CHAPTER 3
Reasoning in 3D: A Critical Appraisal of the Role of 3D Modelling and Virtual Reconstructions in Archaeology

This article discusses the use of 3D modelling techniques and virtual reconstructions in archaeology, arguing that, while they are widely used for broadcasting a tangible cultural heritage to both specialized users and the general public, they are not often used for digital, virtual conservation of objects or monuments, and are even less often employed in the reasoning process of archaeological scientific research, despite the fact that a great deal of archaeological work is often invested in building 3D models and the virtual objects/worlds. Consequently, here we present basic concepts of 3D modelling and virtual reconstructions and their potential use in archaeological research, mainly as part of the process of investigating and interpreting data; more precisely, as part of the process of turning data into information and into knowledge. By building a 3D model and a VR world, archaeologists can uncover new scientific questions and problems that might be otherwise missed through traditional research.

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Introduction

Early VR and 3D modelling projects involving archaeological data began as early as the late 1980s and early 1990s (for an extensive survey of the history of VR, see Frischer et al. 2002). At about the same time, there were proposals of possible applications of VR and 3D modelling techniques for solving archaeological problems (Reilly 1989; Reilly & Shennan 1989; Sims 1997). The field gradually advanced, and new models and projects virtually reconstructed archaeological sites, monuments, and artefacts. By the end of the 1990s, several major publications summarized theoretical aspects and practical work in virtual archaeology (Forte & Siliotti 1997; Barceló et al. 2000; Niccolucci 2002). These years also saw the first attempts to establish standards and propose methodologies for the use of VR and 3D modelling techniques in archaeology, especially for communicating data by means of these techniques (Ryan 1996). Others explored the historical credibility of the VR and 3D products, the accuracy of the products from an archaeological point of view (Kanter 2000; Frischer et al. 2000), and the need for transparent data (Forte 2000).

The use of VR projects is constantly increasing, as can be seen in the annual Computer Applications in Archaeology (CAA) conferences, a major stage for presenting innovative projects related to VR. The 2001 conference featured five lectures concerning VR (cf. Burenhult & Arvidsson 2002). By 2004, almost three dozen papers on VR topics were presented. A clear trend can be seen towards two major subjects: communicating cultural heritage to the public and presenting new methods for improving the quality of the VR product, whether from an artistic or computer graphics point of view (a ‘pitfall’, at least from a strict archaeological point of view, already pointed out by Ryan 1996). If we include presentations at VAST conferences from 2000 to the present (e.g. Arnold et al. 2003; Chrysanthou et al. 2004), there is a large bulk of information, more than a hundred articles, dealing with various aspects of VR and archaeology. Most of these papers are concerned with different aspects of computer graphics innovations and educating the public about cultural heritage.
artefacts and sites through VR and 3D models. Very few examine the methodological and theoretical aspects of VR and 3D modelling applications in archaeology (e.g. Vatanen 2004) or use these tools as an investigative aid for archaeological problems (e.g. Beex & Peterson 2004). Therefore, after a five-year boom in VR and 3D modelling archaeological projects, hardly any of these projects have impacted or changed archaeology.

Several questions arise at this point: should archaeologists bother at all with VR and 3D? Beyond an occasional consultation on the ‘credibility’ of the VR model, they become no more than authentication tools—’is the model archaeologically proven'? And does VR actually benefit the field? More strongly emphasized, why should archaeologists spend the time and effort that VR requires? Why not leave it to computer graphic specialists? An immediate answer is that any research result must be communicated to the public, and VR and 3D modelling has proven itself as a most efficient tool for communication of cultural heritage. More importantly, the research process can benefit from these tools in the investigation of human past activity and its context. They can also be linked to a more general issue regarding the archaeologist’s goals (beyond the obvious—excavating is fun!) of reconstructing human history and daily life from cultural remains and their natural context. It is precisely here that VR and 3D modelling can make a great contribution, by visually expressing alphanumeric data and by graphically expressing thoughts and ideas, and translating ‘empirical phenomena into geometric language’ (Frischer et al. 2002: 11). This point has also been made by Niccolucci (2002: 3):

 [...] 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.

The following paragraphs will present some basic VR and 3D modelling concepts and how they can contribute to the archaeological scientific process.

**VR and 3D models: basic definitions and applications in archaeology**

A simple and comprehensive definition of VR is the simulation of a real or imagined environment, experienced visually in three dimensions (cf. Jones 1996; Rosenblum & Cross 1997). In order to understand and analyze the complexity of the real world, people draw pictures or build abstract descriptions or models. By focusing on selected details and relevant factors, we can build models that explore a particular problem or predict the behaviour of a particular phenomenon. A model has value, however, only when it can provide insight to some situation or answer a specific question, and the model can be analyzed, i.e. is accessible to critical evaluation (Jones 1996).

Thus we see VR’s potential. In order to understand a past human activity, we must imagine it and thus reconstruct its context, whether environmental, anthropogenic, or social. Once this context is made visual, it becomes mobile, immutable, and reproducible (Latour 1986). Researchers in cognitive psychology have found a positive relationship between the ability to visualize (to manipulate or transform an image of spatial patterns into other arrangements; cf. Ekstrom et al. 1976) and the use of visualization tools (Sein et al. 1993). The implication is that the better the visual tool, the better the explanation and the comprehension of information. VR and 3D visualization of concepts, objects or spaces and their contextualization provide a visual framework in which data is displayed. The example in **Fig. 1** demonstrates the difference between a traditional and a 3D presentation of data. Being interactive, the 3D model can be rotated. All of its views can be captured and analyzed as in a traditional presentation. But additional data are added and made available for interpretation. A quick glance at building heights and tower shapes and heights make clear the visual range of soldiers on guard. The 3D visualization of the military
camp also helps estimate its spatial organization, such as efficiency of movement in case of emergency: the model could be populated with soldiers running from barracks, climbing the ladders, and readying for battle, to see how easy it would be move about under different circumstances.

3D visualization is also an invaluable method for turning data obtained during the excavation, survey or investigation of the archaeological site into information that is available for further study and investigation, as well as generating a portable form of the elaborated data. VR enables interaction with data organized on three dimensions, facilitating the interaction between human, data, and information (cf. Stone 1998; Warwick et al. 1993). There are increasingly large amounts of information being generated by all scientific fields, and visualization helps to access, manage, interpret and share all of this data (Tufte 1990). The displayed environment shown in Fig. 2 is based on the results of several otherwise disparate fields of enquiry. Geomorphological studies estimated the erosion degree and thus the shape of the valley where the habitation is located. Palynological work studied fossilized pollens and spores, and paleobotanical and paleoclimate studies examined plant life and climate in the area. Finally, human habitations in the area were recontructured from ethnographic and architectural work on human remains. All this information was used to estimate changes in the environment’s ecology over a given period of time, as estimated by radiometric dating methods.

Moreover, 3D visualization allows experiments or simulations (based on scientific rules and constraints). The interpretation of accurate predictions or numerical simulations (Silver 1995), in turn, permits the investigation of new phenomena. For instance, Fig. 2 could be used to simulate available land for agriculture, and the amount of labour invested in deforestation could enable an estimate of the population of the archaeological site under research and its subsistence economy.

**Fig. 2.** Reconstruction of the environment of an archaeological site (after Negroni Catacchio & Cardosa 2001).
Fig. 2 demonstrates another aspect of 3D visualization, which is the conversion of data from an alpha-numeric to a visual display. In other words, VR transforms information, making it more accessible to the human eye and more easily perceptible (Friedhoff & Benzon 1989; Brown 1997). The two methods contain the same information, but the visual display translates a table of palynological data into a realistic representation of vegetation. This stimulates new questions regarding the relationship between the human settlement and its environment, such as catchment analysis, how exposed the habitation areas would have been to forests, and so on. Fig. 3 further exemplifies the capability of 3D visualization to enhance perception in the context of scientific interrogation. Pliny the Elder, quoting an earlier historical source (Marcus Terentius Varro), describes a mausoleum apparently built by Lars Porsenna, last of the Etruscan kings and ruler in Clusium (present-day Chiusi, Tuscany). The mausoleum was apparently destroyed by an earthquake in the 5th century BC. All traces were erased in Pliny’s time (1st century BC). A virtual reconstruction of the mausoleum and its scientific analysis would therefore 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), enables the detailed virtual reconstruction of the monument. The model can be subjected to architectural analysis (static and dynamic laws) to test whether it is structurally feasible. Alternatively, it can be used to posit other possible models, taking into account the soil characteristics, building materials and engineering knowledge of the period, and possible location. Needless to say, there are certain requirements for building a scientifically valid 3D model. The resources and assumptions upon which it is based should be explicitly presented (Allen 1998) and open to evaluation, while alternate reconstructions should be made available to the user (Roberts & Ryan 1997).

Moreover, 3D visualization can be enhanced (as 4D) through predictive models, evaluating scenarios, alternative versions of past events. In this sense, VR allows archaeologists and the public alike to view the past in a more experiential way, from within a certain time or place.

The process of 3D modelling

A virtual representation of an archaeological entity is based on data originating from various sources, such as historical records of graphical nature (ancient maps, drawings, paintings, mosaics etc.), texts, archaeological field investigation (surveys, soundings or excavations), comparative studies, and, last but not least, the modeller’s informed imagination. Fig. 4 shows the typical stages of 3D modelling and its basic components, which can also be expressed as an equation where the various kinds of data are the variables [Fig. 5]. It should be stressed that these variables are in turn informed by further, usually unrelated to each other, variables (e.g. accuracy of measurements, reliability of historical texts, ancient maps etc.).

1. ‘Namque et Italicum (labyrinthum) dici convenit, quem fecit ibi Porsenna rex Etruriae sepulcri causâ, simul ut externorum regum vanitas quoque ab Italis superetur. Sed cum excudat omnia fabulositas, utemur ipius M. Varronis in expositione ejus verbis: Septultus 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, quattuor in angulis, in medio una: in imo latae pedum quinquis septuagenûm, altae centum quinquagenûm: ita fastigatae, ut in summo orbis aeneus et petasus unus omnibus sit impositus, ex quo pendeant exapta catenis tinnundula, quae vento agitata, longe sonitus referant, ut Dodonae olim factum. Supra quem orbem quattuor pyramidis insuper, singulae extant aliae pedum centenûm. Supra quas uno solo quinque pyramides; quarum altitudinem Varronem puduit adjunctore’ (C. Plinius Secundus, Naturalis Historia 36.18.4).

2. The Latin text above states that the monument was ‘under the city of Chiusi’. There are legends of labyrinths and hidden treasures in the many underground passages that still exist today in the city’s old centre. However, a monument of such size—an estimated 190 m in height—would be by far the largest monument in antiquity and was most probably located outside the city, e.g. in a nearby valley. The 3D visualization in Fig. 3 allows us to put the historic source to the test, in terms of whether the monument described is structurally feasible.
In order to evaluate the model’s reliability and allow its (virtual) deconstruction, various steps need to be taken to arrive to the final \(M_n\) and alternative \(M'\) models, from the first draft \(M_0\) [Fig. 6]. After examining the surviving building, any collapsed elevation material around the tower, any existing parallels (in this case, a church tower bell of the 12th century), as well as the relevant historical sources, a first reconstruction can be attempted \(M_0\). On this basis, it is then possible to create two further models: a version of the building with defensive elements \(M_n\), and a version that features a bell-tower \(M'\). An oblique line clearly distinguishes the actual, surviving features from the reconstruction. At each step of the reconstruction process, metadata are generated (for more on sources and their reliability, Niccolucci & Hermon in press). This permits data transparency and satisfies scientific requirements for the model. The relationship between archaeology and VR should be explicitly stated, for instance through a slider interface on the display system that allows the user to choose what data is displayed (e.g. ranging between archaeological reality, ‘1’, to conjecture, ‘0’). Unreliable data or conjectural elements should be displayed as ‘ghosts’, i.e. alternative models in fainter colours.

**Visualization tools and basic requirements**

Visualization tools can be divided into two main groups: interpretative and expressive (Gordin et al. 1996; Nielson et al. 1997). The former help users to view and manipulate visuals, extracting meaning from the information being visualized; they help clarify difficult and/or abstract concepts (Levin et al. 1987). One such use of 3D visualization is exemplified in Fig. 7, showing a vertical cross-section of the old centre of the town of Chiusi, in southern Tuscany. The large building is a 16th century palace. The cellars, some of them of Medieval date, provide access to a series of underground tunnels and a complex water system from the Etruscan period. Users can investigate the superimposition of the various strata and follow Chiusi’s urban development. Information about the Etruscan
Fig. 6. 3D model and alternative model (after Niccolucci & Hermon in press).

The water system, its tunnels, and the subterranean lake can be used to study water systems in later periods and technical development over time. Using the same data, the model can also aid the study of the Etruscan water-supply system, by simulating the process of tunnel-digging, and showing the tunnels’ inclination, probable length and height, as well as the amount of accumulated water in the cistern. The user gains a realistic impression of the underground system and is able to select parts of the conduit, or the entire complex, for viewing from a number of angles.

Expressive tools, on the other hand, visually convey sets of beliefs, cuing and accelerating comprehension through visual coding. Fig. 8, a screenshot from a digital elevation model (DEM), shows part of the Tuscan coast that endured major changes through the Quaternary. These changes culminated in modern times in the formation of a lake, Prile, where there was once an open sea and a bay. The model shows the relationship between the changing landscape and the human settlement pattern and the inhabitants’ subsistence economy. The modern coastal line is displayed as a line connecting the two parts of the former bay. Human occupation sites are represented by dots, which are colour-coded to indicate particular historical periods ranging from the Upper Paleolithic to the Roman periods.

Among the various methods available for data manipulation and information creation, selective emphasis allows the user to detect, identify and visualize hidden patterns by highlighting or hiding parts of the visualized data (Erickson 1993). Fig. 9 illustrates this application. To evaluate the regularity of the edges of a flint tool, an important attribute for classifying these objects (cf. Hermon et al. 2001), the tool’s contour can...
be selectively visualized and subsequently processed into a mathematical formula, enabling fast and reliable classification based on predefined criteria. This process, when done by hand, is not only time-consuming but also less reliable than the automated application of a priori classificatory criteria (see also Karasik et al. 2004; Karasik this volume, for a similar approach to automatic classification of pottery).

The transformation of non-visual data to an image can clarify the former and allow for new interpretations (cf. Risch et al. 1996; van Teylingen et al. 1997; Freeman et al. 1998; Herman et al. 1998). And, contextualization provides a visual framework within which data are displayed and investigated (Erickson 1993). Looking back at Fig. 2, for example, shows how human social interaction affects the settlement pattern and its relationship with the surrounding environment, as well as the subsistence economy.

Summary and conclusions

The last decade has witnessed a growth in VR and 3D modelling in archaeology. However, despite VR’s great potential as a research tool and the fact that it has already been used in many disciplines, it has had little impact on archaeological scientific research, in the sense that the 3D modelling and VR toolkit has not been fully adapted to the archaeological reasoning process. There is too much emphasis on artistic, instead of intellectual, aspects; typically, archaeologists are concerned with how accurately a VR model represents archaeological entities, not how it can enhance an understanding of the past. Nevertheless, VR can greatly contribute to archaeology, its ideal place on the archaeological chaîne opératoire being perhaps after data classification and before data dissemination. It enables the visual expression of numerical data as well as abstract notions, serves as a platform for hypothesis-testing, aids the integration of various kinds of data in a visual form. It permits not only reconstruction, but also deconstruction and alternative interpretations. Evading language barriers, visualization fosters inter-cultural communication in the scientific community and the public. The dissemination of both the reasoning process and the final results in planned and intuitive fashion encourages the transmission and understanding of information. Therefore, VR facilitates the transformation of data into information and knowledge.

Bibliography


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