Three Dimensional Visualization and Virtual Reality in the Research and Interpretation of Archaeological Data

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"…Imagination, or visualization,
has a critical role to play in scientific investigation…"
René Descartes 1637

Introduction

The history of Virtual Reality (VR) and Three Dimensional (3D) modelling (hereafter 3D) applications dealing with archaeological data starts in the eighties of the last century, with several attempts do virtually reconstruct ancient monuments or artefacts. Since then, despite a large number of publications, some emphasizing the potential of these methods for the archaeological research and others focusing on methodological matters, still today, almost a quarter of century later, 3D is mostly used for communicating Cultural Heritage to the public (in museum environments, some on the Internet and fewer still in on-site installations at archaeological parks) or for education purposes, mainly for undergraduate students.

Several reservations kept archaeologists from using 3D as a research tool so far: traditionally, archaeologists are accustomed to interrogate 2D material (maps, plans or photos) and a shift to a 3D method of reasoning is still in its infancy; the credibility of a 3D product is most often not explicitly expressed and thus in many occasions not reliable from a scientific point of view; creating a 3D product is a complex process, which requires extra time, resources and specialists. Despite these apparently strong drawbacks, 3D can greatly contribute to archaeological research: recent technological studies show how 3D can be relatively easily implemented in daily archaeological research and there are several solutions (presented below) on how to quantify contingency of 3D products. This chapter will deal with the first reluctance on using 3D, mentioned above.

The text will focus on presenting and discussing examples that illustrate how 3D can be used as a research tool for archaeological research. The main arguments are that 3D can help in: presenting a different approach to investigate an archaeological problem, by visualizing in 3D the remains under research, representing in 3D hypotheses and simulations of past conditions (both socio-cultural or environmental), but mostly, as we will see below, reasoning in 3D opens a door to new sets of questions to investigate and possibly reach reliable answers, by visually expressing alpha-numeric data and by graphically expressing thoughts and ideas, and translating "…empirical phenomena into geometric language…" (Frischer *et al.*2002:11). This aspect was summarized by Niccolucci (2002): "…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 2002:3).

The following paragraphs will present some basic concepts on what is 3D modelling and how it can contribute to the archaeological scientific process of understanding past human life.

Virtual Reality and 3D models – basic definitions and applications to archaeology

A simple definition of Virtual Reality is: "…the simulation of a real or imagined environment, experienced visually in three dimensions…". In order to understand, represent and analyse the complexity of the real world, people draw pictures or build abstract descriptions, or **models**. By selectively and carefully omitting details and including relevant factors, a model can provide a useful tool for understanding a particular problem or predict the behaviour of a particular phenomenon. A model has a value only when it can provide insight on some situation, (answer a specific question), and the model is analyzable, i.e. accessible to critical evaluation. Moreover, researches in cognitive psychology have shown the positive relationship between the visualization ability (the ability to manipulate or transform the image of spatial patterns into other arrangements) and the use of visualization tools and thus perceiving the information in a more appropriate way. The implication is, the better the visual tool, the better the explanation and the interception, in our case, of the archaeological information.

In order to understand a past human activity, we must imagine it, and thus reconstruct its context, be it environmental, anthropogenic or social. Once this context is made visual, it is mobile and reproducible. Consequently, virtual reality allows the 3D visualization of concepts, objects or spaces and their contextualization – it gives a visual framework in which data is displayed. The example in Figure 1 demonstrates the difference between a traditional and a 3D presentation of data (in this case, a roman military camp at Avdat, Israel).

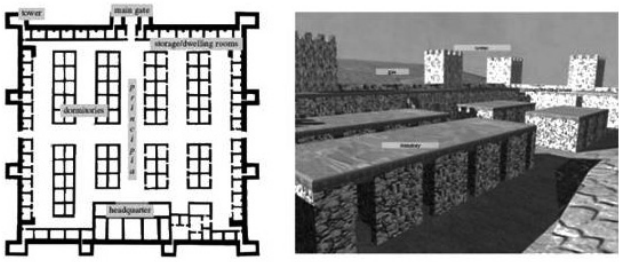

Fig. 1. left: traditional 2D illustration, right: 3D representation (after Hermon and Fabian 2002)

Being interactive, the 3D model can be rotated and all its views (above – traditional, side – stratigraphic) are analyzable. Thus, while keeping the traditional representation, additional data is incorporated within the same illustration: probable height of buildings, shape of towers and their height (both estimated according to the debris of fallen stones found around the walls and/or historic sources), type of roof and floor and inside structures.

Moreover, the process of reconstructing the 3rd dimension of the structure under investigation raises new research questions: how far soldiers serving in the towers could see (or, alternately, how tall towers had to be in order to cover the widest possible horizon), how the camp functioned in case of emergency – the model can be populated with soldiers running from barracks, climbing the ladders and preparing for battle, or a more general simulation of the life in a roman camp at the eastern frontiers. These questions may be approached by creating virtual environments and setting up behavioural rules upon which the virtual soldiers behave within the given environment.

3D visualization is also an invaluable method of turning data (obtained during the excavation, survey or investigation of the archaeological site) into information, ready and available for further study and investigation, and into knowledge, communicating the study's results. In this context, VR enables interaction with data organised three dimensionally, facilitating the interaction between humans and data. A key issue of visualization is related to its potentiality in facing, accessing, managing, interpreting and sharing increasing amounts of information being generated by any (including archaeology) scientific field.

Figure 2 exemplifies the above statement. The displayed environment is based on the results of geo-morphological and geological studies (estimating the erosion degree and thus the shape of the valley where the habitation is located), palynological and palaeo-botanical studies (in order to reconstruct the vegetation), both being related to palaeo-climatic studies, in order to reconstruct the environment's ecology in a given period of time (by radiometric dating methods) and finally the human remains in this natural context (habitations being reconstructed on the basis of ethnographic comparison and subjected to architectural laws).

Another aspect of 3D visualization, exemplified in Figure 2, is the possibility of conversion of information not perceived by the human eye into forms suitable for it. Thus, a table which traditionally would include a list of palynological data is translated in Figure 2 in a real representation of the vegetation that could raise additional questions regarding the relationsheep between human settlement and its environment, such as a visual site catchment analysis, exposure of habitations, closeness to forests, etc. Moreover, the ability of 3D visualization to simulate scientific phenomena, enabling the steering of experiments or simulations (based on scientific rules and constraints) as they happen, and the interpretation of accurate predictions or numerical simulations, may lead us to the investigation of new phenomena of the past under research and thus visualize results of hypotheses and predictive modelling. Turning back to the example in Figure 2, simulations of the amount of available land for

Fig. 2. Reconstruction of the environment of an archaeological site (after Negroni Catacchio and Cardosa 2001)

agriculture, (and subsequently the amount of labour energy invested in deforestation would lead to an estimate of the population of the archaeological site under research and its subsistence economy.

Figure 3 further exemplifies the capability of 3D visualization to convert information not perceived by the human eye in forms suitable for it, susceptible to scientific interrogation.

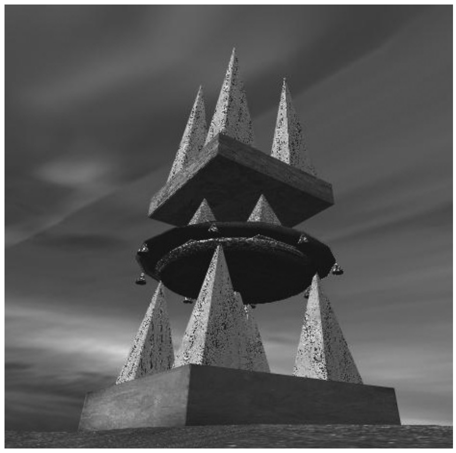

Fig. 3. VR of Porsenna's mausoleum

Plin. N. H. XXXVI. 18,4.— "…Namque et Italicum (labyrinthum) dici convenit, quem fecit sibi *Porsenna rex Etruriae* sepulcri causâ, simul ut externorum regum vanitas quoque ab Italis superetur. Sed cum excedat omnia fabulositas, utemur ipsius M. Varronis in expositione ejus verbis: *Sepultus est, inquit, sub urbe Clusio*; in quo loco monumentum reliquit lapide quadrato: singula latera pedum lata tricenûm, alta quinquagenûm; inque basi quadratâ intus labyrinthum inextricabilem; quo si quis improperet sine glomere lini, exitum invenire nequeat. Supra id quadratum pyramides stant quinque, quatuor in angulis, in medio una: in imo latae pedum quinûm septuagenûm, altae centum quinquagenûm: ita fastigatae, ut in summo orbis aeneus et petasus unus omnibus sit impositus, ex quo pendeant exapta catenis tintinnabula, quae vento agitata, longe sonitus referant, ut Dodonae olim factum. Supra quem orbem quatuor pyramides insuper, singulae exstant altae pedum centenûm. Supra quas uno solo quinque pyramides; quarum altitudinem Varronem puduit adjicere…".

The Latin text narrates Pliny the Elder's description of a mausoleum apparently built by Lars Porsenna, last of the Etruscan kings and ruler in Clusium (modern day Chiusi, Tuscany). Pliny quotes an earlier historical source (Marcus Terentius Varro) to describe the huge mausoleum, apparently destroyed by an earthquake in the 5th century BC, its traces being completely erased in Pliny's time, the last century BC and the 1st century CE. Even if one may doubt the historical credibility of the narration and may perform a thorough historical research, combined with archaeological excavations (no remains whatsoever have been found in the area), without doubt the virtual reconstruction of the mausoleum and its scientific analysis would clarify many aspects of the historical text.

The accuracy of Pliny's description, with all details and parts of the mausoleum accurately provided (including sizes and raw materials), enabled a detailed virtual reconstruction of the monument (Figure 3). Consequently, the model can be subjected to a minute architectonic analysis (static and dynamic laws), in order to estimate the plausibility of the reconstruction, and alternately, what would have been a reasonable monument, given the soil characteristics, building materials and engineering knowledge of the period. Moreover, other research questions can be posed: if the monument existed, what could have been its location? The Latin text explicitly notes that the monument was "under the city of Chiusi", which lead to many legends regarding labyrinths and hidden treasures in the many underground passages that still exist today, cutting under the old city centre. However, a monument of such a size (some 190 in height, by far the largest monument in antiquity) was located outside, possibly in a valley outside the city, under it in terms of altitude. Thus, the visualization in 3D of the historic text of Pliny the Elder enables its authentication as a historical source, at least from the physical possibility of its existence, its material form and its spatial localization.

Quantifying contingency of VR and 3D models

There are some basic requirements from 3D models in order to be accepted as scientifically valid. Their resources and the criteria on which they are based should be explicitly presented and open to critical evaluation. Alternate reconstructions should be made available to the user. Figure 4 shows an example of typical stages of a 3D model building and its basic components.

A virtual representation of an archaeological concept, object or monument is build upon data originating from various fields, such as historical sources, which can be ancient maps, drawings or other graphic representations (including paintings, mosaics, etc.), texts or quotations from other texts, it may derive from archaeological field investigation (surveys, soundings or excavations), comparative studies, and, no less important, the imagination of the modeller, based on his/her accumulated knowledge. Thus, the model is expressed as an equation with several variables (field data acquisition, historical sources, imagination, etc.), these in their turn being influenced by other variables (such as accuracy of measurements, reliability of historic texts or ancient maps, etc.), usually without a defined inter-relationship. Apparently, the 3D model is a function with an unknown syntax, un-quantifiable variables and a final value independent of its variables.

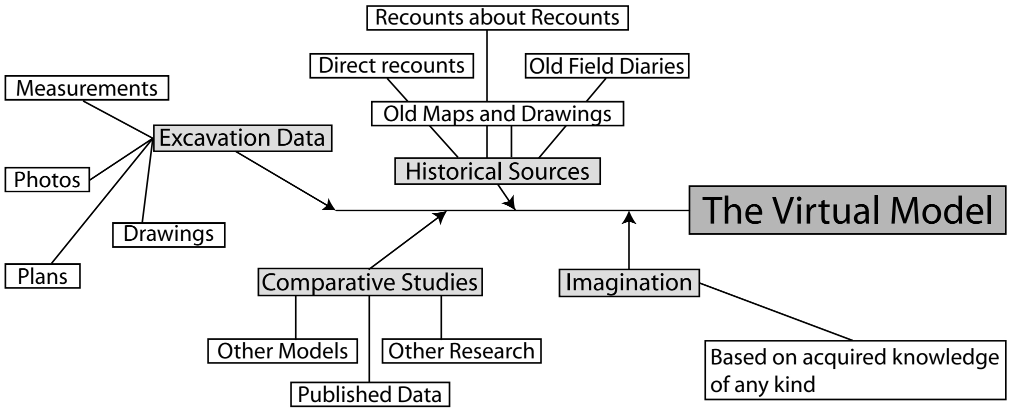

Fig. 4. Schematic diagram of a 3D model building stages (after Niccolucci and Hermon 2004)

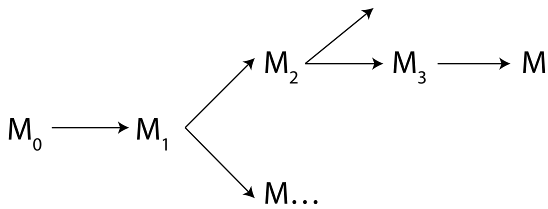

Fig.5. Schematic representation of the process of building a 3D model

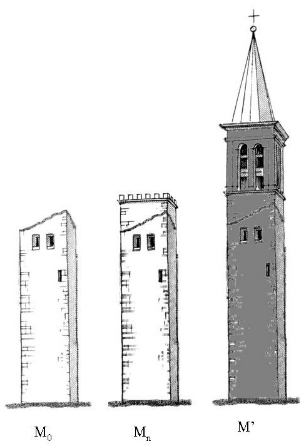

Fig. 6. 3D model and alterative model (after Niccolucci and Hermon 2004)

In order to estimate the reliability of the model and allow its (virtual) de-construction for a critic evaluation, it is important to represent the various steps that lead from the first draft of the model (M_0 to the final model M, or alternatives – M') (Figure 5).

Thus, each M_n model is the union of the preceding models in a determined mutual position, each previous step having its geometry, material and unique spatial position. The process ends when the model satisfies our needs (ideal model), there are no more resources to be incorporated or we run out of time or resources (commonly occurring). Figure 6 exemplifies the process described above. We start with an M_0 model, based on the existing structure in modern times; considering the amount of fallen stones, historical sources and comparisons with other similar structures (in this case a church tower bell of the 12th century), we reconstruct the entire structure, offering two relevant models (M_n and M'), one representing a version of the tower with a double function, as a defence building as well (M_n), while the other (M'), representing the tower as a regular bell-tower. Note that in both models there is a clear distinction between the reality and the virtual (the oblique line dividing between what exists in modern times and what has been virtually reconstructed).

Thus, for each step in the reconstruction, its metadata has to be presented (sources and their reliability), in order to secure the data transparency and thus to satisfy the scientific requirements from the model. Moreover, the relationship between the archaeological and the virtual realities should be explicitly presented, drawing the boundary between these realities. A threshold slider can be installed on the display system, allowing the user to choose how much reliability he/she wants to be displayed (ranging from the archaeological reality – 1, to pure imagination of modeller – 0). Other solutions would be the representation of uncertainties as ghosts, alternate models with fading colours, etc.

Visualization tools and basic requirements

Visualization tools may roughly divided into two main groups: interpretive and expressive. The first group of tools help users to view and manipulate visuals, extracting meaning from the information being visualized; they help to clarify difficult-to-understand and/or abstract concepts, making them more comprehensible. A simple use of (3D) visualization as an interpretive tool is exemplified in Figure 7.

The image represents a vertical section through the old centre of the town of Chiusi, in southern Tuscany: the large building is a XVI[th] century palace; through its cellars, some of the medieval periods, one may access a series of underground tunnels and a complex water system from the Etruscan period. The user may investigate the superposition of the various strata and thus follow the urban development of Chiusi, by analysing the 3D model in Figure 7. Moreover, the information regarding the Etruscan water system, its tunnels and the subterranean lake, may be used to investigate the water system in the following periods and consequently the development and the changing in techniques through time. The same represented water system may be used to understand the ancient Etruscan technique of water supply to the town, by simulating the entire process of digging the tunnels, their inclination, probable length and height, the amount of accumulated water in the cistern and so on. Figure 7 is also an example of visualization of a series of underground structures, mostly closed to visitors; thus, the user may have a realistic image of the entire underground system and analyze it entirely, from various angles, being able to select parts of it, or the entire complex, within its spatio-temporal context

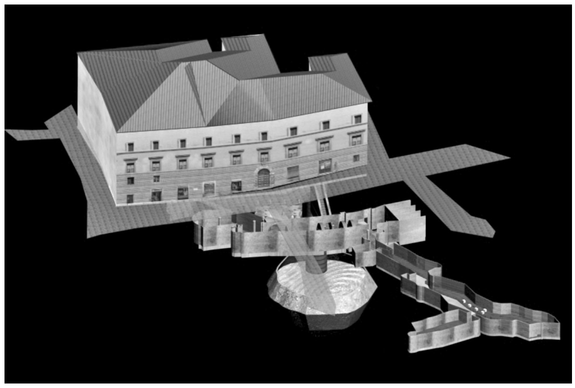

Fig. 7. Virtual reconstruction of the underground Etruscan water system at Chiusi, Tuscany

Expressive visualization on the other hand helps to visually convey meaning, in order to communicate a set of beliefs. In this sense, visualization uses designed representations in order to simplify the process of understanding.

Figure 8 illustrates a screenshot from a dynamic elevation model representing a part of the Tuscan coast, which suffered major changes through the Quaternary, culminating in modern times in the formation of a lake (Prile), where once an open sea and a bay existed. The model exemplifies the relationship between the changing landscape and the human settlement pattern, and the subsistence economy of the inhabitants. The modern coastal line is expressed as a line connecting the two parts of the former bay; the human occupation sites are represented as spots that appear according to their temporal position (from the Upper Palaeolithic to the Roman periods).

Once the visualization tools have been defined, there are several ways of how to best benefit from them (or, in other words, how visualization contributes to our manipulation of data in order to transform it into information):

1. selective emphasis – allows the user to detect, identify and visualize hidden patterns by highlighting or hiding some parts of the visualized data.

The example in Figure 9 illustrates the use of selective emphasis of visualization tools – in this case, a flint tool (shown in the right side of the figure), depicted only by its contours in the left figure, in order to evaluate

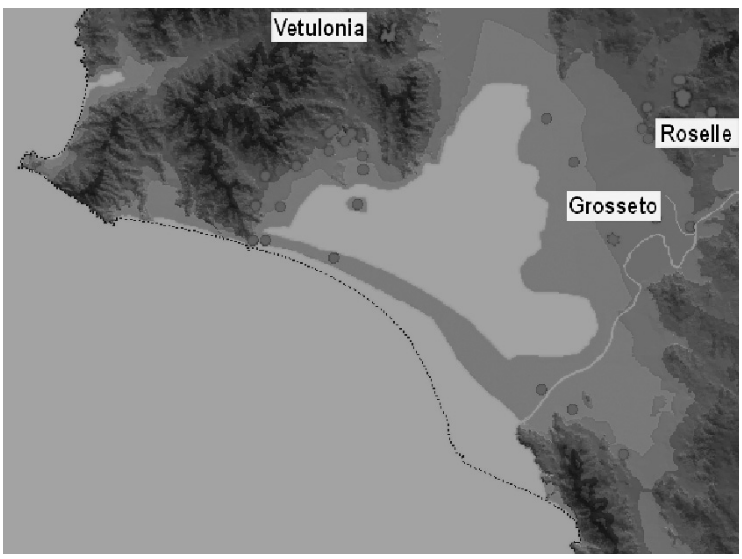

Fig. 8. 3D model of Tuscan coast temporal development and settlement pattern (Ceccarelli and Niccolucci 2003)

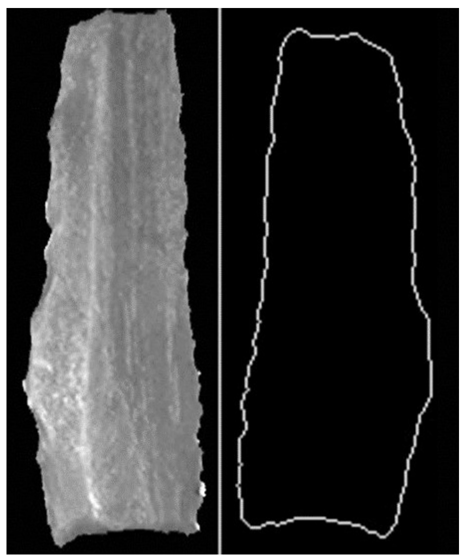

Fig. 9. Flint tool and selective contour (after Hermon, Calori and Petrone 2001)

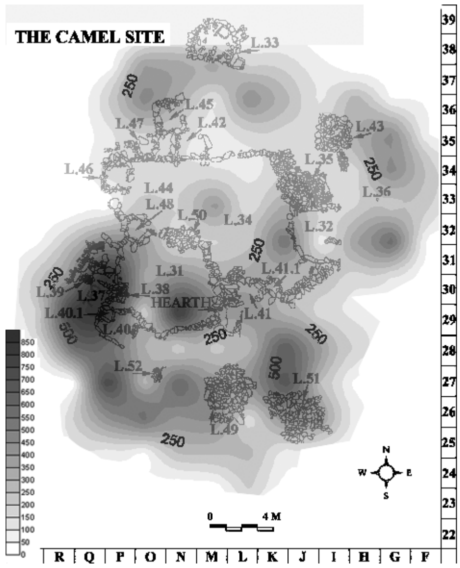

Fig. 10. Spatial distribution of flint artefacts at a prehistoric site (Hermon and Rosen, in prep.)

the regularity of the edges of the tool, an important attribute when classifying these objects. Thus, the contour can be processed and further transformed into a mathematical formula enabling a fast and reliable classification of objects, according to pre-definite criteria (such as regularity of edge, shape of ends, etc…), a process that is done usually manually in the lab, requiring much longer time than the computer processing; moreover, the computer classification would increase the reliability of the classification, being based on "objective" criteria, *a priori* defined by the user.

2. A second way in which visualization tools may help the archaeological scientific research is the **transformation** of non-visual data into a visual image by mapping its values into visual characteristics.

The example in Figure 10 displays a simple representation of the spatial distribution of flint artefacts within the confines of a habitation area of a prehistoric site.

A simple superposition of a density map of the flint artefacts over the architectural plan of the site revealed important information, easily retrievable from the visualization of the image: the highest density of flint items is in close vicinity to a hearth, within the confines of a habitation structure, while open areas, which probably served as animal enclosures, are poor in terms of flint artefacts. Thus, numeric data (quantity of flints in each excavation square) was transformed into a distribution map and visualized by being superimposed on the architectonic plan of the site under investigation.

3. contextualization – is the provision of a visual context, or framework, within which data is displayed and investigated.

The example in Figure 2 (discussed above), is a simple example of how human social interaction with the environment, the settlement pattern and its relation with its surroundings, the subsistence economy and many other aspects approached when examining the human settlement of an archaeological site are enhanced when provided with the visual context of the subject under investigation (in this case, the archaeological site and its interaction with its environment).

Summary

The last decade has witnessed a constant growth in VR and 3D models applied to archaeology. However, despite the great potential of VR as a research tool, already applied in most disciplines, it had little impact on archaeological scientific research, the latest developments in the field concentrating on improving computer graphics methods and artistic skills rather than adopting 3D modelling and VR in the archaeological reasoning process. Often, a typical question of archaeologists being confronted with a VR model would be "how accurately it represents the archaeological reality", and if so, an artistic evaluation of the product would follow, and rarely "how it can enhance my understanding of the past?". This articles proposed to view VR as a tool with its own methodology, which can greatly contribute to the archaeological research, having it position on the reasoning pipeline after the classification of the data and before disseminating the result – VR can be used as a medium for visually expressing numerical data, ideas and check hypotheses, gathering various data formats and giving them a visual form, which can be analysed and subjected to deconstruction. Moreover, in VR, one can freely move in 3D, but also in 4D, by creating predictive models or evaluating scenarios and alternative of past events, given particular parameters. In this sense, VR can serve the archaeologist as a "time-machine", by visualizing the past environment (the archaeological world under investigation), and allowing its study "from within", the archaeologist being an integrated part of the VR model that represents his/her depiction of the past under scrutiny.

VR also facilitates the transformation of data into information and into knowledge; having no language barriers, (an image does not need to be translated), it sustains the communication between the scientific community and the dissemination of both the reasoning process (data transparency) and the final results in an easy-to-understand format.

Thus, a VR model, which can be viewed as a simulation of an environment, constructed with the meaning of shedding light on an insight of a particular problem or to predict the behaviour of a particular phenomenon, can be used as a research platform where multiple format data are integrated into an homogeneous system, which allows the creation of an integrated archaeological research framework.

VR and 3D modelling applications in museum environments

Three basic requirements describe Virtual Reality systems: immersion, interaction and visual realism. In the following paragraphs, each one of these characteristic will be summarized.

Since we, archaeologists, are trying to "reconstruct the past" and archaeological museum display objects from the past "ripped" from their original space/time context, the users (museum visitors) must "***immerge in time***" in order to understand the exhibited objects and perceive them not as art objects but rather as artifacts with a history within a well-defined context (***look at the past with the eyes of a past viewer***). Visualization can be used as our "time machine" in order to achieve this goal, through the reconstruction of the desired (past) scene, its population with virtual humans (optional) and the possibility of the user to interact with the ancient world reconstructed. Intuitively or based on previous knowledge, the user (the visitor in the museum) will be able to experience actions and see past environments. This "time travel" could be performed either by changing the time scale, the visitor being able to discern changes through time in a delimited space, or, alternatively, "visiting" different environments in a given time slot. Relatively simple and on-hand applications to achieve these products are game engines utilized to create interactive environments, either role games or adventures based on real events.

The ***interaction*** of the user with the virtual environment should be made as simple and as intuitive as possible stimulating the curiosity of the user and his/her willingness to further explore the system, providing the user with a full transparency to the metadata. Needles to say, the interaction should be adapted to user needs and the environment of the system.

The ***level of trustworthiness*** is measured by the capability of the system to display a clear demarcation line between the real and imaginative; at the same time, whenever different explanations of the illustrated phenomena are available, they should be displayed, the user being able to choose whichever version should be displayed. Moreover, each alternative visualization (model) should be complemented with the relevant metadata and a contingency evaluation of the version.

When involving VR and 3D models in communicating Cultural Heritage, it is important to trace down and define the inter-relationship that should exist between the information source (what is projected, transmitted: a movie, an interactive game, a film, etc), the interface through which the information is transmitted and through which the public interacts with the information (a computer mouse, a touch-screen monitor, a virtual theatre, an exhibition, etc) and finally the target public of the information transmission (a group of people, single persons, virtual visitors, etc). Needless to say, the location of the system (the exhibition space) is of particular importance (open/close space, size of space, luminosity of the area, etc), since it will have a strong influence on the way the information will be perceived by the public.

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