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3D Modelling as a Scientific Research Tool in Archaeology

Abstract: This paper addresses two key requirements for the use of Virtual Reality (VR) and three dimensional digital modelling (3D) of archaeological objects (sites, structures or artefacts) as valuable research tools: data transparency and reliability of reconstruction. Both requirements are necessary for a scientific review of the 3D outcome; while data transparency allows an evaluation of the raw data used for the digital reconstruction, reliability refers to a method of (subjective) quantification of the research results, by the researchers themselves. This method, based on the concept of fuzzy logic, allows the major steps in the decision making process of the 3D outcome to be numerically evaluated by assigning a "reliability index", based on the "weighted importance" and "consistency" of each component of the 3D outcome. Finally, the paper will present a research framework and interface, based on open source technology, to demonstrate the use of the abovementioned concepts.

Introduction

VR and 3D modelling have been applied to archaeology for more than three decades now (Hermon / Nikodem / Perlingieri 2006). While much has been written on the potential of these tools for archaeological scientific research (Hermon / Niccolucci / D'Andrea 2005), most projects involving these technologies focus on the communicational aspects of 3D modelling in various media (internet, museum installations, etc.) or technological improvements of 3D modelling tools, and much less on their use as a tool for scientific investigation. 3D outcomes are generally viewed as "nice toys" or "nice visualization outputs"; the potential of 3D visualization for scientific research, as already applied in many different research fields, is greatly underestimated. One of the reasons for this drawback may be related to the fact that there are very few archaeological reports which present new results obtained while using 3D as a research tool. A recent attempt at defining guidelines for prerequisites for applying 3D as a research tool may be found in the London Charter (www.londoncharter.org). In this article, we will focus on two of the prerequisites described in the London Charter: the primary data transparency issue and the reliability of visualized 3D reconstruction.

VR and Archaeological Research

A very simplistic definition of archaeology is "the science that investigates past human life mainly through a systematic analysis of its cultural remains and their context". Thus, three important aspects are relevant to our discussion. The first is how closely we can match the original environment (created by humans in the past) with the one that has been preserved for us until the moment of its unearthing and analysis. The second aspect of archaeological research regards the meticulous analysis of artefacts of material culture as products of human society. The third and last step consists of linking artefacts to historical objects, and understanding the mutual relationships between them and the dynamics that have occurred from the time of their creation to the moment of their discovery.

VR can enhance the analysis of past phenomena by providing a method for the visualization of ideas, translating "empirical phenomena into geometric language" (Frischer et al. 2002). Moreover, as Niccolucci put it, "since interpretation, explanation and communication involve reasoning, Virtual Archaeology can provide virtual creations to organize and synthesize known facts, showing them with greater clarity to others or to one's 'inner eye' or virtual substitutes of physical objects" (Niccolucci 2002). VR is a simulation of a real or imagined environment; (3D) models are constructed in order to represent, analyse and understand the complexity of the present and, in our case, the past. They help us to understand a particular problem or predict the behaviour of a particular phenomenon, under particular circumstances.

One of the basic criteria for a 3D model to have value is that it should provide an insightful perspective on a particular situation. To do so, it must have a well defined aim and answer a specific question. Consequently, a scientific model is one that is open to critical evaluation. Thus, a scientifically reliable model, from a Galilean perspective (i.e. repeatable with the same results, beyond experimental errors), has to be open to deconstruction and its primary data presented for evaluation. These factors would enable a reconstruction of the cognitive process that leads to the construction of the model and thus a scientific evaluation of the model's scientific contribution. A complementary aspect of VR relates to cognitive capabilities – there is a positive relationship between the ability of a model to be visualized (Ekstrom / French 1976) and the use of visualization tools; the information inherent in a superior model is perceived by the user in a more appropriate way. In other words, the better the visualization tool, the better the explanation and reception of the (archaeological) information. Since our world is also a three dimensional one, and we are used to acquiring and assimilating large amounts of 3D data from our interaction with our environment, there is seemingly no reason why the same medium shouldn't be used when attempting to analyse a past environment.

In the following paragraphs we will present a method, based on open-source technology, of addressing two key issues of scientific modelling in archaeology: data reliability and transparency. While the concept of data transparency is a relatively simple one to address (in practice related to which and how much primary data is necessary to render a sufficiently expressive 3D model), data reliability is a more complex issue. When, for example, we are classifying an artefact, often we are not sure in which class/type/group we should place it. However, since we have to produce an inventory list of the material culture, we must force the item into one of the groups, sometimes arbitrarily. This is precisely the moment when we may start thinking about the reliability index – translating the sentence "I am not sure about my classification" into a numerical reliability index. The same is true regarding VR – for example, we can be relatively sure that the shape of a window was round without disregarding other options as well. We can choose one option and again, assign to it a reliability index, expressing our doubt or certainty about the choice. The reliability index reflects the confidence the researcher has in his or her interpretation of primary data and is subjective to the researcher's decision.

Evaluation Criteria

Two main indices were defined in order to provide the evaluation criteria for a 3D model: importance and reliability. The importance index measures the "contribution" of a part of the model in relation to the model overall; it is a subjective evaluation and reflects the researcher's opinion about the potential contribution of the part to the whole. This index is directly related to the aim of the model: for example, if we are reconstructing a Roman house of Pompeii and we are interested in the interior decorations during this period, the paintings on the walls are of great importance, so the importance index of their reconstruction will be high. On the other hand, if we are interested in understanding urban architecture in Pompeii, the inside paintings will be of low importance and will be assigned an accordingly low importance index. The second index is the reliability, based on the primary data (its quantity and quality), analogies and other comparative researches, scientific deductions, etc. Taking the example above, the reliability index of the paintings in a room where some parts of the original paintings were preserved will be higher than in one with no remains.

Assigning Reliability and Importance Indices

As already discussed in another paper (Hermon / Nikodem / Perlingieri 2006), the first step towards quantifying the reliability of a 3D model is to assign reliability and importance indices to each of its components. On the base of the established criteria, values from the interval [0, 1] will be assigned to describe the level of trust the author of the model gives to its parts. This is based on the foundations of fuzzy sets and fuzzy logic (Zadeh 1965), which gives a better way to describe the uncertainty of some ideas – not only Boolean true or false (black and white) values are possible, but also all the shades of uncertainty (grey) between them. The given parameters will then be used to define the mode of rendering of the model so that researchers can get the most out of the 3D model.

Our case study is a simplified version of a hypothetical ancient Roman military camp *(Fig. 1)*, chosen as an example only, due to its relatively simple geometry which makes it suitable for exemplifying our ideas.

As seen in the table below, the model was divided into eight components referring to model's eight

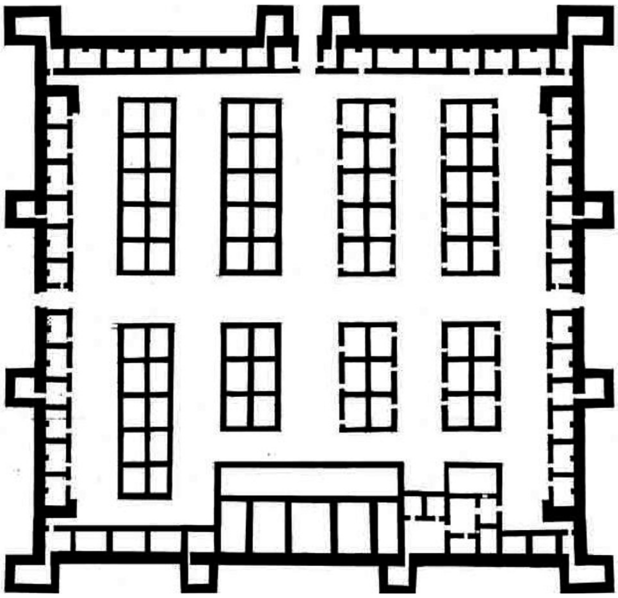

Fig. 1. General plan of the reconstructed object.

main structures, all of them divided into smaller details. Reliability and importance indices were assigned as shown in *Table 1*.

While the table is currently just a simple structure designed to be filled with regular data in a standard office application, some new options will appear if we transform it into a database.

Database Structure

The proposed system is more of a data storage and visualisation toolkit than a 3D graphics framework. For this reason, a complex database was prepared to store all the metadata connected to the models' components. A relational schema was chosen to enable fast and easy communication with statistics and data analysis applications (e.g. MS Excel statistic toolbox; correlation coefficient and trend line (see Hermon / Nikodem / Perlingieri 2006)). It is also compatible with the tools used for 3D modelling and visualisation.

As shown in *Fig. 2*, the main table is Component, created to store the name, location, size and description of the main structures of the reconstructed model. Each component consists of some details described by name, reliability and importance indices and some additional comment. Components are stored with their sources; here references are given in the Data Source table, with columns like data source author, type of data and publication date. If images are available for a component (3D scans, photos, drawings) their thumbnails and links

component	detail	reliability	importance
surrounding wall	existing	1	1
	estimation	0.6	1
	walking path	0.4	0.6
	defensive parapet	0.3	0.6
	access stone stairs	0.3	0.6
	wooden stairs	0.2	0.6
corner tower	existing	1	1
	estimation	0.5	0.9
	internal steps	0.4	0.6
	top	0.3	0.6
gate	gate	0.3	0.4
	maneuvering system	0.3	0.4
soldier barracks	walls	1	1
	estimation	0.3	0.5
	roofs	0.2	0.4
	gates	0.2	0.4
	wall plaster	0.2	0.6
	room equipment - beds	0.2	0.4
headquarter	walls	1	1
	estimation	0.3	0.5
	roofs	0.2	0.4
	gates	0.2	0.4
	wall plaster	0.2	0.6
	furnitures	0.2	0.2
storage facility	walls	1	1
	estimation	0.3	0.8
	roofs	0.2	0.4
	gates	0.2	0.4
	wall plaster	0.2	0.6
	straw floor	0.3	0.4
	stored goods	0.2	0.4
officer barrack	walls	1	1
	estimation	0.3	0.5
	roofs	0.2	0.4
	gates	0.2	0.4
	wall plaster	0.2	0.6
	furnitures	0.2	0.2
gate tower	existing	1	1
	estimation	0.5	0.9
	internal steps	0.4	0.6
	top	0.3	0.6
	antechambers	0.3	0.4

Tab. 1. Reliability and importance indices given to the model details.

may be stored in the Image table, in some cases supported by additional information in the Acquisition Mode table.

Though simplified, the schema fulfils the main condition given by the London Charter (the need for data transparency), and gives a basis for justification and scientific discussion of the model according to its reliability.

3D Visualization

A special interface was implemented to communicate between metadata stored in the database and the 3D virtual model itself. It is based on a script run in the application window and offers a set of functions for: (1) exporting 3D objects' attributes into a database, (2) searching the database and (3) conditional rendering of the model. Conditional rendering was implemented by means of a threshold related to

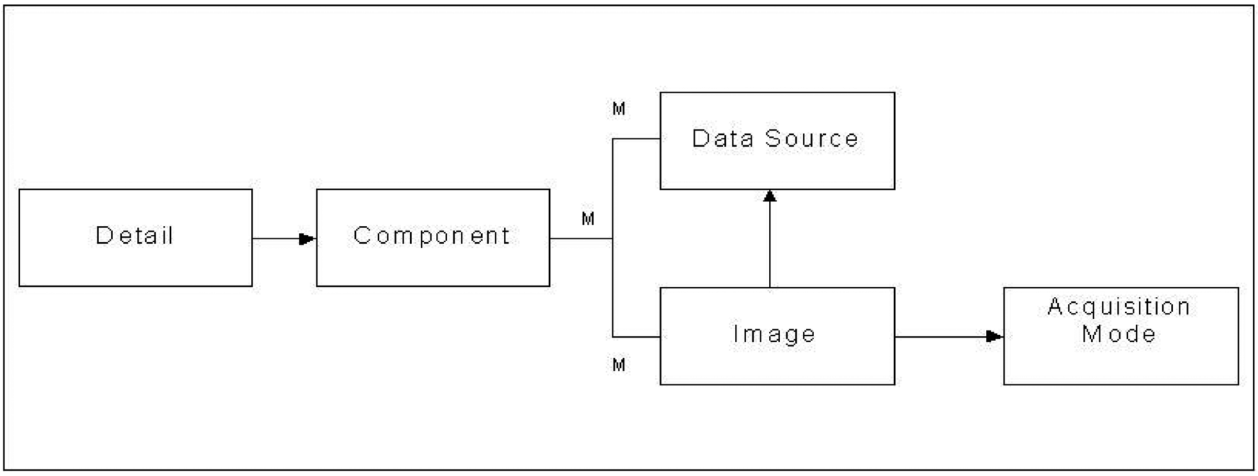

Fig. 2. Database schema.

the details' reliability and importance indices. It is also possible to base the threshold on a combined parameter concerning both indices, which was defined in a separate paper (Hermon / Nikodem / Perlingieri 2006) by the formula:

$$R = r\left(\sin \frac{p}{2}\, i\right),$$

where r is the overall reliability and i is the overall importance of the detail.

The proposed function causes more attention to be paid to the reliability than the importance index, that is, details with a high reliability index generally get higher overall value than those of a low reliability even when the latter is also of high importance. The formula chosen represents the nature of the relationship between the two indices, reliability and importance, according to our needs. If, for example, in some model we wished to pay more attention to the importance index than the reliability index, we would switch the position of the indices in the formula (i.e. switch r and i) and the final R would reflect this choice.

The effects of the conditional rendering are presented in a screen shot below *(Fig. 3)*. Note that the barracks are filled with solid green on the left before rendering, but are shown as wire mesh after the rendering process on the right. This is a situation where an object does not fulfil the criteria given by the threshold and so is only partially rendered. The wire mesh is a way of indicating that the model is incomplete.

Changing the position of the threshold changes the search criteria in the database and as a result the mode of rendering of a detail. This may be considered an answer to one of most frequent doubts about 3D virtual modelling – is it really a scientific research tool when we can only see the final closed product? Access to far-reaching documentation in conjunction with manipulation tools allow the model to be considered not only as an illustration of an idea, but also as a data analysis environment, which undoubtedly is a scientific research tool.

Another aspect of the visual presentation of a 3D model is the access to the source data. Here a continuous connection with the database is proposed, which allows descriptive, numerical and graphical data to be reviewed at any time of the reconstruction and analysis process.

Modelling Pipeline

The process of building a model of an archaeological object should begin with a general description followed by the definition of the main components and structures, which should be implemented inside the database (inserted into the Component table). Each detail added as a part of the model should be described in the Detail table and, if accessible, all images and other source data should be inserted into the Data Source, Image and Acquisition Mode tables. At any step of the reconstruction process, reviewing the model is possible through statistical operations based on the metadata (such as reliability and importance indices), comparing the graphical visualisation with the given description and, in the final phase, through a threshold supporting conditional rendering of the 3D image. This should be done simultaneously with the drawing process,

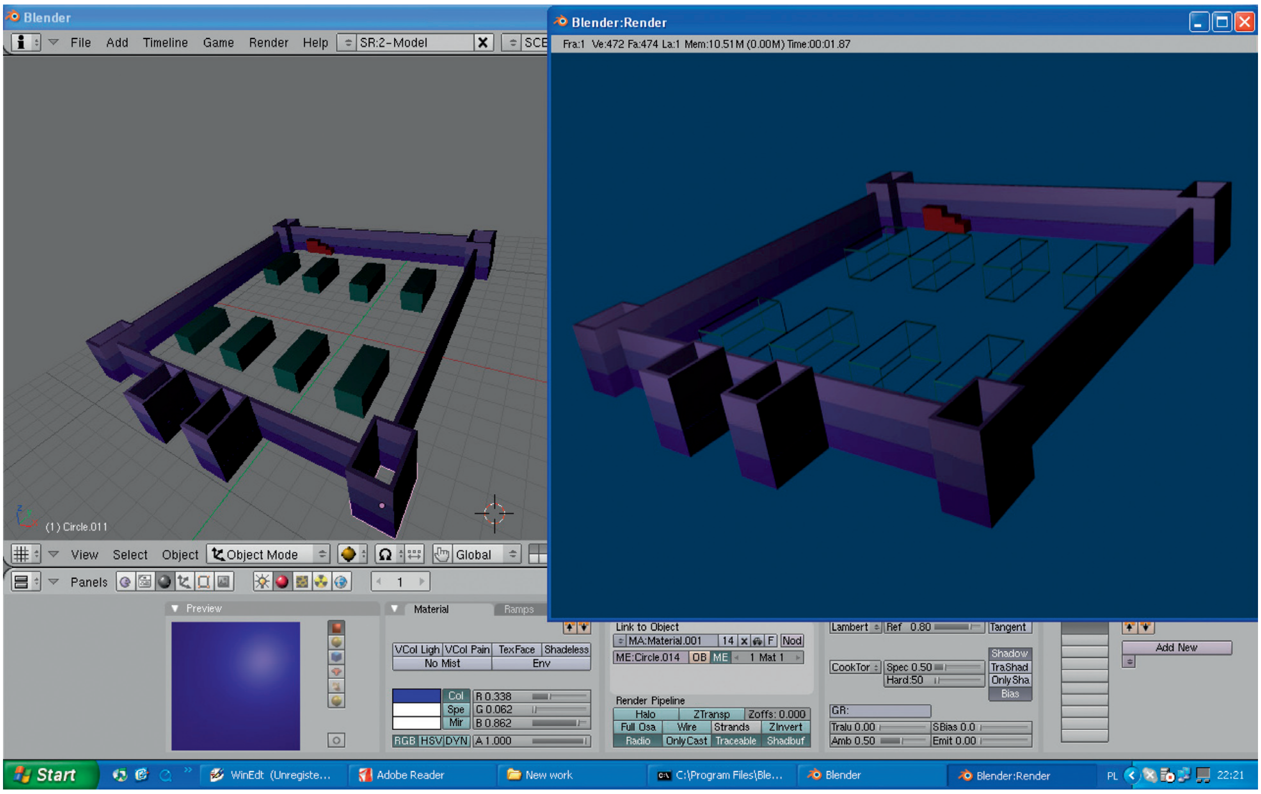

Fig. 3. Conditional rendering performed by the presented software.

to avoid following a wrong path, which might cost and time and money.

Software Selection

As the main technical conditions defined for the project were low cost, modest hardware requirements and functionality, open source applications were chosen as a programming environment. Blender (www.blender.org) was chosen as a 3D graphics tool. It is an object oriented environment based on Python scripts (www.python.org), with a well defined graphical project interface and application programming interface. A module mysqldb (mysql-python.sourceforge.net) offers a flexible connection to a MySQL database system. MySQL (www.mysql.com) is a relational database management system, which offers all the standards required in this phase of the project.

Summary

Though the idea of integration of a database with a 3D modelling tool has already been explored in some papers (Okamoto et al. 2005), no solution had been given for the virtual reconstruction of no longer existent structures. The software and modelling pipeline presented in this article sheds some new light on the subject of archaeological data archiving and presentation. Access to the data is easier and the model itself more flexible, which transforms it from a nice artistic visualisation into a serious analytical tool. Further research should focus on improving the database structure towards standardisation and universality. More tests would help to improve the interface functionality. Since time and costs needed to complete the model and supply all the metadata are relatively high, a general discussion about data exchange and copyrights also seems to be urgent.

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