



The scientific method applied to the reconstructive hypothesis

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Resumen

Un estudio de las reconstrucciones virtuales de arquitectura romana realizadas con técnicas infográficas, revela que con frecuencia carecen de rigor científico, el acceso a los criterios seguidos para la reconstrucción no es posible, y falta transparencia en el proceso de trabajo y su comunicación. Estas lagunas se traducen en la importancia de determinar una metodología adecuada para las reconstrucciones virtuales, siempre en el ámbito de la arquitectura romana. El método que proponemos en este artículo se basa en el análisis arquitectónico y constructivo, buscando la validación de las hipótesis de trabajo mediante su aplicación, en un proceso abierto y transparente.

Palabras Clave: RECONSTRUCCIÓN VIRTUAL, ESTRUCTURAS ANTIGUAS, PATRIMONIO ARQUITECTÓNICO, EQUILIBRIO ESTRUCTURAL.

Abstract

The literary review of Roman architecture virtual reconstructions elaborated with computer graphics techniques revealed that they often lack scientific rigour, the access to the reconstruction criteria most of the time is not possible and lack the transparency in the process of work and communication. This paper proposes a scientific method based on the architectural and constructive analysis applied to virtual reconstruction field, with an open and transparent process in the validation of the working hypothesis.

Key words: VIRTUAL RECONSTRUCTIONS, ANCIENT STRUCTURES, ARCHITECTONIC HERITAGE, STRUCTURAL STABILITY.

1. INTRODUCTION

This paper is the result of several considerations arising from study and professional experiences of the authors in the field of Cultural Heritage and in the use of Information and Communication Technology as support, development and enhancement tool.

In the last years the use of data acquisition systems and the virtual representation has allowed to raise awareness among a wider audience about archaeological sites otherwise

unknown or neglected. The use of technology allows to make some important historical places more visible to the general public. Mainly it allows scholars to have at disposal a methodology and tools able to show and make transparent all the steps in the chain "cultural heritage - digital cultural heritage", ensuring a long-term preservation both physical and virtual.

In particular, the scope of this paper focuses on Virtual Reality from the perspective of the History of Construction, in order to analyse the architectural virtual reconstructions from a

technical point of view. The interest in the History of Construction as the base for virtual reconstructions, was born during the years of work of the two authors of this article at the CNR (ITABC), dealing with Roman architecture projects. This experience gave us the opportunity to study in detail Roman construction and to better understand how ancient remains have to be interpreted and communicated. Moreover it was the starting point, then developed through the doctoral thesis of the first author (that is how to represent the Architectural Heritage through Virtual Reality), to create a methodology rigorous from the scientific point of view.

We found out that the Architectural Heritage representations elaborated through Virtual Reality often lack in scientific rigour, often there is not transparency, nor the work-flow followed or a communication process, thus it is very difficult to validate the hypothesis elaborated.

In a virtual reconstruction, especially to demonstrate that the 3D representation is correct from a scientific standpoint, it should be included the information about the level of reliability applied to the reconstruction itself. Furthermore, this transparency concept applied to Virtual Reality makes the viewer involved in the process and methodology of the 3D model development, providing the type and the level of data accuracy (Barceló *et al*, 2000)¹.

This lack of transparency and scientific rigour in virtual reconstructions has brought out the necessity to develop a methodology for performing computer graphic reconstructions combining the scientific method with the historic-archaeological accuracy.

In particular, the paper will focus on:

- state of the art about virtual reconstructions;

¹ In this vein, the Ethical Codes are essential to guarantee a correct professional practice.

- methodology to elaborate reconstructive hypotheses based on structures analysis and construction and static rules (based on structural behaviour modelling methods and on construction science with the support of stability checks; taking into account the individual elements, the whole and the external agents);

- transparency in the process to ensure traceability and constant updating;

- knowledge dissemination among professionals.

2 STATE OF THE ART

A review of the scientific literature (based on 87 case studies about Roman architecture²) reveals that the architectural virtual reconstructions made with computer graphics techniques often lack of scientific rigour. Most of the times, it is not possible to access to the reconstruction criteria, there is no transparency in the process nor in communication; it is not possible to validate the work hypothesis, even in those cases elaborated from scientists. From this awareness arises the necessity of a method which provides virtual reconstructions with scientific rigour from an architectural point of view. Our study started from the principles of the London and Seville Charter.

The London Charter is the first international initiative that defines best practice in the computer visualization of Cultural Heritage (<http://www.londoncharter.org/>). As also Frisher remarks³, in the Charter is highlighted the necessity to publish the "paradata" along with the digital visualization of an

² "La restauración virtual según la interpretación arquitectónico-constructiva. Metodología y aplicación al caso de la villa de Livia". Doctoral thesis by Lola Vico.

³ FRISHER, B. (2012): "Embracing Uncertainty and The London Charter: Case Studies with the 3D Restoration of Ancient Sculpture", in On line Proceedings of CAA 2012, 26-30 March, Southampton.



archaeological artifact or monument. In fact, “paradata” is defined as “information about human processes of understanding and interpretation of data objects”, able to include descriptions stored within a structured dataset of how evidence was used to interpret an artefact, or a comment on methodological premises within a research publication. Often, in the case of 3D digital models that reconstruct lost or damaged artifacts, the paradata focuses on elements that are uncertain and gives the information how the uncertainty was defined and resolved.

The Seville Charter

(<http://www.arqueologiavirtual.com/carta/>) deals, among other principles, with the interdisciplinarity (principle 1), encouraging collaboration between different professionals in the field of Virtual Reality. As in the case of the authors of this paper, it is very interesting to join two different professionalisms in order to unify the technical and architecture knowledge with history and archeology: in fact, in the specific case it has been possible to evaluate the work methods from the beginning and to face various virtual reconstruction issues in a multidisciplinary way.

The Seville Charter⁴ introduces an innovation respect to the London Charter, having as objective that one to "establish principles and criteria for measuring the quality of projects," or "generate easily understandable and applicable criteria for the whole community of experts, including indistinctly computer experts, archaeologists, architects, engineers, general managers or specialists in the field".

The elaboration and development of the proposed method has the scope to meet the criteria set out by the Charters mentioned above and to contribute with the suggested work tools to their definition.

⁴<http://www.arqueologiavirtual.com/carta/wp-content/uploads/2012/03/BORRADOR-FINAL-FINAL-DRAFT.pdf>

3 METHODOLOGY: APPLICATION OF THE SCIENTIFIC DISCIPLINES TO VIRTUAL REALITY

The knowledge of the empirical rules of the traditional building⁵ (Figure 1) is the basis for proposing a methodology that includes aspects of the construction technique history, and allows to understand the behavior of ancient structures. These are usually geometric rules and they had a wide dissemination; they are empirical rules that are translated into simple geometric constructions, or into values expressed by fractions, that express the proportionality principle⁶ (Figure 2) (HUERTA, 2004). In the past, the general attitude of engineering historians pointed to the impossibility of deducing valid rules due to the ignorance of the static science, ignoring systematically these rules, in favor of the static rules knowledge (PARSON, 1965). The reason why we consider these ancient rules and treaties important to understand the ancient structures, it is because the most important structures (except for the huge bridges of the early s. XX) correspond to the period before the analysis of structures (such as the Pantheon's vault, with a diameter of 43 m.). Facing with the enormous complexity of establishing a valid method from a scientific point of view for architecture virtual reconstructions, the authors propose a method based on a scientific discipline, that is the calculation of structures and science of construction.

⁵ As the rules of Fray Lorenzo de San Nicolas, Rodrigo Gil de Hontañón, the principle of similarity of Galileo, the treaties of Palladio, Alberti, or the pseudo-scientific rules of Wreng, or the recommendations of Vitruvius whose have still validity in many cases.

⁶ There are cases (e.g. large portico) wherein the solutions are not always the proportionality but the reduction.

⁶ The use of the nonlinear FEA (Finite Element Analysis) revealed a number of drawbacks as it requires skilled personnel with knowledge in nonlinear processes to adequately characterize the materials; moreover the time for modeling, calculating nonlinear analysis for each load combination and interpreting the results, is too long for a virtual reconstruction work.

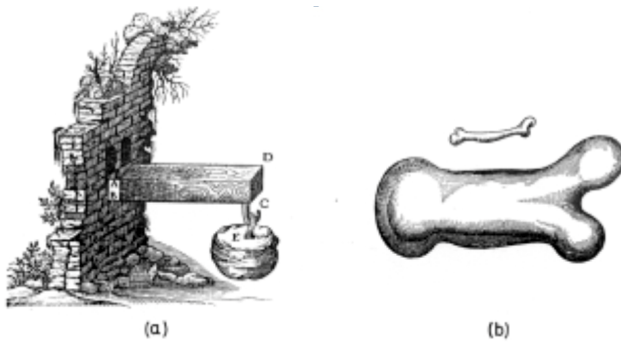


Figure 1. Illustrations from the "Dialogue concerning two new sciences" of Galileo (1638): (a) Problem of Galileo: endurance limit of a cantilever loaded at its ends. (b) Effects of increased size in animals bones.

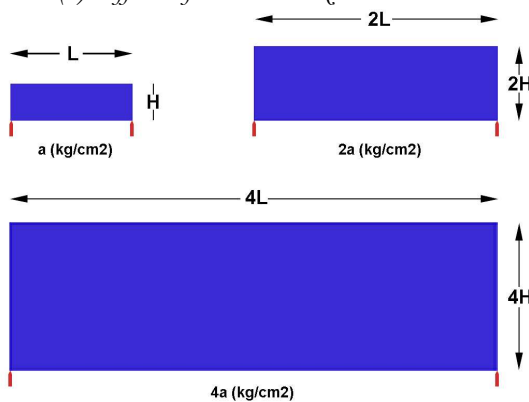


Figure 2. Example of how the tension changes increasing the size.

It is important to say that this is not "the method", but for the authors it is a scientifically valid method to ensure that the model generated through this procedure is valid from a constructive and structural point of view. That is to say, if a stair has been built through this method, it would guarantee its structural stability (so it can be assured that that is one of the possible scenarios and it is valid from an architectural point of view). Moreover, for the study of ancient structures, the picture of the situation reveals that the analysis is more appropriate for breakage, instead of the classical theory of elasticity (HEYMAN, 1967). In order to define a method, the modeling of structural behavior with the Finite Element Analysis (FEA⁷), the limit analysis theorems⁸

⁸ The limit analysis combines the possibility to estimate with adequate precision the collapse mechanisms, stress distributions and load capacities.

and simulation (use of software as MidasGen, Sap 2000, or CYPECAD) have been performed. In all these cases, for different reasons, the result was acceptable but with a very long processing times. Since they are ancient structures with very heterogeneous materials, many simplifications of the remains have been made, elaborating a series of hypotheses within the working hypothesis⁹. These tests showed that the result is good: but the work required is very huge in comparison with other methods such as the graphical static, then that has been finally chosen.

As previously stated, a method that allows to realize virtual reconstructions of architectural organisms scientifically valid has been developed: a methodology that relies on knowledge of the architecture from not only a historically perspective but also constructive, with special attention to issues about traditional construction and implementation of static concepts.

Traditional architecture is based on fundamental principles whose knowledge is useful to elaborate virtual reconstructions. Besides the issues of static stability, it is clear that the dimensions of each element of a building have a direct relationship to each other. Performing a virtual reconstruction, it is important to prioritize the existing data and explore, through precise calculations, the stability relations between each of the parts in isolation and in the whole work.

Another advantage of the limit analysis is the small number of parameters needed to characterize materials, considering the difficulties for evaluation in the case of ancient structures.

⁹ To use computer calculation programs a series of data that are generally missing in case of ancient architectures are necessary: therefore a number of simplifications that reduce the accuracy of the result is needed. The same as to determine the traction resistance, or the shear stress of a masonry structure. For example, to determine the resistance of the mortar in a masonry wall, the values may vary between 5 and 150 kg/cm². Lacking data, it is necessary to make assumptions.

The methodology is divided into three phases:

- I. Documentation and data collection.
- II. Elaboration of the topographic virtual model at urban scale.
- III. Elaboration of detailed photo-realistic models of the monument.

In the III phase, solutions for every detail of the architecture in an iterative work process are defined. In this last phase the methods to study the stability of the construction elements such as walls (isolated or as arch support), arches (symmetric and asymmetric load) and vaults, are performed. By studying the stability of the wall it is possible to check the stability of the buttresses, while the study of the arch is used to determine the line of thrust and check its stability (figure 3).

The virtual reconstructions performed by the proposed methodology can be validated through a series of parameters that clearly show the criteria used to realize them and the their correction from an architectural point of view. This method generates a series of data and calculations that are archived in a complete table/ file for each virtual reconstruction, including the dimensional values of the elements, their characteristics and materials, the criteria and the calculation method used in each case.

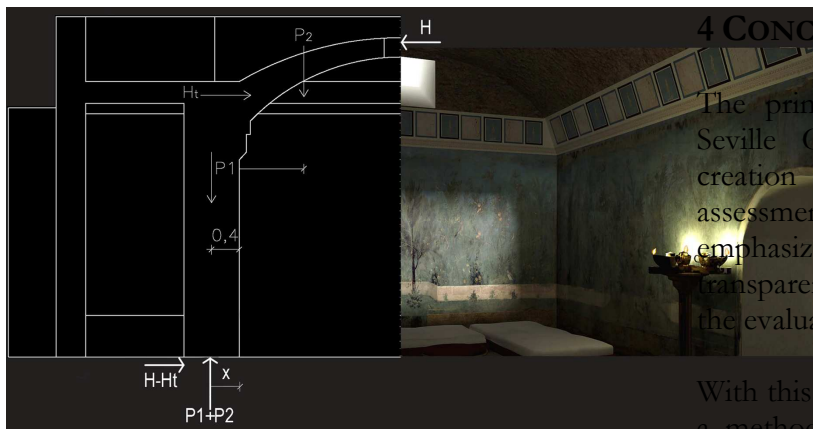


Figure 3. Study of a roman vault.

Therefore a table with all the parameters of the structures has been elaborated in order to construct the virtual models: through these elements it is possible to control for instance the constructive scheme of the covers, dimensions, slopes, water drainage systems, the presence of eaves, thickness of walls, pillars and architraves dimensions, type of coating, flooring, holes and woodworks.

This method was tested for the Roman architecture, with a clear decoding in particular for the Imperial period (WILSON JONES, 2000). However, this method can be extrapolated and, with some exceptions and adapting a number of elements and taking into account the existing ones, it might be valid in other cases of traditional historic buildings. In fact, for the static and constructive functioning and the transparency that the method provides, most of the elements are common to all the historic architecture.

Both in the London Charter (principle 4) and in the Seville Charter (principle 7), are highlighted the importance of the scientific transparency. The methodology here presented it follows these principles and in the context of data transparency, the models will be classified into levels, depending on the reliability of the reconstructions (certain, probable and hypothetical). The models produced by this method are accessible, queried and can be easily updated.

4 CONCLUSIONS AND FURTHER WORKS

The principles set out by the London and Seville Charter defined the rules for the creation of virtual reconstructions and their assessment: with this paper the authors emphasize the need of a deepening for transparency and reliability rules introducing the evaluation of the static methodology.

With this procedure the authors worked to find a methodology based on scientific disciplines (building science and mathematical calculation) in order to create virtual reconstructions that

are scientifically valid, open, transparent, up-datable. The utility is to have a method that is based on measurable elements and rules, making possible the test of one of the most important things of a building (and of its virtual reconstruction): its reliability and thus its stability.

We started to use this methodology in Roman architecture case-studies, but we can assert that can be applied to other ancient and historic architectures made of similar materials (wood, stones, mortar and their associations), taking into account the necessity, for complex architectures, to dissect the structures in more simple geometries.

Our procedure can be used to pre-emptively generate diverse and multiple architectural test models that as a whole reflect the range of more precise interpretations of a building and thus shows the most probable solution provided with the interpretative paradata.

As previously said, one of the tests it was the use of simulation software applied to historic buildings. Although the software used are good tools to analyze structures from the more complex to the simple ones, the difficulty is in the simulation of ancient and dis-homogeneous materials that often present different and various super-impositions and techniques, complicating the computation and duplicating the hypotheses¹⁰.

For this reason, currently our static evaluations have been carried out with the elaboration of some tables to calculate the results on the base of the rules and characteristics (static and stability rules, kind of materials, measures, etc.) inserted. As a further step we plan to develop an application able to support the work of the

archaeologist on the base of simple interactive parametric interfaces. The insertion of the available data, the static rules, the materials, the measurements of the remains, will be elaborated in order to give the preliminary information to be used in the virtual reconstruction. This will help to evaluate the real, or the most probable dynamic of the elements together with modal analysis results, and to have a more sure vision of the ancient architecture since it will be based on firm rules. The work carried out by the first author's doctoral thesis is a first step in this activity, with the aim to provide the scientific community with a complete and updated census about virtual reconstructions. As to future development of the work of gathering virtual reconstructions, this could be also the starting point to respond to the Art 8.4 stated in the Seville Charter: the necessity to create a large globally-accessible databases able to provide information about projects (with a specific focus on the transparency principles).

¹⁰ Other software for the simulation and literature cases have been taken into consideration, but they work better on the objects simulation, making difficult the application to complex architectures. Moitinho de Almeida, V., Barceló, J. A., Reverse Engineering Archaeological Artefacts, in On line proceedings of the CAA2012, 26-30 March, Southampton.



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