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Methodologies and Techniques for the Reconstruction of Ancient Architectures

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This document is the result of a study, which began five years ago, about the relationship between archaeology and architecture, past and present, science of constructing and reconstructive evaluations. Thanks to the opportunity given by a funded project, the work has been carried on as a challenge in the comprehension and reconstruction of the ancient architecture, and the methodologies and techniques useful to this scope.
Moreover, this paper examines how virtual reconstruction models are a spatial observation system for hypothetical environments; it also raises many questions about what kind of perceptual information they can offer, opening a new approach in the analysis of the architecture.

Keywords: virtual reconstruction, roman architecture, virtual reality

1. Introduction

The paper here presented is the result of a multidisciplinary collaboration, created as part of the research project of the "Virtual Museum of the Ancient Via Flaminia", about the 3D reconstruction of the archaeological landscape, developed for the realization of a doctoral thesis.

The research project, carried out at the Virtual Heritage Lab of the Institute of Technologies Applied to Cultural Heritage (National Research Council-CNR of Rome, Italy) was aimed to the virtual reconstruction of the ancient road and its archaeological landscape, contextualized in the current territory. Furthermore, the final integrated result has been the creation of a permanent permanently Multiuser Virtual Reality application, exhibited in the Roman National Museum of Rome.

In general, the study area has involved different levels of detail. The first one represents a wider vision of the road from Rome to Rimini, based on historical maps, information on the archaeological excavation, technical cartography, and aerial and satellite photos (also for the realization of a Web-Gis). The second one, reproduces a micro-space vision, focusing the attention on some sites, with the aim to represent and contextualize the local entities within the "ancient landscape" entity .

In particular, one of the areas of monographic interest is the Villa of Livia.

2. The study case: the Villa of Livia

The great archaeological complex of the Villa of Livia at Prima Porta is situated at the IX mile of the Flaminia, and is traditionally identified with the imperial villa of Livia Drusilla, wife of Ottaviano Augusto. The villa was built between 30 and 25 b.C., on a previous structure of the Republic age and it was occupied at least until Severan age (VASSALLO *et al.*, 2006).

Its historical and archaeological relevance in a diachronic sense (both for its use over the centuries in an almost continuous way both for the study interest by scholars from different disciplines) and the current presence and visibility of most of the archaeological structures *in situ,* allowed to choose the Villa of Livia as a bed-test in order to realize a complete methodological and empirical study (AA.VV., 2007).

Thanks to the use of integrated technologies of acquisition and visualization during all the phases of the work, it has been possible to propose interpretative reconstructions of the architecture (and the landscape in all its entirety) (Figure 1).

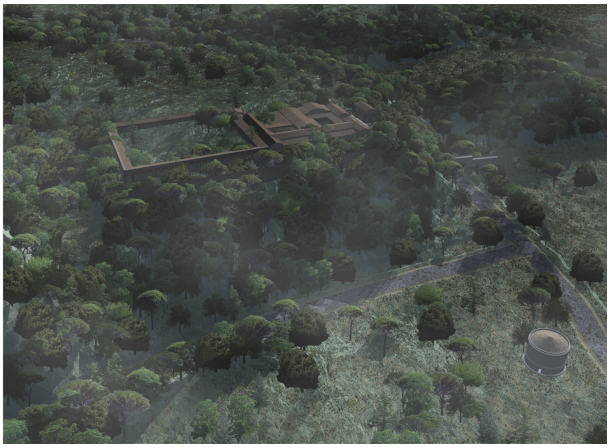

Figure 1: *Top view of the Villa of Livia in the ancient landscape (virtual reconstruction).*

In fact, the virtual restoration and the interactive simulation allows to test different hypothesis, to avoid invasive investigations on the field, and to make it possible to modify or update in every moment according with new information.

Our paper wants, in particular, to focus on a specific part of the research work: the methodological and experiential reconstruction of the Villa of Livia thermal baths.

2.1. Methods and Techniques

The methodology was developed for a doctoral thesis (Vico L.) and is organized in 3 steps: 1. Documentation and data collection. 2. Development of the virtual model on a urban scale. 3. Production of a detailed photo-realistic models of the monument. In the 3rd phase, we propose solutions to every detail that defines the architectural building in an iterative way. In this last phase are also embedded the techniques to study the stability of the construction elements such as walls (isolated or as carriers of arcs), arcs (symmetric and asymmetric load) and vaults. By analyzing the stability of the wall, the method allow to check the stability

2.2. The thermal baths

The thermal complex of the Villa is quite common and very similar to the standards of the time, except for the plan, because of the insertion in the preexisting building. In this baths it has been possible to recognize at least two phases: the first one dated between the Claudius-Nero and Domitian age; the second one in the Severan age (Figure 2).

Because of a series of communication and archaeological considerations, it has been chosen to include, as a reconstructed island within the virtual system, this last chronological plan.

2.3. The thermal baths reconstruction

The review for the reconstruction covered various types of documents related to the baths: literature, drawings, studies, and direct observation of current urbanism (MESSINEO, 1991). During this preparation, the baths were also completely plotted using digital technology.

The analysis was completed with information providing architectonic and historical context, looking especially at baths in other cities and contemporary buildings. Indeed, thanks to the standardization of this part of the building, it has been useful for the reconstructive hypothesis not only the suggestions coming from Vitruvio, but also the comparison with other coeval systems.

Moreover, the use and support of the computer graphic, thanks to the presence of well conserved walls of the second phase (then easily acquired and measured), allowed us to analyze and make structural calculations for the test of the stability of the vaults.

Data gathering about the current status of the various elements of the architecture requires to draw on a broad spectrum of instruments and techniques. Each technique should indeed be adapted to the morphology and scale of the surveyed entity. The instruments used to acquire data are: laser scanners, photogrammetry, computer vision, Total Station, and differential GPS.

Using an advanced technology such as the laser scanner, for the case of the Villa of Livia, we obtained three-dimensional sets of points. The level of resolution is 6 mm, or about 30,000 points by square meter. A total of 7,000 square meters were surveyed. The points were then triangulated (using Rapidform) and a first decimated model produced.

The information was compiled and consolidated in order to produce a chronology (as complete as possible) of the interventions made on the baths starting from their con-

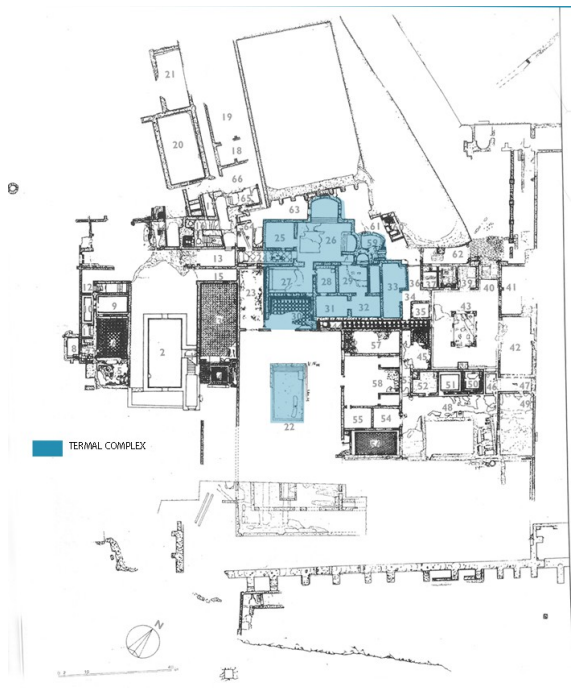

Figure 2: *Top view of the Villa of Livia with thermal baths, blue highlights (current state). SAR.*

struction, as well as a set of references for the building elements (e.g. vaults, arcs, doors) useful to underpin the hypothesis formulation.

2.4. The support of computer simulation

Computer simulation, in the field of cultural heritage documentation, facilitates the public access to the architectural and archaeological heritage that is slowly dissapering or is simply transformed.

Dealing with such delicate issues, like the reconstructive hypothesis of architecture and spaces with computer graphics technique, both from scientifically and informative point of view, it appears that communication tools are indubitably visual. The image in this contexts is useful to explain something that not more exists, and its three-dimensional nature requires the use of a graphic language (BARCELÓ et al., 2000).

The realization of virtual reconstructions of ancient monuments using computer techniques, also allows to have a useful tool in order to check working assumptions through the simulations.

The scientific correctness implies the possibility to repeat an experiment and the virtual reconstruction can be separated into a series of explicit steps that can be repeated and tested at any time.

2.5. The application to the case study

The analysis of ancient architecture and the constructive elements has been essential in order to propose a correct reconstructive and interpretative hypothesis of the thermal complex of the Livia's Villa. The study of the historical context, the techniques of construction, and of the *instrumentum domesticum* provides a necessary overview for the correct interpretation of architecture.

The knowledge of the architectures begins with the survey; analytical, structural, functional, philological, historical interpretation, and so on.

Of course, the 3D laser scanner survey of the Villa is a very important database to understand the functioning of the building (Figure 3).

To achieve the reconstructive hypothesis of this construction, a detailed file for each environment has been realized, collecting data about structures, floors, functions, techniques, presence of hydraulic devices, remains, and technical and stylistic parallels.

Simultaneously, the research has been done through the philological study of coeval architectural cases, through comparative analysis of construction types, and architectural and decorative plans.

Often archaeologists do not consider the study of materials from a mechanical point of view: instead this aspect is essential to determine a number of characteristics that are conditioned by the mechanical properties of materials, as the height of the walls, roof systems, etc. The study of geometry and materials, typological parallels, and static calculations is crucial for understanding the

Figure 3: *Top view of the Villa of Livia thermal baths (current state with laser scanner reconstruction).*

building (VICO *et al.,* 2006).

We have developed a methodology that includes simple structural calculations for the architectural elements present in the virtual reconstruction, where the determination of visible and invisible elements derives from real problems (weights, proportions, choice of appropriate materials, etc.) leading to a solid structure that works from a static and formal point of view.

The ancient builders and architects had utilized the geometry and the proportions in order to establish a set of construction rules. The emphasis on geometry in the ancient treaties of construction, Vitruvius in particular, is essentially correct (WILSON JONES, 2003). The safety of a masonry structure depends on its geometric shape regardless of its size and in this sense, the rules that emphasize geometric aspects are correct and reflect the comprehension of the essential parameters of the project.

For the correct interpretation of the architecture of the Villa of Livia, it has been necessary to know and understand the Roman building technique and the modern theory of masonry structures.

Roman architecture is essentially based on traditional brickwalls and *opus caementicium*, in which is expressed the balance of shapes and masses. The modern theory allows us to analyse and quantify (GIULIANI, 1997) what our predecessors catalogued as shapes. A modern analysis of a masonry structure leads to geometric statements.

2.6. The validity of traditional proportional rules in architecture

One of the fundamental supports for the virtual reconstruction of this thermal complex is the study of historical constructions and buildings.

We can often find virtual reconstructions of architecture

made without architectural or constructive criteria. However roman architecture is very codified, and virtual reconstructions of roman architecture can be made according to architectural and constructive criteria.

Roman architecture follow proportional criteria, resulting in structural design. We can't find structural written formulae used for the construction of architecture, but we can observe proportional rules.

A great majority of these formulae are "proportional" and they produce "similar" forms in a geometrical sense. They believe in the existence of a "law of similitude": a valid structural form continues to be correct independently of its size. However, Galileo demonstrated the impossibility of the existence of this kind of principle: in structures supporting the main load as well as their own weight, as for example animals and masonry buildings, the dead load rises as the cube of the linear dimensions while the section of the structural members rises as the square; the tensions rise, therefore, linearly with the size. Figure 4 shows Galileo's illustration of the effect of hanges of size on the bone of an animal. Galileo's argument has achieved the rank of law, the "square-cube law", in structural design. In roman constructions we can't resolve the problem of intercolunnio or architrave dimensions, by increasing it.

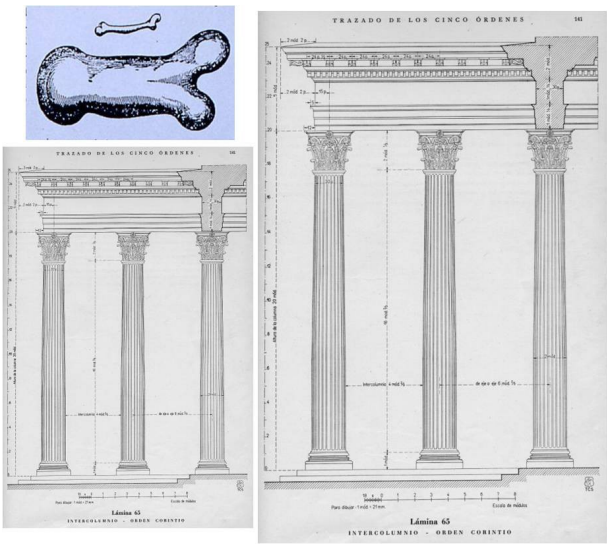

Figure 4: *Galileo's illustration of the effect of changes of size on the bone of an animal and for intercolumniation (GALILEO, 1638).*

A study of roman architecture reveals a persistent presence of "proportional rules", rules that produce structures geometrically similar.

The stability of masonry structures subject to its own weight imposes certain overall dimensions, which can be translated in some geometrical form. This leads to certain "'valid forms" for buildings, masonry arches, vaults, and domes. The traditional geometrical rules provided a means to "fix" this safe proportion of masonry structures and are, consequently a rational and valid form for the structural design of masonry structures, within the normal range of dimensions. These considerations have received little attention by civil engineering historians.

The possibility of using geometrical rules, relying on models, and the use of previous buildings as "full-scale" models, has undoubtedly played an important function. It lets us explain the success of structures such as the Pantheon, almost doubling in size any structure ever constructed before.

For the thermal area reconstruction we have to validate the constructive hypothesis through *statica grafica*.

2.7. In the mind of the ancient

This way, virtual reconstruction appears as a useful support for the interpretation and the study of the ancient architectures, even more in the case we have no references or well conserved ruins. Moreover, it is becoming increasingly important for preservation, educational and research purposes. In fact, these techniques are now used by scholars, cultural institutions, but also media, for example, to visualize the appearance of the sites (HAPPA *et al.,* 2009).

Figure 5: *Particular of the reconstructed thermal baths of the Villa with insertion of the illumination studies.*

This means that we do not search only the aseptic reconstruction of the environments and of the landscape, but also a way to contextualize them and discover what has led to some choices.

So, not only the technical requirements related to the technical stability of buildings, but also those related to the light exposure, heating and habitability of the structures should be taken into account and through the use of computer graphics, provide suggestions to the virtual reconstruction.

During the reconstruction process, the choice of the openings (doors, windows, *impluvium*, etc.) beyond providing guidance on the shape of an environment, will help to understand the type of lighting selected during the construction phase and for what purpose (to heat an

environment? Receive more light during the day? Local climatic conditions? Bring out a wall decoration?). The type of lighting used within the environments appears very important in order to interpret them, determining both the intended use and the purpose.

In the case of the reconstruction of the baths of the Villa of Livia, the study was also conducted on the basis of other criteria, thus simulating not only the structure itself, but also the techniques of operation. This, in fact, is another aspect that helped us to interpret the environments of the Villa's thermal baths. The known remains belong, for the most, to two phases, to the age of Nero-Claudius/ Domitianus and to the Severian age. In particular, the best conservation of the last phase has allowed to test, on the base of the technical characteristics, the functioning of the systems and to explain the disposition of the rooms, the materials and the look of the structures.

For this aim, a study of the functioning of the tubes, of their relation with the heating, water system and airing installations, has been set up.

The reconstruction of these technical characteristics, the comparisons with other coeval conserved cases and the physics study about the behaviour of the fluids subjected to heat , has provided the information useful for the understanding of the structures (Figure 6).

Figure 6: *Study of the physical behaviours in the comprehension of the thermal structures.*

Moreover, other than being of support to the elaboration of the reconstruction, this study has been very useful in order to facilitate the communication of the technical features to the general public in the learning (Figure 7).

Conclusions

This research has made possible the creation of a visual analyzer able to collect and to connect different sources of documentation within the same environment (databases, geometries, textual documents, analyses, etc.). The geometrical and topographical reconstruction of the monument is made according to advanced and integrated systems of digital acquisition. The micro-topology of the structures gives a deep spatial knowledge of the architectonic context.

Through the 3D reconstruction of the architectural heritage and its real time display, it has been possible to obtain an accurate and communicative interpretation that suits for research purposes, and to transmit the importance of conservation to the general public. This is perceived as an effective way to divulgate and publicise an information that is often accessed only by the scientific community.

The product has been elaborated always taking in consideration the aspect of the transparence: this approach in fact gives the possibility both for the viewer and for the operator to see the methodology and the sources used and modify all the steps in case of new information.

This way, all hypothesis and solutions adopted are accessible, guaranteeing a protocol for the repetition and the modification of the reconstructive process.

This experience will permit to study future possible ways and development patterns that will be necessary and useful for both architectural heritage enjoyment and research .

Figure 7: *3D reconstruction of the apodyterium.*

An immersive experience in a reconstructed architecture involves new ways of analyzing and studying architecture through three-dimensional representation, from the construction of the 3D model, to the continuous observation of its characteristics in an active and interactive dialogue process between represented space and their qualities.

Furthermore, we think that this research study will also be useful for other purposes. In fact, the database concerning all the information about architecture, decorations, iconography and so on, can be the starting point from which it could be possible to test different subjects: the illumination, the acoustic, hydraulic, heating, etc.

Furthermore, this study has allowed us to reach the awareness of the need of further developments related to the creation of architectural reconstructions. Specific-

ally, we are working to develop a system capable of managing, through the standardization and the insertion of variables, a collection of reconstructed elements and used materials, in order to elaborate dynamic digital libraries.

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