Computer Graphics and Urban Archaeology
Bracara Augusta's case study

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Abstract

Computer Graphics is undoubtedly an important tool, widely used for representing and manipulating enormous amounts of highly complex information.

Usually, the archaeological information is highly complex, so its representation using computer graphics technology is a true and engaging challenge.

Virtual reconstructions representing archaeological sites, as for example the roman town Bracara Augusta, should be considered a fundamental tool for research improvement carried out by experts. It is also extremely important for the uprising consciousness of cultural heritage.

Keywords

Virtual Reconstruction; Multimedia; Visualisation; Urban Archaeology; Virtual Archaeology

1. INTRODUCTION

Archaeology produces and manipulates an immense amount of highly complex information [Barcelo98]. Therefore, the representation of this information, using 3D data acquisition techniques and 3D reconstruction methods, is an exceptionally demanding challenge. Computer graphics certainly is a response to this challenge because it has been progressively used, over the last years, to represent archaeological data. This virtual representation has not always been developed to serve archaeological purposes, in spite of its unquestionable importance for archaeology. Generally, computer graphics experts use these virtual models to test and validate different modelling, visualisation and walk-through algorithms.

As a matter of fact, many computer graphics applications related with the reconstruction of archaeological sites or remains produce extremely realistic reconstructed objects. These virtual reconstructions are often exaggeratingly realistic considering, in some cases, the poor documentation and incomplete data that are used for reconstruction purposes. This fact shows that, in the past, the archaeological discourse has not been (and in some cases it still are not) understood by computer graphics experts.

The adoption of new technologies in archaeology, specially in urban archaeology, for research, management and presentation of the past is a natural feature that has resulted from the necessity of managing a large amount of data and also from the quick evolution of the new technologies, increasingly adaptable to the processing and generation of archaeological information [Martins00b].

The development of virtual reconstruction representing archaeological sites, such as the roman town *Bracara Augusta* (in our days the city is called Braga and it is located in the north-west of Portugal), should be considered an important and powerful tool for the research improvement carried out by experts (archaeologists, architects and urban planners) and for the uprising consciousness of cultural heritage.

1.1 Motivation

The existing archaeological remains about some structures might be some extremely damaged wall fragments, foundations, pillars or columns. A building or an infrastructure might have been altered or rebuild several times, which implies significant exchanges both in appearance and functionality. Therefore, the archaeologists need a tool that is capable of representing alternative archaeological site interpretations, as well as the modifications, which ocurred over the years.

The excavations carried out in Braga for the last 27 years produced an immense amount of information, which is only understood by experts. These specialists produce a particularly proper discourse, which is not always correctly or easily valued by the general public, due to its specificity. Nevertheless, it is necessary to simplify the archaeological discourse to touch the population regarding the problems and difficulties urban archaeology faces, particularly in Braga, and to democratise the knowledge.

So, this work will not optimise or develop new technologies in computer graphics, but rather to understand the archaeological discourse and translate this discourse into the computer graphics language. This is the only way to assure rigour and quality in the dissemination of archaeological results, using computer graphics: the virtual models will not produce only pretty pictures, but they will be used as a tool in the archaeological research.

1.2 Objectives

The main objective of this work is the virtual representation of the town *Bracara Augusta* and its evolution over five centuries. The virtual visitor will be able to walk trough the virtual world that represents *Bracara Augusta*, regardless his expertise. Furthermore, it is also possible to show a sequential evolution of the city, enabling a chronological reading of the city.

The same model will also serve the architectonic restitution validation, which results from the interpretation of archaeological data. The advantages of these virtual reconstructions are not only the share of knowledge. Often, the tri-dimensional model creation process leads to additional discoveries.

So, on the one hand virtual reconstruction should serve as a research tool for experts that have to deal with archaeological data. On the other hand it has to accomplish dissemination functions of the same archaeological data, which has been already analysed and treated, to a wider public.

2. THE BRACARA AUGUSTA PROJECT

Until the sixties the relation between the Portuguese historical cities and archaeology was similar to what append in other European countries [Martins00a]. During the fifties and the sixties roman remains appeared on a regular basis all over the country. The reason for this was the renovation of some urban equipment, such as the phone, water and drainage networks, that began at those days. During the implantation of this equipment, some ditches were opened and various remains were discovered.

At the same time and because of the emigration money, the entire country suffered a wild urban expansion in places where ancient roman cities were buried. The uncontrolled urban growth of Braga during the seventies began to destroy the existing structures and ruins of *Bracara Augusta*, fundamental to enhance the knowledge about the city's past [Martins92].

To prevent this, the Portuguese government decided to create in 1976 the Urban Archaeology rescue project of *Bracara Augusta* [Martins98]. The scientific responsibility of this project belongs to the Archaeological Unit of the University of Minho in collaboration with the Museum of Archaeology *D. Diogo de Sousa* and the Archaeological Department of the Town Hall.

Since the very beginning, this project faced several adversities, and passed through different phases responsible for different strategies and archaeological intervention rhythms in the city of Braga.

Initially, the objective of this project was the rescue of the roman city's archaeological area and involved a set of legislative initiatives and an immense archaeological rescue and emergency work. Geophysical prospecting to limit, with some accuracy, the area of *Bracara Augusta*, followed this work. This rigorous definition of the old roman city's area was very important to define a legal protection area. In the eighties, the rescue project turned in to a research project that aimed the definition of the architecture and urbanism of *Bracara Augusta*. However, the project has now a day a research component but also a rescue component and this fact turns the project in to a pioneer and unique urban archaeology project in Portugal.

This project was also innovative in the area of computer assisted archaeology. In fact, since 1996 the research team responsible for the archaeological project has been computerised the data of numberless interventions realised in Braga [Martins98]. These data were integrated in the archaeological information system of *Bracara Augusta* (**S**istema de **I**nformação **A**rqueológico de *Bracara Augusta* – SIABRA), that is a GIS dedicated to the Bracara Augusta Project [Giestal98].

The next step of this project was to take advantage of the potentiality of virtual reconstruction and proceed with the tri-dimensional representation of *Bracara Augusta*. This kind of representation, based on the data stored in SIABRA, enables a better understanding of *Bracara Augusta*, since it is possible to visualise the reconstructions of some areas of this roman city.

3. COMPUTER GRAPHICS IN ARCHAEOLOGY

Computer graphics applications, particularly virtual environments and multimedia, are widely spread out in areas such as architecture, urban planning, medicine, scientific visualisation and education and training. However, virtual heritage has become a very important issue regarding conservation, preservation and interpretation of an immense worldwide historical legacy [Refsland00]. As a matter of fact virtual environments are a privileged form of disseminating cultural and scientific subjects. Culture and science are assimilated and understood more easily since the users are able to interact with a virtual world and manipulate data, producing different models of knowledge.

The first computer graphics applications in archaeology began in the seventies [Badler78] and become more common in the late eighties and early nineties.

However, when the application of new technologies to archaeology began, the results were not always satisfactory to the experts expectation and to the publics inquisitiveness [Addison00]. Basically, this was due to the fact that technology was still in an earlier stage and, also, the technology experts did not understand the archaeological discourse. These difficulties are, now a day, more softened because there has been an enormous evolution of technologies associated to virtual reconstruction and mul-

timedia and the research teams that work on archaeological site reconstruction projects are multidisciplinary.

One of the first works presented in this area in Portugal was de reconstruction of the Monastery of Santa Clara-a-Velha in Coimbra [Teixeira97]. As it might be noticed in [Brodlie87] and [Spicer87] the computer graphics interest in archaeology is lasting for a great while and this interest even becomes greater with the evolution of computer graphics [Berndt00].

3.1 The importance of CG in Archaeology

The archaeological reconstruction, using a large number geometrical modelling and computer graphics techniques, is an extremely useful tool to support research, if the models are accurate. Since accuracy is a great objective for all archaeologists, it is necessary to invest in resources that enable accuracy achievement in order to preserve and transmit certain subtleties. These subtleties might, otherwise, be lost, be ignored in future studies or even be forgotten by future generations.

The dissemination of archaeological information using virtual environments and multimedia is tremendously important in the democratisation of knowledge. It renders an important assistance in the archaeological information decoding process to the great public and, consequently, to the consciousness of archaeological heritage importance.

The archaeologists have to create models, from ruins and fragments of different artefacts, which are able to transmit the way of living of some communities that disappeared for centuries or millenniums. Their task is not only to dig, assemble and organise data, but fundamentally to interpret and create cognitive models of the past.

In order to create a visualisation of the past, the archaeologists have a set of computer graphics tools available that materialises their mental representations through tri-dimensional models. These virtual 3D reconstructions are useful for research purposes and to be shared with non-experts. The work of [Abouaf99] reflects well this situation.

In fact, virtual environments in archaeology are particularly interesting tools for archaeologists to divulgate their interpretations. In spite of describing an excavation using text and sketches, it is possible to rebuild an archaeological site in three dimensions and explore it interactively.

Besides, the more data are discovered and presented the more actualised the virtual model will be. Another way to improve the models of the past is to give them more detail and accuracy, using computer suported cooperative work among experts. This share of knowledge is also valuable for the general public. Normally, the information about an archaeological site is disseminated in publications and through museum exhibitions. However this might present some restrictions:

- A great number of museums reserve only some space for their exhibitions, therefore each might be visitable for a short period and might show only part of the remains,

- During the exhibition of archaeological site's remains there is always some risk of damaging the objects or they might even be stolen;

- Some objects might be damaged by the light or by the polluted air.

A way of minimising these restrictions is to use virtual environments to disseminate not only the remains of an archaeological site, but also the contexts in which they were found.

So, to preserve the accuracy of scientific information it is necessary to pay a great attention during the production of contents to be disseminated. These depend, naturally, of the different target public. For the expert the most important is the content and not the dissemination method, because they are interested in the accuracy of the scientific information.

In fact, the archaeologist sees the simulations in virtual environment as a complement to the information of the maps, plans and sections to which they are familiar with. The student is more interested in the way the information is transmitted. For the general public the interest might be in the technology innovation aspects used to disseminate the contents. In this last case, the contents should have general information that might be understood by a less demanding public.

3.2 Some Projects

There are some very interesting projects regarding virtual environment applied to the reconstruction of archaeological remains, as it is presented in [Steckner98] and [Brogni98].

A very interesting work in this area is presented by [Zheng00]. The project, which comprises a team of archaeologists, museum conservators and computer science researchers, uses computer graphics, virtual environments and multimedia to recover some relics excavated in China, in the "Museum of the Terra Cota Warriors and Horses". The archaeological site was discovered more than 20 years ago and has a team of 80 researchers, which unearthed about 3000 sculptures among 8000 that are estimated to exist there. This recovery project seeks to materialise the following objectives:

- Scanning of the excavated remains;

- Test and employment of recovery techniques in virtual environments;

- Present the results in a virtual exposition.

Although the virtual reconstruction of remains is unquestionably important and, according to [Papaioannou01], justifies a particular attention from computer science, this technique is mainly used in the reconstruction of structures of buildings that have already disappeared or which are in very bad conservation conditions. An example of this is the work that has been performed in the roman site of Sagalassos (Southwest of Turkey) [Pollefeys98].

There are also projects that seek to reconstruct structures in a more complete form, like the reconstruction of Nero's *Domus Aurea* and the *Colosseum* of Rome [Forte98a], the baths in Badalona (*Baetulo*), Spain [Costa98], the reconstruction of the medieval city of Turku, Finland [Uotila98] or the reconstruction of the castle of Ferrara, Italy [Forte98b].

Currently there are several projects that use virtual environments as an interface to archaeological research and analysis. One of these projects is ARCHAVE, which is a system that represents all the archaeological excavation components in the context of an architectonic reconstruction of the Petra Temple in Jordan [Acevedo00].

ARCHEOGUIDE (**A**ugmented **R**eality based **C**ultural **H**eritage **O**n-site **Guide**) is another project and uses augmented reality for the study and dissemination of an archaeological or culturally interesting site [Hildebrand00]. All these examples confirm, undoubtedly, the importance and intensification of computer graphics in archaeology.

4. THE *BRACARA AUGUSTA* CASE STUDY

The urban evolution of Braga was responsible, in some cases, for a massive destruction of important archaeological remains that came mainly from the roman period. Because of this, the already difficult and subjective archaeological interpretation became an extremely sensitive and complex task.

Consequently, the three-dimensional reconstruction of *Bracara Augusta* has been, and will continue to be, a very difficult task. However, the constant archaeological research will rise new remains, which may contribute to enrich and complete the current reconstruction.

The three-dimensional model of *Bracara Augusta* is based on a constructive process that comprises a set of tasks, which may be grouped in the following phases (see figure 1):

- Data Analysis;
- Modelling of the structures and surrounding terrain;
- Texturing of the models;
- Integration of the structure and terrain models;
- Definition of a suitable illumination model for the virtual scene;
- Visualisation of Bracara Augusta's virtual reconstruction.

4.1 Data Analysis

The starting point for the entire virtual reconstruction process of *Bracara Augusta* is the analysis of the already interpreted data from the excavations. This data is available in the SIABRA and it basically corresponds to:

- Excavation plans;
- Facades, plans and sections of the excavated structures;
- Terrain level values;

- Photographic information;
- Written information;
- Facades, plans and sections, which result from the excavation data interpretation;
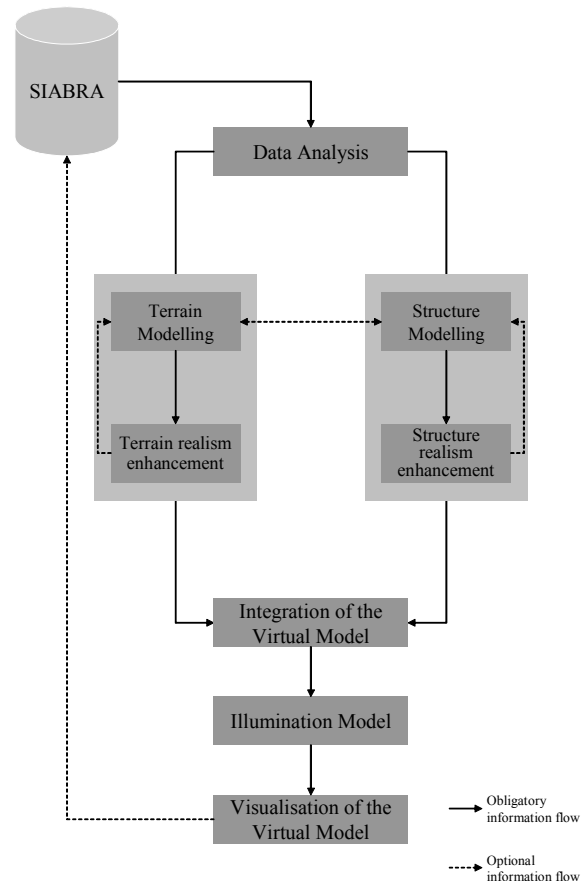- Architectonic proposal for the building reconstruction.

Figure 1: *Bracara Augusta*'s reconstitution methodology

It is mainly this last kind of information that will be crucial for the three-dimensional modelling of the structures found in *Bracara Augusta*.

All the other elements are necessary to increase the level of realism and the level of accuracy of the 3D models of the structure that constitute the virtual model of *Bracara Augusta*.

The analysis of all this data is enormously important, since it enables:

- The understanding of *Bracara Augusta*'s dimension and complexity;
- The correct setting of the hierarchy in the 3D models;
- The definition of the accuracy level in the creation of each 3D model;
- The establishment of adequate levels of detail for visualisation purposes;

4.2 Development of the Virtual Models

As mentioned before, the most important data used for the volumetric reconstruction of *Bracara Augusta* are the plans, the facades and the sections about the structures that were found. These elements gave origin to architectonic proposals for the interpretation of the different buildings. Based on this data, all the known buildings and infrastructures of the roman town were geometrically modelled using constructive solid geometry (CSG) [Mäntyla88].

The surrounding terrain of the roman town was recreated using the iso-lines of a map from the 19th century. Having in mind the nature of this data, the kind of modelling that was used in this case was the surface modelling.

4.2.1 Architectural Structures and Infrastructures

The three-dimensional reconstruction of architectural structures of *Bracara Augusta* was a rather complex exercise. It obeyed to a common methodology and was developed in two phases:

- Modelling – seeks to reconstruct the geometric model of each structure, using CSG;

- Realism Improvement – seeks to improve the realism of the previously developed geometric model.

The 3D models of the architectural structures were developed using *MicroStation 95* from *Bentley* [Olson96] and *Caligari trueSpace^{TM}4 V4.3* [CALIGARI98].
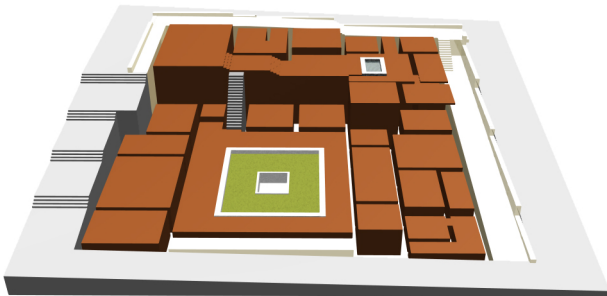

Figure 2: Pavement representation

In the case of *Bracara Augusta*'s architectural structures, the first step was to model platforms that represent the floor of each building, using the information of the plans and the terrain level values. As it is shown in figure 2, the floor is represented by a set of cubes. Each cube is modified using adequate geometric transformations, until the desired shape is obtained. In the particular case of *Bracara Augusta*'s infrastructures it was necessary to adapt street and wall planning the terrains morphology, which is very irregular.

The next step in this phase is to model the interior and exterior of the building. Both, interior and exterior are modelled using cubes that are modified with geometric transformations. In this way, it is possible to position the different parts of the model correctly and to give them the approximate shape (see figure 3). The third step comprises the creation of solid blocks with the outer contour of the windows and doors, based on the information of the facades and sections. These solids must be thicker than the walls of the models, because they have to be positioned correctly in the model. Afterwards they are subtracted from the model, creating the openings of the model (see figure 4).
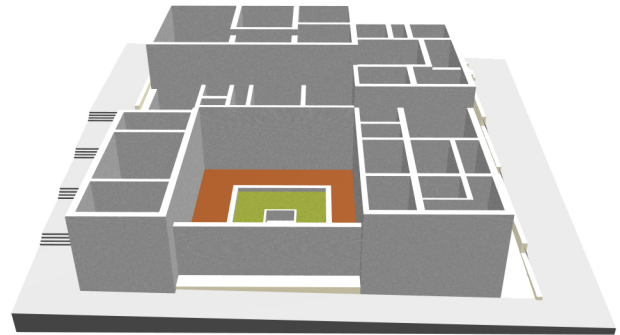

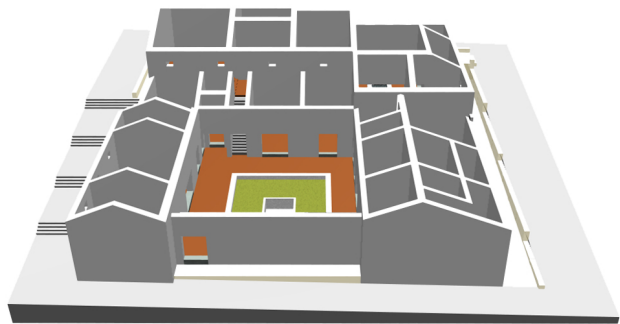**Figure 3: Building structure**

Figure 4: Wall openings

Having still in mind the information about the plans, facades and sections it is possible to model the structure that supports the roof, as you might see in figure 5. Once again, this structure is modelled with a simple cube that is modified with regular Boolean operations and geometrical transformation to obtain the desired shape. Afterwards, the obtained object is positioned over the already existing model and covered with objects representing *tegulae* (roman roof-tiles). For infrastructures this last action is dispensable.

One fundamental concern during the modelling phase is related to the adequate hierarchy that has to be established between the various objects that compose the virtual scene. In this way, the rendering and animation task becomes much easier.

Figure 5: Complete 3D model of a roman building

The realism of an object can be enhanced using a correct definition of its material properties and an adequate texture mapping.

The data structure of the virtual model of *Bracara Augusta* is a three, where the leaves represent all the objects of the scene and the knots represent a set of objects that have the same material. This way it is not only easier to apply the same material to different objects, but one can minimise the chance of applying the materials erroneously.

The virtual reconstruction of *Bracara Augusta* uses 120 distinct materials with the following properties:

- Colour;
- Diffuse and specular reflection;
- Refraction index;
- Shininess and Transparency;

The texturing task of the three-dimensional model began with the creation of textures that give the model a more realistic look. Sometimes, the structures found during the archaeological excavation are in a very good conservation state. In this case, the textures are obtained from photos of the structures.

After creating the textures, the next step is to map correctly the textures to the object's surface.

4.2.2 Surrounding Terrain
The reconstruction of the terrain model has, basically, the same phases as the structure reconstruction: modelling and realism improvement. The tasks of these phases are very similar to the tasks described for the structure reconstruction. However, in this case the modelling will be performed using surface modelling techniques, rather than CSG.

The 2D processing of the terrain information was realised with *MicroStation 95*, but the three-dimensional reconstruction of the terrain was performed with *AutoCAD Land Development Desktop R2* [Autodesk99].

The terrain reconstruction is based on Braga's cartography information from the 19th century. This information was used because it is a way to ensure that the reconstruction of the terrain is the most similar to the terrain from roman epoch. Therefore, the first step was some pre-processing work to ensure that all iso-curves were closed and that they were at the correct high.

Afterwards, and using the *AutoCAD Land Development* tools for terrain creation, the surface, corresponding to *Bracara Augusta*'s surrounding terrain, was modelled and represented using a **t**riangulated **i**rregular **n**etwork (TIN). This surface was transformed into a quad-mesh, to reduce the number of polygons of the terrain surface.

The realism improvement process in the terrain modelling is very similar to the one performed in architectonical structures. It is necessary to define a colour, to set the diffuse and specular reflection, the shininess, the transparency and the refraction index. For the texturing of this model a texture is used that results from the combination of two distinct images.

4.3 Integration of the Information
The integration of the three-dimensional models consisted on position the different structures and infrastructures correctly on the terrain model of *Bracara Augusta*.
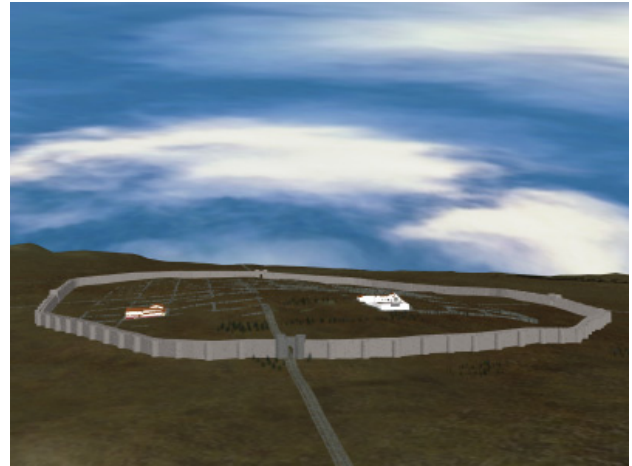

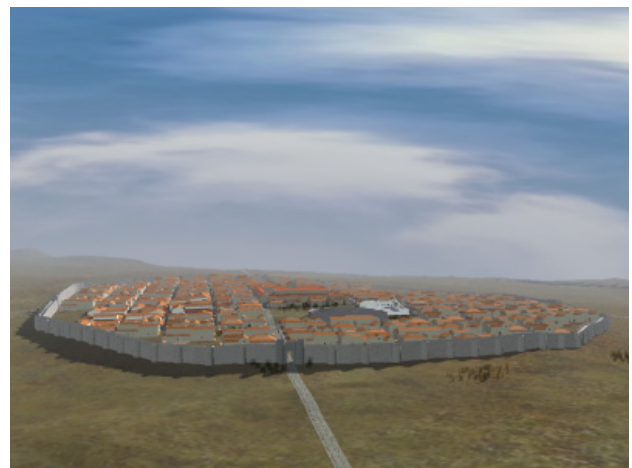**Figure 6: Information integration**

Figure 7: Global reconstruction of *Bracara Augusta*

Naturally there are always some adjustments to do during the integration of the structures and infrastructures. But in *Bracara Augusta*'s case this was not a very difficult process since SIABRA assured the high quality and acurrateness of the information. Figure 6 shows the final result of the object integration phase.

Besides the rigorous models, some less accurate models were created to fill the missing quarters of *Bracara Augusta* (see figure 7). The information about these quarters is either not yet studied or it is insufficient and poor.

4.4 Illumination Model
The illumination model should be a way of improving visual realism in a virtual scene. This objective can be achieved by using a combination of different types of lights and sources of light, such as:

- Ambient light;
- Directional light source;

- Point light source.
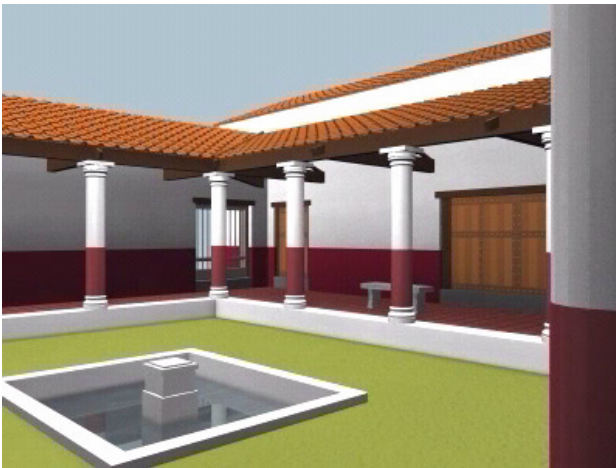

Figure 8: Global Illumination

Figure 9: Interior Illumination

The virtual reconstruction of *Bracara Augusta* uses an illumination model that combines only directional light sources with point light sources. The illumination model of virtual *Bracara Augusta* has also a directional light source that simulates the Sun. This light source had to be positioned strategically to enhance the illumination model. Figure 8 shows the global illumination of the entire virtual scene.

Besides directional light sources, point light sources were used to simulate the illumination associated to the virtual model buildings. The different combinations of these kinds of light sources produced a set of shadows that improved the realism of the interior compartments and exterior areas that were rebuilt (see figure 9).

5. CONCLUSIONS AND FUTURE WORK

The past is increasingly important for mankind. Therefore, the representation of the past should be increasingly accurate in order to reach satisfactory levels of correction for the scientific community. However, it is important to keep in mind that this representation of the past is not the past itself, but just a model that results from the available data and its interpretation.

Clearly, Computer Graphics, Multimedia and Virtual Environments are important tools for the representations of the past and they contribute, with its techniques and methodologies, to a better conservation, preservation and interpretation of cultural heritage and, particularly, archaeological heritage.

Bracara Augusta's virtual representation was an important step for the archaeological project of *Bracara Augusta*, in the sense that from now on the excavation data will be, if possible, always represented in three dimensions. Beyond the three dimension of the space, also the chronological evolution of the space occupation is done in three dimensions.

The importance of this way of representing the archaeological information has a direct influence, mostly, in the dissemination of the excavation results to a broader public. Actually, the non-specialist public understands better an archaeological site if it is virtually reconstructed. On the other hand, the archaeological information will no more belong exclusively to the archaeologist or to a restricted scientific community, since an important democratisation of the knowledge takes place. In this way, it is easier to alert the inhabitants for the preservation and conservation problems of the archaeological heritage and to give them a greater conscience about heritage.

Nevertheless, the advantages are immense, also for the specialist that is studying an archaeological site. The virtual representation of a certain site is always based on the interpretation of a multi-disciplinary expert team (archaeologist, architects and historians and computer scientists). This representation is just one of the interpretative models. Since the representations are geometrical three dimensional models, it is easier to create alternative representations representing different interpretations.

On the one hand, the experts have to validate the virtual models, but on the other hand, the virtual models can be used to correct some interpretations. Traditionally the interpretation of a site is represented as a bidimensional draft on a paper. However, when this information is used to build the three-dimensional models one can easily discover some inconsistencies that are quickly overtaken.

Although it is very positive to represent the archaeological heritage in virtual environments, this does not mean that this proceeding has only advantages in archaeology. The computer graphic representations are sometimes so realistic that they might be confused with reality. This can be a serious problem, since a less informed public might misunderstand virtual models with reality. This is not intended with the application of virtual environments to archaeology. In this sense, the application of virtual environments to archaeology must be always supported by systematic criticism to avoid wrong generalisation about past and misunderstanding of the archaeological heritage significance. This application should be understood as a way to recreate the past, helping its assimilation and the enhancement of knowledge, since its representation develops the metal grids which the archaeologist uses to read the archaeological register.

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