ROME REBORN – VIRTUALIZING THE ANCIENT IMPERIAL ROME

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ABSTRACT

From 1997 to 2007 an international effort involving research groups both in US and Italy, developed a virtual model of ancient Rome, as it appeared in 320 AD. The primary purpose of the project was to visually present theories and hypotheses about how the capital of the Roman Empire appeared at the peak of its development. The model is therefore a representation of the state of our knowledge (or lack of it) about the urban topography of ancient Rome.
In order to create the model several topographic and historical sources were used. The standard sources such as ancient plans, references in historical texts, archaeological studies of past scholars, have been used for the well documented monumental buildings, such as the Colosseum and the Roman Forum. For most of the vernacular architecture (i.e. the small "filler" buildings in between the monumental ones), no many sources are available. Thus the virtual model have been inspired by the famous 1:250 physical model "Plastico di Roma Antica" conserved at "Museo della Civiltà Romana", in Rome that have been surveyed at high resolution and transformed in a digital model suitable for standard virtual reality applications. This paper overstress this point of the whole project, describing the process from the physical to the digital representation of the city.

1. INTRODUCTION

Three-dimensional digital modeling of Cultural Heritage has found various applications as tools for both the conservation and the study of ancient artifacts, buildings or archaeological settlements.

When the model relates to a currently existing city, the data from which it is possible to build the model are often acquirable on the field or are available thanks to existing photogrammetric or topographic surveys, if recent enough to include the structures to be modeled.

When, on the other hand, the model to be created represents a city in an historical phase different from the current one, the possible sources of data are more varied.

Though the standard source is always the traditional paper forms of documentation, some cases may exist where useful data are "trapped" in a physical model. For example, this is the case for some places in Europe whose past appearance is described in great detail only in the French plan en relief built from the XVII to the XIX century and currently kept at the Hotel National des Invalides, in Paris [Buisseret, 1998; Fortier and Prost, 1987].

The study described in this paper dealt with a similar case, where the city to be represented is Rome in the Constantine period (4th century AD), and the plaster-of-Paris model is the famous "Plastico" created by Italo Gismondi from 1936 to 1974 and preserved in the Museum of Roman Civilization in Rome. Although the physical model is not contemporaneous with the period it describes, some archaeologists believe it contains some valid intuitions and deductions that are not far removed from the way Rome actually appeared in the period modeled. The scope of this project was therefore to extract from the physical model those data useful for reconstructing a digital model of ancient Rome, while editing out the reconstruction hypotheses that were considered unreliable or implausible.

2. CAD MODEL VS. ACQUIRED MESH

The scope of a 3D digital model may be manifold and differs considerably depending on the kind of entity that we hope to obtain from the original object. We can make a basic distinction between two different categories of 3D digital models.

On the one hand we have those models obtained as the outcome of a manual process, where the operator draws by hand, with the aid of specific software packages, elementary solid elements to be composed, or more articulated curves from which complex parametric surfaces are generated. This is what is commonly called a CAD (Computer Aided Design). Independently of the specific construction modalities employed (Volume or Surface based), this kind of model is always the expression of an operation that defines its dimensions, shape and position in the 3D space. The original object that the digital model tries to imitate can be surveyed rigorously with theodolites or photogrammetric systems. Alternatively, it can be represented in approximate way, as happens, for example, when the model maker takes into account the proportions of the formal elements though simple photography but treats the details with great interpretative freedom. This freedom may be tempered by his previous knowledge of the specific artifact, such as, for example, in the case of an ancient Greek or Roman building the Classical Orders. In other cases, various other philological or interpretative elements can supply the gaps that still exist after survey. A model like this is strongly influenced by the perception and by the educational background of the model maker, and without doubt it does not represent a "photographic" representation of the reality but rather a synthesis based on a specific line of reasoning. In principle, it is neither good nor bad: depending on the use to which the model is put, this approach to model-making turns out to be virtuous or defective.

On the other hand we have a second category of digital models, nowadays more and more used, obtained through an automatic

laser scanning process or automatic stereo matching, providing high resolution forms of survey. As well known in 3D community if we want to describe the geometry of a complex artifact through range images given by a 3D device several images from different points of view are needed, until the whole surface of the object is fully covered. Then we digitally assemble the subject's shape by properly aligning and merging all the partial views [Bernardini and Rushmeyer, 2002]. The final result is an extremely dense set of points, connected to each other by planar facets. This entity, the so-called "mesh," represents a digital model of the initial physical object. Such a model is characterized by a strong correspondence to the real object because, in comparison with the first category of models, the survey component strongly prevails over the model maker's interpretation. To be sure, interpretation may still occur in the final mesh editing phase when unavoidable gaps and possible topological errors are corrected.

The two model typologies offer different advantages and disadvantages, depending on the required application. By way of example, let us imagine a study of the erosion speed of some decorative elements exposed to air pollution. In this case it is rather obvious that only the faithful recording of the real surface, attainable with a range camera, could provide an accuracy level high enough to allow a sub-millimeter magnitude comparison between the model taken at a certain time and the model of the same artifact after a known time of exposure to the erosive agent (e.g., one year).

If, contrariwise, we intend to make the digital representation of a monumental building, approximating the ideal shape that the designer intended to express, a more interpretative approach will allow us to remove all the spurious elements generated by the natural decay of the object, as for example the subsidence of the structure, disappearance of decorations by natural or human causes, wall cracks, etc., that could be properly "filtered" by CAD modeling.

The two methodologies can be fully employed in the cultural heritage field, but they should not be necessarily addressed as antithetical approaches. In some cases the two methods can be integrated, as happens when an acquired model is used as a reference for the re-design of a CAD model.

The different methods for passing from the former to the latter are currently object of research, and are articulated in a variety of different approaches depending on the nature of the object: its formal complexity, the metric accuracy require by the object representation, and the kind of mathematical form adopted to describe each surface (B-Spline, NURBS, Subdivision Surfaces).

One of the key points influencing both the quality of the reconstructed model and the number of man-hours required to produce it, is however the "a priori" knowledge of the object by the modeler. Let us suppose, for example, that we have acquired the digital model of a brick whose shape is a parallelepiped. The laser scanning and the resulting modeling process give us a mesh that represents a kind of digital mold of that object. Knowing in advance its geometrical characteristics, we know that both that specific brick and the "ideal" brick of which the exemplar in our hand represents only a particular instance has to be a parallelepiped. If for some reason it would not be shaped like that, this would be the result either of a fabrication error (anomaly in the original) or of a lack of precision in the acquisition process (anomaly in the survey). The CAD model production from the mesh represents in many cases the path of an archetype re-generation starting from a specific exemplar. Therefore, in the generation of the mathematical model from the measured data, it is appropriate to take into consideration such preliminary knowledge and to

define the shape synthesizing the starting data set (the mesh) with simple mathematical surfaces as, for example, the planes identifying the parallelepipedon faces. The specific modalities for detecting such planes can be various: we can try to identify the set of planes representing the best-fit of the starting data, or to single out the solid shape characteristic data starting from proper sections of the mesh. The final result will be in any case a synthesis: the amount of data required to represent the mathematic parallelepiped is very little (e.g., three plane equations and the size in the three orthogonal directions), while the original mesh is constituted by a dense sampling of the analyzed surface, and the involved number of data may be larger by some order of magnitude.
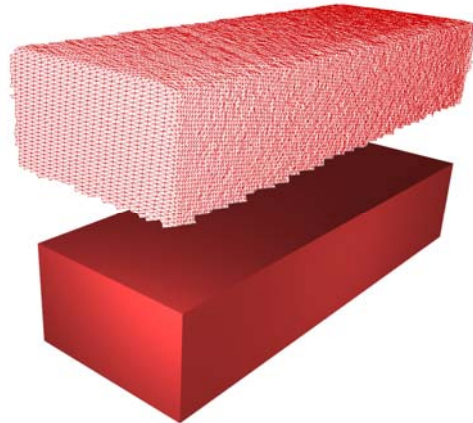

Figure 1. Acquired mesh vs. CAD model of a brick.

This size difference strongly influences the model's applicability. The one generated through 3D scanning will be easily explored with 3D software oriented to geometric inspection or to off-line rendering. If, on the other hand, the ultimate scope of the model is its visualization, possibly through stereoscopic virtual reality systems, the model evaluation criteria are different. In that case the most important activity is real-time rendering. In that case a graphic engine has to generate a frame sequence representing the model during its exploration, with a frame rate compatible with the perceptive properties of the human eye (20/30 frames per second). As the time required to generate a single frame – given a certain virtual environment – is directly proportional to the number of polygons of the model, the possibility of reducing to the minimal number of model polygons – typical of CAD models – becomes a fundamental prerequisite. The made for generating the "filler architecture" of Rome Reborn, was exactly based on this approach: transforming a huge mesh model acquired scanning the famous "Plastico" of Rome by Gismondi, in a CAD model, similar but not identical to the original one, capable of being easily updated, and suitable for efficient real-time rendering.

3. "A PRIORI" KNOWLEDGE ABOUT THE PHYSICAL MODEL

The knowledge about an artifact may be different as compared to the simple one described above. The plaster-of-Paris model which we have studied is a large and complex object that represents at a 1:250 scale the shape of ancient Rome, as it may have appeared in the period of the emperor Constantine (ca. 320 A.D.). Our knowledge about ancient Rome is obviously very extensive, but what we know about this specific plaster-of-Paris model is quite limited, since the author did not leave a written report or even notes, leaving aside a few random sketches of

domus and insulae [Pisani Sartorio, 1993]. The line of reasoning made for the CAD reconstruction of the "Plastico" is based on an aspect of its structure that can be divined by just looking at a detailed image of it: the model is basically made with two categories of buildings. On one hand, there are the monumental buildings that scholars of the ancient city have repeatedly represented, studied and documented, about which much relevant archaeological information is available.

On the other hand, the urban fabric, or "filler architecture," mainly consists of vernacular buildings. In reconstructing these Italo Gismondi exploited all his archaeological experiences gathered on the site of Ostia starting from 1910, when he helped make reconstruction hypotheses about the same kind of buildings – the insulae – that in Ostia are quite numerous and very well preserved. Although a substantial amount of fantasy was used for visualizing these structures, a solid point was constituted by the amount of debris discovered at the foundations of each ruin, which allowed scholars to establish at least a good estimation of the volume of each building. Gismondi with his plaster-of-Paris model left therefore an interesting hypothesis about the city's structure and appearance. The reconstruction project we undertook is related only to the part of Gismondi's physical model that represents the urban fabric, which provides a plausible background for the monumental buildings reconstructed within other research projects of the basis of more precise archaeological data [Frischer et al., 2003].

Due to the scarceness of elements at our disposal, we hypothesized that the authors would have defined a limited number of minor buildings archetypes, as hortus, domus and insulae, with 4 or 5 variations each, employed with small variations of shape and size, all over the area covered by the model.

4. MESH ANALYSIS AND REMODELING

The first step for the realization of this path was the three-dimensional digital acquisition of the artifact, up to the generation of a detailed mesh of its whole surface. Such operation presented noticeable technical difficulties due to the very wide extension of the model (16 x 17.5 m), presenting, at the same time, very small details (houses 2 cm tall). Since scanning systems are generally suited for a specific range of volumes, in this case it was necessary to resort to non-standard equipment such as a FM CW Laser Radar [Guidi et al., 2006], integrated with other survey methods [Guidi et al., 2003]. The 3D acquisition result is an enormous mesh made by 260 million polygons. Even if new methods for visualizing huge meshes are now available [Borgeat, 2005], we chose to re-model the entire structure in order to allow the modifiability of the constructive hypotheses, and the updating of the model based on the last archaeological discoveries. Once the acquired mesh was completed, it has been exploited in a novel way with respect to customary usage. The mesh has been in fact used for studying the structure of this complex physical model, searching for the existence of recurrent elements and, once identified, analyzing their number and positions. Having a "digital mold" of the real "Plastico", constituted by the polygonal model, permitted us to undertake an indirect analysis of the physical model using its digital replica as a "mediator." The capability to produce any kind of representation (plans, sections and facades), or to put the point of view at a distance not reachable in the museum, allowed us to use the digital model as a source of information which was not available by traditional means.

Figure 2. Acquired mesh model of the "Plastico di Roma Costantiniana".

This allowed to verify the initial hypothesis, namely that the urban fabric had been modeled by using a limited series of archetypes. The studied elements were the covering shapes, the angles between roof pitches, the shape of building plans, the position and shape of windows, and the articulation of colonnades. In this way around twenty base structures have been identified, and by means of them it has been possible to obtain a digital approximation of most of Gismondi's "Plastico."

Once the study of recurring shapes was completed, the systematic construction of a new digital model was started, constituting a regeneration of Gismondi's version. The new model is made up of a mixture of some acquired parts representing all the non-built parts, such as the Digital Terrain Model (DTM), or the shape of rocks and embankments. On this are inserted the vernacular buildings, created as a combination of the identified archetypes, as well as the monumental buildings, modeled by the research group at UCLA and the University of Virginia, with which we collaborated on this project.

The approach for creating architectural archetypes followed two different approaches. The first one was based on analyzing the mesh for generating a set of geometrical parameters (roofs shape size and inclinations, repetitions of horizontal and vertical sections, archetypes recurrent grouping, etc) that led to a library of elementary buildings made with the Maya software package by Autodesk Inc., that were then re-used and located on the acquired mesh, in place of the corresponding original scanned elements.

Figure 3. Acquired 3D model of a temple and corresponding instance of a digital archetype.

A second approach was suggested by the recent studies on procedural modeling [Mueller et al., 2006], where models of buildings are created according to a vocabulary of shapes and

Figure 4. Snapshot of the Rome Reborn model from a real-time rendering engine.

rules for linking them together (shape grammar), that can be embedded into the digital model. The digital archetype of a building allows therefore to create instances of several different actual models, characterized by a common set of rules.

This approach was chosen for a limited set of elements where such approach seemed more fruitful, such as city walls, temples, aqueducts and bridges on the river Tevere. The actual software package for generating the digital archetypes was Houdini (Side Effects Software Inc.).

5. CONCLUSIONS AND FUTURE PERSPECTIVES

Many applications could be made of this model, including a series of tests designed to check the accuracy of this physical model in comparison with the most reliable archaeological results. For example, once the digital model has been completed, it will be a relatively easy task to count the actual number of houses in the Gismondi model and compare it with the count given to us in two fourth-century A.D. catalogues of the building stock of ancient Rome.

This potential, in addition to the more obvious and communicative purposes, make Rome Reborn a possible source of information not directly readable from the original sources, revealing possible "hidden information" contained in the geometry of the Plastico.

Its practical use can be twofold. On the one hand it can be used by scholars as a digital platform for discussing archaeological theories and possibly proposing amendments and new ideas in a cooperative fashion. On the other hand it can be used to teach students or general public how the city looked, in order to recognize the relationships between the ruins currently available and what were the original architectural structures.

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