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ARCHAEOLOGICAL BUILDING INFORMATION MODELING: BEYOND SCALABLE REPRESENTATION OF ARCHITECTURE AND ARCHAEOLOGY

The transition to the digital portrayal of the architectural knowledge that is driving the contemporary building industry is influenced by many important methodological changes, aimed at the satisfaction of increasingly persistent regulatory, economic and qualitative requirements. Collaborative processes taking deep advantage of the IT, just like the Building Information Modeling (BIM) or the Virtual and Augmented Reality authoring environments, reveal all their strategic potential in the organization and management of datasets distinguishing the construction project throughout its lifecycle (Eastman *et al.* 2008).

Information exchange and dataset interoperability are basically the main actors of this scenario, in which many disciplines converge into a shared framework that encompasses process management and digital representation, although preserving their fundamental identities (Garagnani 2015). Data flow among figures involved in architecture and engineering, carrying definitions about shapes, costs, materials and assembling instructions. In the AEC field, processes are now driven by data exchange, which is fostered by digital models. These are no more simple three-dimensional representations of buildings, but heterogeneous databases involving the collections of many different elements.

Taking into account these premises, this paper deals with the application of such a paradigm to the archaeological field, whose intrinsic peculiarities already encompass the knowledge belonging to many research fields, even if they are not often sharing the same tools or procedures. The application of these methodologies to the particular case study of Kainua aspires to be exemplary, since it is referred to different architectural scales, from the building to the urban settlement.

1. The Kainua Project, a challenge in complexity

The digital reconstruction of individual artefacts, together with computer-based simulations of archaeological excavations, is already well documented by the scientific literature, especially when abiding by the Virtual Archaeology domain (Reilly 1991). However, the representation of a building, from single evidence, is much different from the digital description of part of it; the complexity increases when tackling the re-enactment of a whole town. It is not, of course, a matter of shape only, but such a project entails the collection and analysis of historic sources and building traditions as well, mixing

Fig. 1 – a-b) The first photorealistic representation prepared for House 5, *Regio* IV, 1; c) The first photorealistic representation prepared for House 1, *Regio* IV, 2.

this way the knowledge from many disciplines in an ideal flow that has been part of scientific literature from several years (Levesque, Brachman 1985).

Following a path of increasing complexity, the Kainua Project was proposed. It consists of three main sections: the reconstruction of the most documented portions of the Etruscan town (from the foundation rite to the recently discovered temples), the scientific visualization of the whole urban environment by means of virtual devices able to give an immersive experience to visitors, and the deep analysis of construction techniques through a new process named "ArchaeoBIM", initially applied to main buildings.

Beginning from the established sources (Vitruvius among the others), and taking full advantage of the excavations' documents, the reconstruction of the town started from dwellings. House 1 (*Regio* IV, *insula* 2) and House 5 (*Regio* IV, 1) were studied and modelled at first, mostly considering the space design, materials and techniques applied to rooms and surroundings (Fig. 1, a-b). The first approach was mainly dedicated to the shape of single components, digitally assembled in order to get the whole building rendered, even if soon after it was clear that the description of the morphological appearance of a totally reconstructed building is, perhaps, not enough to organize and disseminate an archive of information whose data are collected from all the different sources.

Mapping technologies and geographic information systems for a long time have become part of the contemporary archaeology field, and they are already based on information sheets linked to graphical representations (plans, schemes, notes on site excavations and so forth); however, the rebuilding of Kainua aimed at a digital representation able to host data and being the expression of its analysis.

The Kainua town as a whole gave the opportunity to evaluate many circumstances, such as the actual impact of the roads' width, the perception of voids and masses in the urban settlement, the visual perspective related to monumental excellences and many others significances. Every single investigated element was related to the context, leading to a wider academic perspective (Garagnani, Gaucci, Govi 2016; Garagnani, Gaucci, Gruška 2016).

2. The immersive experience walking in virtual Kainua

Initially, the research plan was focused on the reconstruction of Kainua placing single well-documented or monumental buildings among dwellings generated by procedural shape-grammar-based software; some tests were made using CityEngine by ESRI, which takes advantage of a generation system called CGA shape to efficiently create large-scale 3D environments within defined rules and parameter ranges. Although it was possible controlling proportions, volumes and typologies, most of the features of the Etruscan houses, such as the *atrium* (the internal courtyard that connected different rooms), were not satisfying when modelled procedurally.

This way, most of the *Regiones*, at least those whose knowledge on shape and function was enough plausible, were manually modelled to recreate a realistic Etruscan urban environment, authoring shapes with Autodesk Maya and 3D Studio Max software: lately three-dimensional models were accurately placed on a DTM generated by GPS-based photogrammetry from UAVs, compensated by terrestrial laser scanning for the upper acropolis, whose plants and high trees made it difficult to fly over.

Digital models were draped using textures painted to mimic materials and details: one of the purposes of the reconstruction was a philologically correct representation of Kainua, so the amount of textures was kept low in quantity and resolution, since that information had to be managed almost in real time for the whole town. Still renderings in fact, even if detailed, are mere representations of spaces, while a virtual model rendered in a real time environment can be considered as an authentic tool (Fischer 2008) to understand relationships between buildings, blocks' extents or time to actually spend in order to reach different part of the town (Bruno *et al.* 2010). Texture and geometries were modelled as simply as possible to allow this approach.

3D models from Maya and 3DStudio Max were exported into Unity3D, a game engine developed by Unity Technologies, which is primarily used to develop videogames and simulations targeting multiple platforms (Fig. 2, a). The Unity3D rendering software proved to be reliable in the exploration of the digital environment: some specific scripts were written to simulate a first person view avatar, dynamically guided by a common videogame controller. The immersive experience was further enhanced compiling the Unity code

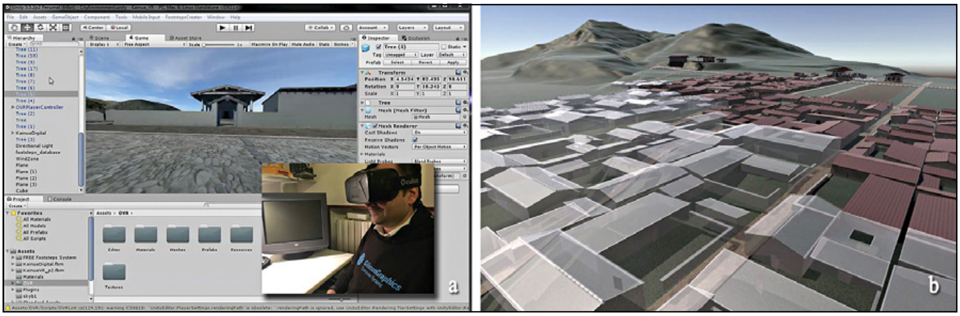

Fig. 2 – a) The virtual reconstruction of Kainua into the Unity3D framework, with the imported 3D model compiled using Oculus Rift stereoscopic libraries; b) The simplified virtual town that can be explored through immersive technology: transparent volumes are referred to dwellings whose known information does not allow to properly setup a philological reconstruction.

with VR libraries, who showed the potential of this technology when applied to the archaeology (Gaitatzes, Christopoulos, Roussou 2001): the digital world was next explored wearing prototypes of stereoscopic goggles such as Oculus Rift Development Kit 2, manufactured by Oculus VR after a successful crowd funding campaign. The DK2, now out-dated, has a higher-resolution (960×1080 per eye) low-persistence OLED display, a higher refresh rate, a positional tracking sensor, and it takes advantage of fast computer's graphic adapter (Goradia, Doshi, Kurup 2014). The equipment was tested and presented to many users during the KAINUA 2017 International Conference, promoting a virtual walk in the digital rebuilt city.

However, another interesting low-cost equipment was successfully tried on Kainua's models: Google Cardboard. It consists of a fold-out cardboard mount for smartphones that, when assembled with stock lenses, a magnet, velcro straps and a rubber band, can be held in front of eyes, to simulate a convincing VR experience, thanks to an app that can be run on phones. Google released a software development kit (Cardboard SDK) and a plug-in for Unity3D so that a common model, properly simplified for the reduced computational power of a smartphone, was used.

The software basically translates three-dimensional scenes into virtual environments visible through a stereoscopic camera rig, just like in Oculus Rift, where the camera position is fixed and the orientation is related to the smartphone's gyroscope, magnetometer and accelerometer, which allow a good synchronization between the user's head and the visual direction.

Even if visualizing much less detailed models, this small, cheap, do-it-yourself device opens several interesting opportunities: it is simple to assemble and the core technology can be embedded into smartphone application, taking advantage of very common widespread devices.

The panoramic images that can be visualized using Google Cardboards or equivalent goggles can be freely experienced visiting the website http://www.kainuaproject.eu/kainua_vr/, a dedicated portal taking advantage of html5 technology in order to adapt to different devices connecting, streaming contents according to devices' features and specifications.

3. A change of scale: the "ArchaeoBIM" as a validation process in buildings' reconstruction

The wider and wider adoption of Building Information Modeling (BIM) as a design paradigm, in which the involved disciplines interact with each other through digital models, suggested the application of a similar process to the investigations in Kainua. In a consolidated BIM process in fact, different disciplines (architectural, constructive, structural, managerial, etc.) converges into models authored by the aggregation of "smart" elements, endowed with a sort of self-consciousness of their geometric, material and behavioural values, able to collect data pertaining to many different fields (Garagnani 2013). Recently, the advantages of BIM have also been appreciated dealing with historic buildings, due to models dedicated to the documentation of the monumental heritage: the HBIM (Historic Building Information Modeling) acronym was coined specifically for this context (Murphy, McGovern, Pavia 2013).

However, in general terms, the HBIM is an approach based on the existing domain, documented by high resolution surveys (by terrestrial laser scanning or digital photogrammetry) and decomposed into constituent elements encoded in semantic categories and then aggregated into parametric models. It is basically a comparison between the registered point cloud dataset and a library of digital objects already prepared to replicate more or less faithfully the reality, superimposed to the survey in order to find similarities and proportions[1]. The analysis and aggregation of many information related to consolidate historical scenarios gave a certain scientific credibility to HBIM, but it was not possible to extend its benefits to archaeology, where evidence is not always well preserved and buildings are often no more existing.

Within the Kainua Project, it has been decided to exploit anyway the BIM process and its tools, but in a completely original way, in particular to justify the architectural choices made to hypothesize the appearance and the purposes of the Temple of *Uni*, which has recently been discovered at Marzabotto.

[1] From the original definition of HBIM: «Historic Building Information Modelling (HBIM) is a novel prototype library of parametric objects, based on historic architectural data, in addition to a mapping system for plotting the library objects onto laser scan survey data», in M. Murphy 2012 (Ph.D. Thesis *Historic Building Information Modelling (HBIM) For Recording and Documenting Classical Architecture in Dublin 1700 to 1830*).

In order to better distinguish this scenario from the peculiar features of HBIM that, as mentioned, starts from different premises, it was decided to refer to the process adopted with the term “ArchaeoBIM”, to underline the common BIM matrix but declining the methodology to the particular field of the archaeological reconstruction. In an ArchaeoBIM semantic model (i.e in the data base, expression of the process), individual elements retain the memory of their associated multidisciplinary information as well as ordinary BIM models, it is the authoring process that is considerably different.

The reconstruction of the temple dedicated to *Uni* was based on the traces that were discovered aside of the already known temple of *Tinia*. Referring to this still readable plan and to the historical literature related to the Etruscan constructive tradition, a virtual reconstruction of the sacred building was started. The ArchaeoBIM procedure adopted was based mainly on the semantic and functional synthesis of architectural components replicated in the digital domain: the meaning of those digital elements can be compared to linguistics. While the syntax, in fact, is the study of letter combinations, semantics is the study of the meaning they take in forming meaningful words: syntax and semantics are part of the grammar, which establishes the rules governing the composition. Like letters and words, architectural elements respect a more general grammar, which expresses their order and function. An ArchaeoBIM model allows the semantic reconstruction of components by specifying their role both from a compositional point of view and from a functional perspective. In order to acquire all the information necessary to characterize them, many different knowledge must collaborate in defining the morphology, the used material, the layering technique, the resistance to stress, the durability of the elements and so forth.

Starting from the Vitruvian indications concerning the proportions and the volumetric and compositional distribution of the Tuscan temple, *Uni*’s ArchaeoBIM models tried to mimic all the physical characteristics of the building materials as of those of the found findings, their use according to the known literature and their availability on site, along with the study of loads and static forces carried out to assess the actual strain expressed in the construction (Fig. 3, a).

In a semantic ArchaeoBIM model, individual elements retain the memory of their associated data, considering the overall geometric reconstruction as a sort of visual index for more extensive content, from measured distances to constructive notes.

The digital environment chosen to replicate the Temple of *Uni* was Autodesk Revit, a software specifically designed for contemporary buildings design, whose all components are structured into a precise “family” hierarchy. Families are sort of exclusive containers for the different types of objects that interact among them according to variable rules depending on their level of

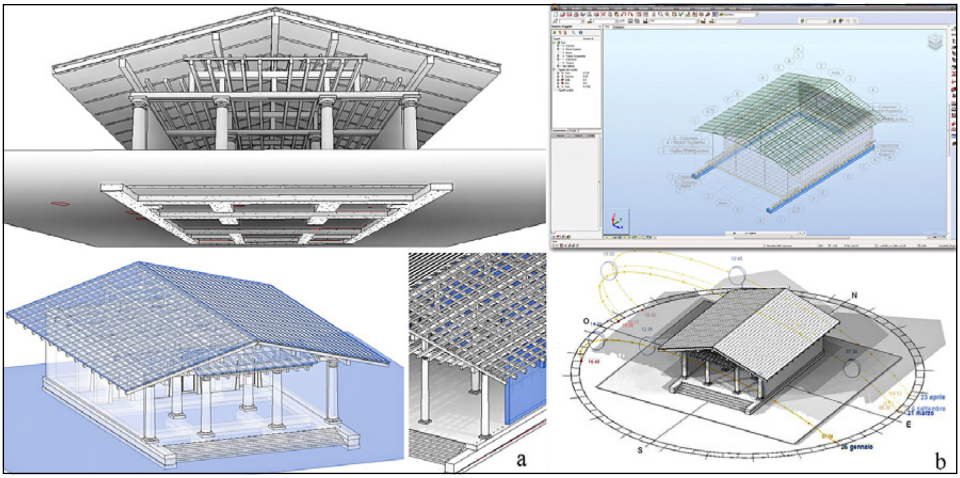

Fig. 3 – a) The ArchaeoBIM model of the temple dedicated to *Uni* in Kainua: all the elements were modelled according to their semantics and features; b) The ArchaeoBIM model was used to perform some analysis on the monumental building's performance, from the structural perspective and considering the natural light analysis.

importance and coded in the grammatical priorities of the software. This way, the authoring of the digital model precisely follows the real building process, with a first check for constructive solutions that is undergoing while modelling. The ending result, depending on the level of detail achieved, can replicate the construction up to the minute detail (Fig. 3, b).

The persistence of continuous underground structures led to the assumption of linear walls supported by stone foundations, with columns growing from a podium placed on plinths. These alignments, expressed as they are in the ArchaeoBIM model, led to hypothesis of proportional height elevation, upper beams profiles and shells, simulated as a broad embankment structure supported by containment masonry. To follow the symmetry shown by the excavation survey, according to the literature, the structures supporting the frontal columns to E were modelled similarly to those in the W even if, for the first ones, no foundation plinths were found. For the second ones, reinforcement to the perimeter and a plinth oriented to the rear axle suggested a well-defined support system.

The typology of the digitally reproduced Tuscan column has a height of 7 diameters and it has been identified as a metric reference for the main elevation, proportioned according to Vitruvian criteria. The resulting trabeation system was completed at the top by the *trabes compactiles*, sort of coupled transversal girders with a height slightly above the column collars, layered along the transverse plane. The digital fabrication model of the temple was complemented by the impressing roof, modelled in its wooden components named *mutuli*, *cantherii* and *templa*, a complex framework of crossed beams with rafters inclined 16 degrees from the horizontal.

On top of roof sheathings, the model clearly highlighted how plausible could be layering about 1300 shingles (approximately 79×25 cm wide, arranged in 39 rows with a length of 17 elements) and 1700 tiles (850 per square foot, approximately 60×51 cm wide). The ArchaeoBIM model allowed evaluating the weight loads resulting from such a composite structure, considering the stress conditions of the members largely imagined as made of deciduous oak wood. This material, in fact, has orthotropic behaviour at deformability with a density estimated at around 670 kg/m^3. With the availability of such a resilient work system, where the considerations expressed by archaeology, engineering, paleobotanics or astronomy specialists can be summed up, the reconstruction of an architectural complex, but also of an urban scenario, could follow more objective criteria of philological validation and plausibility.

The feasibility of a non-existing construction can be validated this way with sufficient certainty, coming to the most minute particular and depending on the level of detail to be achieved.

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Simone Garagnani
Alma Mater Studiorum – Università di Bologna
Dipartimento di Architettura
simone.garagnani@unibo.it

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ABSTRACT

The widespread use of technologies and processes aimed at information management is one of the main trends in today's building industry. Collaboration, coordination and validation of design results are fostered by software and workflows that involve many disciplines. Taking into account these premises, this paper deals with the application of such a paradigm to the archaeological and architectural fields. The application to the particular case study of the Etruscan town of Kainua aspires to be exemplary, since it is referred to different metric scales, from the building to the urban settlement. The digital reconstruction of the whole town, which can be explored and studied by means of Virtual Reality, was validated from a philological point of view using an original interdisciplinary approach called ArchaeoBIM, i.e. a methodology that encompasses the information flow among different disciplines with the same interest in understanding, and virtually reconstructing, lost realities. Using this method, architectural proportions brought by existing literature, physical behaviours of materials and components, layouts of rooms and spaces regulated by rituals or historic traditions are collected in a model that is able to represent morphologies, analysis and functions. This model, basically a geometric database linking heterogeneous documents, can be used in many different ways, from analytic abstractions to static simulations, from solar analysis to visual renderings. It becomes a common language for information exchange among scholars and users interested in the dissemination and study of the cultural heritage.