-LXX). The oak allows the use of great supporting beams but ancient sources testified a maximum lenght of 7-8 m (Orlandos, 1966, pp. 21-23), as recorded in the Temple of Tinia, or up to 12 m in exceptional cases (Cifani, 2008, p. 105, notes 251-252). 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 is not impossible that rafters of the roof were made of other wood essences, as confirmed by paleobotanic analysis, such as maple or ash.

It is interesting to understand whether the length of eaves, as defined by Vitruvius, is realistically achievable, since in temples of great proportions they would present an important projection (e.g. the Temple A of Pyrgi, 3.88 m; otherwise it has been established at 1.5 m in the reconstruction of the Temple II of Ara della Regina in Tarquinia). Other interesting questions pertain to the inclination of the roof slopes (not mentioned by Vitruvius) that, in other temples, can be inferred from preserved architectural decorations. Their inclination angle can be estimated between 12° and 20° (Colonna 1986, p. 493), with a statistical amount between 16° and 18° (Portonaccio in Veio, 12°; Temple B in Pyrgi, 15,30°; Belvedere in Orvieto, 17°; Temple II in Satricum, 17°; Temple A in Pyrgi, 18°; Doric Temple in *Foro Triangolare* of Pompeii, 18° or 16°; Temple II of Ara della Regina in Tarquinia, 18°): the Temple of Uni was modelled following 16° angled slopes.

The connection system among the wooden elements still needs to be investigated: various solutions can be found in the Greek world, as witnessed by the ancient sources (Orlandos, 1966, pp. 45-49; hypothesis of grappe, nails and ties for the Temple II dell'Ara della Regina, Chiesa & Binda, 2009). Noteworthy the considerations expressed by Bonghi Jovino (2012b, p. 38) can be found about the linking between the scheme of the trabeation and structures below.

The roof was covered with *tegulae* and *imbrices*. These elements, mainly similar to modules destined to house roofs (Pizzirani & 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, as it was supposed for the Temple of Tinia, due to the finds recovered from the great cistern-well aside (Sassatelli; 2009, p. 332, Fig. 13). 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.

The last elements to be considered in the digital reconstruction are the openings in the building, which are the doors in the front of the *pars postica*. They should probably be three doors, which followed the tripartite division of the interior space. For a reconstruction of these doors, it seems legitimate to refer to those of the contemporary Temple B of Pyrgi, where the Doric profile along the double doors was enclosed by a finely decorated clay frame (Baglione, 2014, pp. 206, 208). Although accessory decorations cannot be included in the reconstruction, as they have not been found, the Doric profile of the doors can be used, due to the architectural and chronological horizon (Colonna, 1986, p. 450).

4. Digital acquisition of artifacts' datasets

By starting the FIR 2013 project, it was possible to apply and test directly on the site under investigation some of the latest 3D digital acquisition techniques. The experimentation and use of such technologies in the field of archaeological survey have now become an established practice, as confirmed by the widespread use of systems based on active sensors (range-based methods), such as laser scanners and total stations, whose methodology of acquisition and data processing is well known and standardized (Böhler & Marbs, 2004). In recent years also systems based on passive sensors (image-based methods), such as digital photogrammetry and computer vision algorythms, were progressively optimized: the former, today widely used in archaeology, has the metric documentation of objects as a purpose; the latter, more recent, is focused on the automatic 3D modeling (Hartley & Zisserman, 2004; Remondino & El-Hakim, 2006; Buscemi, Militello, D'Agostino, & Sammito, 2014). From the combination of digital photogrammetry and computer vision techniques, algorithms like Structure from Motion (SfM) were implemented into software applications, like Agisoft PhotoScan, which allows users to reconstruct 3D models from photographs following a typical automated process, as experimented along this research work.

During the excavations at Marzabotto in 2014, it was decided to take advantage of these photogrammetric methodologies combined to total station's data acquisitions in field: the aim was the production of referenced 3D models related to the various digging stages, useful not only as accurate representations of the detected areas but also, at a later time, as a metric database to study and interpretate archaeological evidences. Right from the initial applications, the benefits granted by this approach emerged with less time to be dedicated to surveys and data processing if compared to traditional measuring techniques and terrestrial laser scanning.

On an archaeological site, in fact, it is paramount to carry out the survey without blocking the excavations for prolonged times. Moreover, a significant advantage is represented by the limited cost of the necessary equipment since in many cases accurate 3D surveys could represent a significant budget problem (Putzolu & Vicenzutto, 2013, pp. 363-364). The archaeological excavation is in fact an operation unique and slightly destructive, so it is extremely important to detect and graphically document the most of the stratigraphic layers before they are removed, rebuilding their complexity. For this reason 2D datasets are not sufficient for their selective nature, so it is preferable to use 3D modeling methods to get more accurate and faithful results for the complex observations made in the field, adding another dimension to the traditional documentation (Buscemi et al., 2014); furthermore, information on plans, sections and elevations can be quickly exported into ortographic views as well. The metric accuracy of measurements and models made during the excavation of Marzabotto in 2014-2015 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. In the last decades, knowledge about Etruscan roofing systems were significantly deepened by the study of the investigations conducted in the Accesa (Vetulonia), Petriolo (Chiusi), Roselle and Gonfienti (Prato) settlements (Donati, 1994; Giuntoli, 1997; Gastaldi, 1998; D'Agostino & Mearini, 2009; Ciaghi, 1999; Poggesi et al., 2005), with the important contribution of Wikander (1993) related to settlements of Acquarossa, San Giovenale and Murlo, which outlined a greater awareness in the determination of technologies and related types of roofs (Pizzirani & Pozzi, 2010).

In Marzabotto, recent studies highlighted how pitched roofs present in the town could be: the mixed Laconic-Corinthian structures, made of semi-cylindrical tiles, as in the Laconic covering, associated to flat shingles, as in the Corinthian one, were also present in other areas of Etruria, Magna Grecia and Sicily during the late archaic and classical period (Ciaghi, 1999, p. 3, note 3; Pizzirani & Pozzi, 2010). Considering the roof module presented in these works, the clay roofs of Marzabotto can be dated back to the late 6th century B.C. During the excavation campaign at Marzabotto in 2015, several tile fragments hypothetically attributable to the roof structure were found in stratigraphic units 1119 and 1142, respectively adjacent to the western and northern sides of the Temple of Uni. 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). In this case, the simple-shaped brim tiles have a length of 64 cm and a width of 39-45 cm, while those belonging to the Temple of Tinia have a length of 67.5 cm and a width of 50-51 cm. Roof tiles from the latter group are 79 cm long, 25 cm wide and 11 cm high, while those belonging to the simple module have a length of 49.5 cm, a width of 16.4 cm and a height of 9.4-10.6 cm.

The presence of both shapes, albeit in a very small number for the larger one, 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 m^2, slightly larger than the Temple C in the Acropolis. These sacred buildings, both Tuscanic, had probably similar coverage; despite the serious shortcomings of the 19th century excavations, in the area of the Temple C were found "more than sixty almost adorned antefixes, in three different sizes" (Gozzadini, 1865, pp. 22-23, 27-29, illus. 4, 12-14, 10.2). No human face was used as a decorative pattern for the antefixes, but only painted palmette motifs were found. The two specimens from the Temple of Uni have the following measurements: base length of 22.7 cm and a height of 16 cm for the first, about 18 cm and 12.9 cm for the second. According to the decorations and size, the latter could be similar to the "A variant" of the Acropolis: the palmette with five petals on an hourglass-shaped stalk is rather long. It is inscribed in a semi-circular cord, terminating at the base in two opposing spirals; at the corners, two almost vertical drop elements have the tips up; the colour, when intelligible, is made of red pigment for the drop elements and the odd stalk petals while black was chosen for even petals and boundary frame. The "A variant" is divided into two modules: one with the base length of 19 cm and a height of 14 cm, the other of 17 cm and 12 cm (Vitali, 2001, pp. 59-60). The antefixes of the Temple of Uni related to "A variant" is flawed in one of the base corners, but it is probable it had a length of about 18 cm, so it fits between the two modules of the variant. The other antefix could fall into the same typology for the decorative motif, despite the slightly different dimensions (22.7 x 16 cm).

Once verified the right module to use, artifacts in good state of conservation (not coming from the excavation of the Temple of Uni except for the antefixes) 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. 3).

Information and data elaborated will possibly increase the understanding of the Temple C in the acropolis as well as, more generally, the knowledge about the evolution of the templar architecture at the end of the 6th century - beginning of the 5th century B.C.

New 3D modeling techniques, as well as offering precise and accurate results, help users to preserve and document the state of conservation of artifacts because, once built, the digital models can be used for all subsequent analysis: metric and volumetric measures and all the investigations can be performed without damaging the original artifacts, but operating directly on the digital replicas.

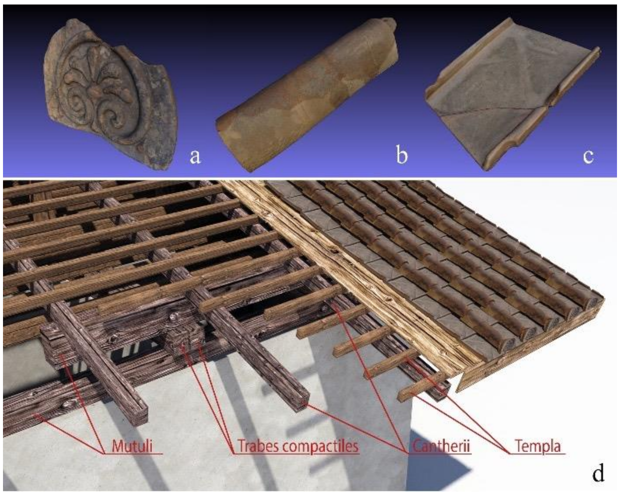

Figure 3: Detail of the ArchaeoBIM model for the Temple of Uni's roof. The original elements were acquired using digital photogrammetry: a) antefix; b) roof tile; c) shingle. Afterwards they were assembled in the final 3D model, following a real building sequence mainly described by Vitruvius (d).

5. ArchaeoBIM: digital semantics for archaeological investigations and reconstructions

Over the past few years, the field of contemporary architecture and building engineering have been affected by a major change in design methodology; many scholars consider this process, which takes the name of BIM, as an approach aimed at the better fulfillment of the requirements that apply to the construction industry (Eastman, Teicholz, Sacks, & Liston, 2008). The transition to the BIM, in its wide meaning of collaborative strategy among actors that operate according to a well-defined logic (Kensek, 2014), discloses all the potential of the "big data" management applied to the building's whole life cycle (Kymmell, 2008). The interoperability among practitioners, often covering many disciplines, unveils diachronic perspectives letting them exchange datasets using digital models, prepared to receive information during the different stages of the building process. In this way, BIM models are 3D representations of facilities based on assembled objects, which include information about their physical properties and mutual relationships, beyond the mere graphical visualization (Fai, Duckworth, Graham, & Wood, 2011).

The understanding of architecture and its grammar using BIM can be compared to the linguistic. In fact, while syntax is the study of the combinations, semantics is the study of meaning: both are part of the grammar, which establishes rules to govern the composition. Similarly to letters that follow the grammar to form correct words, words form sentences following the syntax but, to have logical sense, they must respect semantics. In the same way, architectural elements (if compared to words combined with correct syntax) have to follow semantic rules to combine themselves properly. In fact, on a BIM object-based framework, walls or pillars hold up floor objects, foundations sustain walls and so forth. Even if BIM was developed for new constructions at their industrial level, some research works dealing with the process application to existing buildings and monumental sites has been published over the years (Murphy, McGovern & Pavia, 2013), referring to it as HBIM (Historic Building Information Modeling).

HBIM was originally proposed as a system of modeling historic structures beginning with remote collection of survey data, using a terrestrial laser scanner combined with digital photogrammetry (Quattrini, Malinverni, Clini, Nespeca, & Orlietti,, 2015) in order to generate parametric 3D models by comparing real elements to already prepared digital libraries (Dore & Murphy, 2012). The HBIM method has proved to be effective for the analysis of information related to consolidate historical urban contexts, linking database records to digital models morphologically close to the real buildings. However, it is possible to extend also to the archaeological field these benefits, in terms of analytic simulations and study of semantics, taking advantage of BIM authoring environments able to reproduce architectural components even if they cannot be surveyed or digitally acquired (Nieto, Moyano, Rico, & Antón, 2016).

This experimental approach, as documented in the Temple of Uni's case study, leads to more accurate simulations on how Etruscan monuments could be built, using materials and technologies as they were supposed to be properly applicable over the ancient times. Since the HBIM's features and objectives are mainly 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 specific field of the archaeological virtual reconstruction. If dealing with the real domain, components have to be acquired and prepared following three kinds of characterization (Tang, Huber, Akinci, Lipman, & Lytle, 2010): (1) knowledge about shapes; (2) knowledge about objects identities; and (3) knowledge about the relationships among elements. While the last two aspects are generally investigated by semantics analysis and assays, the first one can be performed mainly through surveys. The Temple of Uni's ArchaeoBIM model was produced investigating semantics and morphology largely following Vitruvian rules, but the only element that could be acquired with surveys was the foundation plan (Fig. 4). A hypothetical reconstruction, consisting of precise metrics for the elevations and sections, was generated beginning from groundwork's extents with the assignment of strict parametric constraints for architectural elements. Proportions were validated according to Vitruvius even if in similar Etruscan buildings some dimensions were

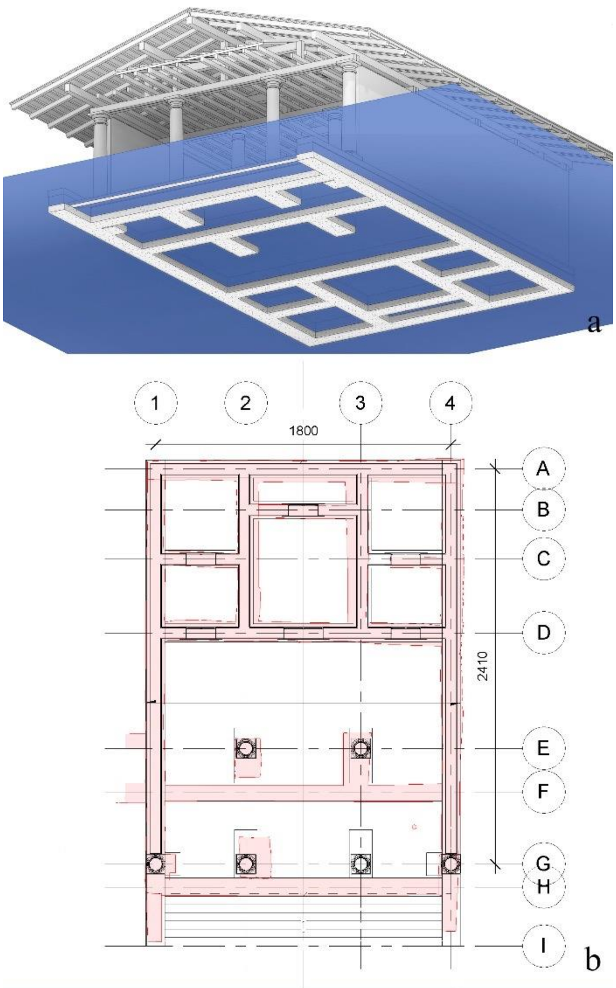

Figure 4: The ArchaeoBIM digital model (a) produced from the real foundation plan (represented in red color: b).

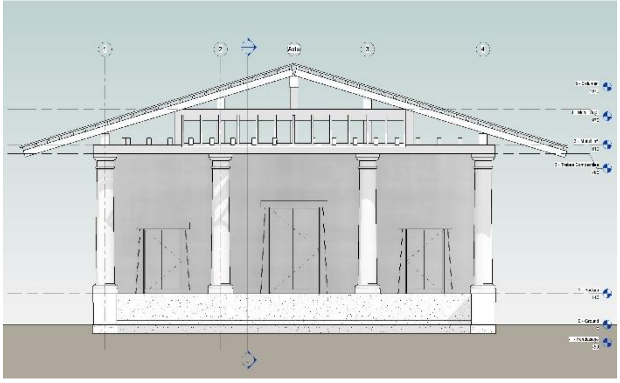

Figure 5: The final model represented in south elevation view: proportions and dimensions were reproduced following Vitruvius' rules.

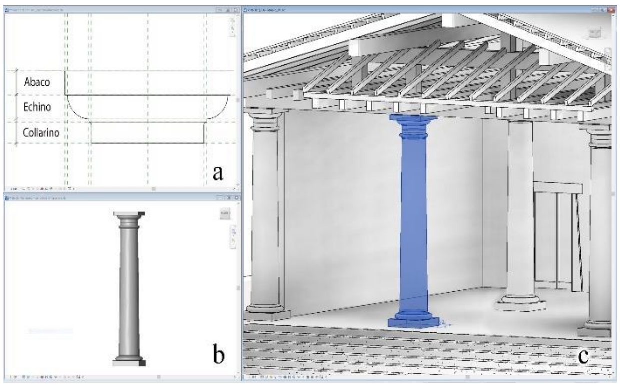

Figure 6: Detail of the parametric column generated as a custom family in Autodesk Revit (a, b). All the Tuscanic elements were modelled using a parametric approach then assembled into the final ArchaeoBIM model (c).

close enough but not completely respected (Fig. 5). The original ArchaeoBIM procedure consists of digital elements that have to be combined just like in the real building assembly: the reliable parametric engine of Autodesk Revit 2016 software was chosen to create these smart components, which were connected simulating supports, connections and finishes. Like in BIM semantics, the individual elements retain memory of data associated to them, so the overall geometric reconstruction is supposed to be some kind of 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 m on the ground line. These elements were modeled in Revit using libraries created from template files, since already prepared Etruscan object families are of course not included in common repositories. Also the Tuscan order columns, digitized with a parametric schema based on the shaft diameter (Fig. 6), were created considering weights and materials, since some structural analysis are still in progress in order to validate elements' dimensions and their stress behaviour. The preliminary results of this methodology suggested some further explanations for the actual position of some plinths found close to the linear foundations. The feasibility of the construction can be validated this way with sufficient certainty, coming to the minutest particular and depending on the level of detail to be achieved (Fig. 7). 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, considered for a maximum length equal to 8 m, were placed in the ArchaeoBIM model following a diagram well-known 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

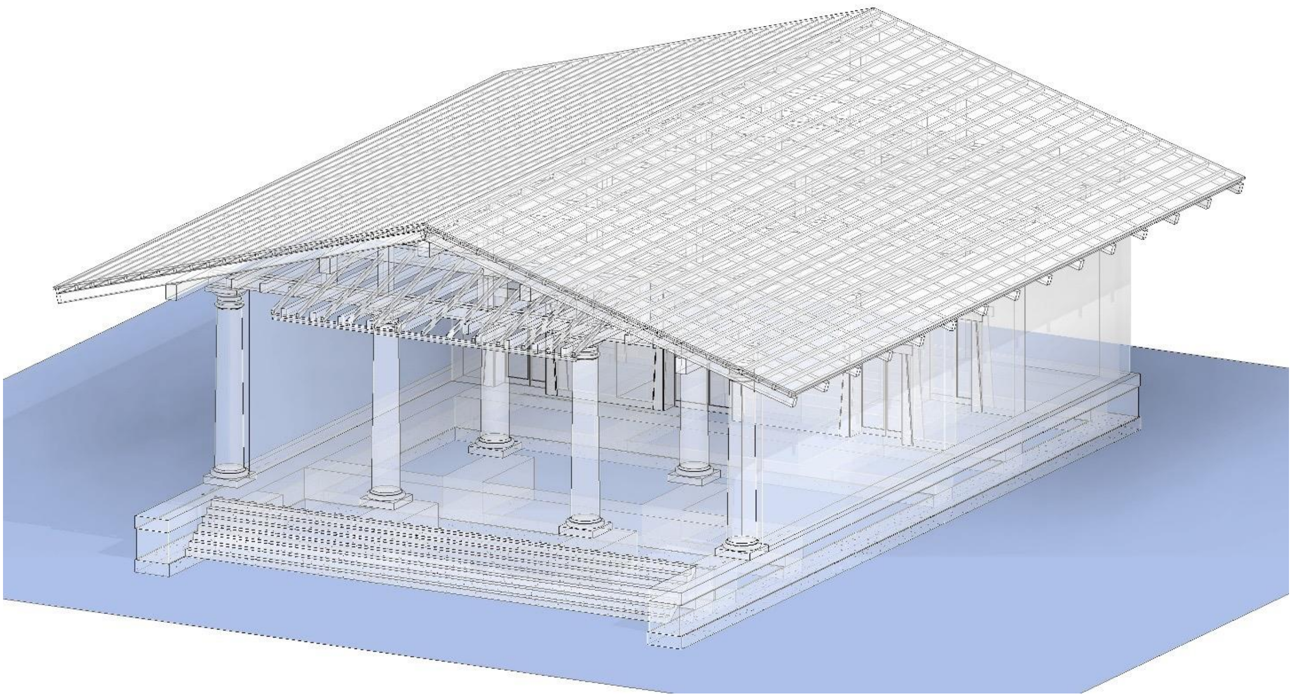

Figure 7: The complete ArchaeoBIM model of the Temple of Uni at Kainua. Several layers of complexity can be managed and organized into a single digital model.

Figure 8: The virtual reconstruction of the Temple of Uni (right) close to the Temple of Tinia (left) at Kainua.

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 (antefixes). The digital model expresses the most plausible dimensions of these elements in order to support loads: deciduous oak was taken into account with its orthotropic behavior to deformability, with a density estimated to be 670 kg/m^3 while about 1300 tiles were probably used to cover the roof slopes. While some simulations are still in progress, especially those prepared to compare different materials and building sequences, the virtual reconstruction of the Temple of Uni, close to the Tinia's one, is a visual representation of a scenario that was made plausible by the ArchaeoBIM approach (Fig. 8).

6. Conclusion

The BIM process (long before the BIM software applications) represents a paradigm shift for the architectural documentation and investigation of new buildings, while HBIM has proved to be effective dealing with existing ones: it really is a digital cross-language for architects, engineers, art historians and technicians, able to let them share specific knowledge in a coherent and referenced way. However, 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 keeps the advantages of BIM-based modeling applying them to no more existing architectural domains that cannot be directly investigated.

The overall model of the Temple of Uni was surely an opportunity to experiment new interactions between engineering and archaeology, culminating in the production of an information 3D dataset that can be updated and modified over time: it can be considered either as a knowledge repository or as an analytical database, since stored information can be used for several purposes.

The authors of this research 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.

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