The concept of virtual archaeology was first proposed by Paul Reilly (1990) to refer to the use of 3D computer models of ancient buildings and artefacts. The key concept is virtual, an allusion to a model, a replica, the notion that something can act as a surrogate or replacement for an original. Virtual reality is being used as a generic word to refer to the growing range of dynamic-interactive visualisation (Gillings 1999, Lloret 1999). Virtual reality is such a hot concept that many people tend to use it even when its use is logically inappropriate. It should be defined as those environments where the human operator is transported into a new interactive environment by means of devices that display signals to the operator's sense organs and devices that sense various actions of the operator. Consequently, many archaeological three-dimensional representations currently displayed in books and videos are not VR systems because there is not this sensitive interaction.

In this volume, you can read (and see in the accompanying CD-ROM) many different applications. From reconstructions of Megalithic monuments to Medieval churches, from Egyptian musical instruments to Roman pottery. In all cases, archaeological data have been translated into images by means of 3D solid modelling. Images help understanding of the complexities of archaeological concepts in many different ways.

The book is divided into several parts: introductory papers, technical papers and archaeological applications.

The first papers (by Barceló, Sanders, Kantner and Holloway) are more general and have an introductory character. The main objectives of virtual reality are presented, and some of the techniques are explained (see especially Holloway's paper for a technical introduction to 3D modelling).

This book offers a complete overview of virtual reality techniques in archaeology. However, approaches are very different, and somewhat difficult to compare for readers without technical knowledge in this subject. Therefore, J. A. Barceló's introductory paper has been written in order to give a preliminary idea about what a 3D solid model is, what kind of model is a computer model, how to build it, and how to use it. Image construction is a reasoning process. Our brain builds images by processing knowledge in specific ways. Because of the quantity of information computer visual models can explain, we must insist on the procedures of image construction. This is the main subject of this first paper: to explain how a virtual archaeological model can be built, and how this process of model building is, in fact, a reasoning mechanism of explanation. We think by building images instead of writing texts. In the paper, the concept of visualisation is first introduced, with a short discussion of the quantitative nature of archaeological data. Different approaches to data acquisition (video-capture, photogrammetry, computer tomography, 3D scanning, and the like) are also presented, and how to build a model once we have obtained real data. Different methodologies are examined, and some relevant archaeological examples are also presented. The difficult concept of reconstruction is also shown, especially questions about how to complete fragmented archaeological data. A general introduction to rendering, texturing and illumination (but see the papers by Lucet, by Pope and Chalmers, and by De Nicola et al.) gives some clues to the concept of realism and why we need realistic models. A final presentation of interactivity and the basis of augmented reality ends the paper. Throughout the paper, the most current archaeological applications of virtual reality techniques are quoted as examples of different approaches.

In his chapter, Donald Sanders reviews some of the drawbacks of traditional methods of publishing, counters
with alternatives based on the use of virtual reality, touches on some complications of new media technologies, and concludes with some innovations that may usher in virtual archaeology of the new millennium. The focus of his chapter is how archaeologists can use virtual reality for the dissemination of archaeological material via excavation reports, teaching materials, and research resources. John Kantner considers how decisions in the creation of virtual architecture are further constrained by the goals of the project and the intended audience, the desired product, the quality of archaeological information, and technological capabilities. The chapter examines how to balance realism vs. reality, and ends by examining how these issues have been addressed in 3D reconstructions that the author has made of prehistoric architecture from the southwestern United States. Dennis Holloway offers an architect’s perspective on the shape of prehistoric buildings and monuments, giving examples and a general framework for building good reconstructions of prehistoric buildings. His examples, taken from the southwestern United States, are related to those presented by Kantner.

A first block of technical papers deals with the problem of data acquisition. In order to solve the realism vs. reality paradox (see Kantner, this volume), we need that the model be a representation of real data. The papers by Gillings, Pollefeys et al., and Attardi et al. introduce different methods of data acquisition, and how a 3D model can be created which fits the empirical data.

Gillings’ paper is an attempt to answer the question: what does it mean to describe something as virtually real? He presents issues such as the relationship between “model”, “reality” and “authenticity”. The Negotiating Avebury project is also examined, within a broad theoretical framework, emphasising the fluidity and contingency of VR models as fully mimetic modes of representation. The goal of the project has been to integrate VR techniques into the generation of primary archaeological records. In this way the idea that VR simulations could, and should, be seen as a natural and complimentary adjunct to the familiar maps, plans and elevation drawings of traditional archaeological research, is strengthened and reinforced. In the Avebury research, VR models are first and foremost seen as primary records, linked directly to specific archaeological problems. For example, to what extent does the bulk of the stones constrain vision within and across the monument? Rather than the creation of a single monolithic “Virtual Avebury” the aim is to create a large number of highly contingent “Virtual Aveburys” through which it will be possible to examine particular questions and problem areas. Directly related to this theoretical discussion, there is the problem of data acquisition, because the more reliable the data, the more useful is the resulting model. The commercial program PhotoModeler is presented, including a number of archaeological applications. Photogrammetry and direct image capture is the subject presented in the other technical papers. Pollefeys et al. compare two different 3D acquisition techniques which have been applied to reconstructions of objects, monuments and buildings of the archaeological site of Sagalassos (in Turkey). Attardi et al.’s paper is a good example of seeing what cannot be seen because it is hidden. Using remote sensing methods (computer tomography), they explore what is inside a mummy, and offer an hypothetical view of the real face of the person. Also related to photogrammetry is Feihl’s paper, in the archaeological applications section.

A second block of technical papers concerns rendering and lighting. Papers by Lucet, De Nicola et al., Pope and Chalmers, Pásztor et al., and Goodrick and Harding, offer a general overview of algorithms and detailed archaeological applications of how to give photo-realism to a 3D computer model. Developing some of the theoretical guidelines presented before (Kantner, Gillings), Genevieve Lucet argues that artistic exploration cannot be the underlying idea of archaeological reconstruction. Archaeology demands exactness and accurate visualisation of architecture, before its aesthetic presentation. In consequence, if one of the aims of a virtual reconstruction of archaeological sites is to obtain a realistic reproduction in order to achieve a close approximation to the original building as it was conceived and constructed by its builders, and if archaeologists want to experiment and live such ancient space, it becomes clear why the precise modelling and simulation of light is a key aspect of realistic reconstruction. De Nicola et al. show how to test and develop a methodology able to fasten and optimise the operations and the times of the photorealistic ray tracing processes. It is exemplified with data from the excavation of an Avarian Age cemetery (7th century AD). Pope and Chalmers present a different rendering algorithm, based on how sound and echoes propagate in closed environments. This methodology is applied to the underground prehistoric Hypogeum at Hal Saflieni, Malta. Pásztor et al. present rendering and lighting algorithms to analyse a specific historical hypothesis: whether the light of the rising sun on the megalithic monument of Stonehenge during a particular occasion interacts with the building in a way that could have been used as an architectural element to enhance proceedings taking place inside it. This computer study deals only with the light and shadow effects generated by the rising summer solstice sun. Very similar is the paper by Goodrick and Harding. They analyse whether the Neolithic monument complex of Thornborough in North Yorkshire was orientated towards stellar constellations, many of which are known to have been so important to other cultures. This could only be achieved with the use of virtual reality or related visualisation techniques, simulating the sky at night with all known stars and constellations in their proper places.
If most VR applications in archaeology intend to reconstruct ancient buildings or monuments, two contributions in this book deal with the replication of archaeological artefacts. C. Steckner analyses the visualisation of ancient pottery artefacts and the estimation of their shape and weight. Here the statistics and geometry of shape meet Artificial Intelligence and Virtual Reality, the one focusing the average object, the other the exemplary shape construction. Brogni et al. offer an example of interactivity between the user and a 3D virtual object. The goal is not only to reconstruct the artefact's shape, volume and texture (an Egyptian flute), but to create an interactive system where the user can use a virtual model of the flute.

Especially interesting are the design of interactive systems, where users can become immersed into a virtual world. The same paper by Brogni et al. is a good introduction to the subject of interactivity. Their system allows total access to the information about the archaeological artefact by means of an environment with text-windows and buttons (Graphic User Interface), which allows us to interact with the application and guide the consultation. The screen is held by the user and pointed along the line of sight to the real position where the artefact would be located. At present this application is used for the representation of an Egyptian glass flute, but it is a suitable platform for every artefact, and the virtual environment could even be a tomb or an ancient palace. The visitor gives orders by touching the screen on graphic buttons, located on the side of the screen, which are easy to hit with the same fingers that hold the screen. At the same time the tracking sensor gives all the information about the movement in the real space relative to the central system, which can prepare the new image for the screen according to the new point of view. During the virtual exploration, it is possible to retrieve particular information about the figures in the decoration of the flute. By touching a button, the virtual exploration stops and a window opens with a photograph and an explanation text.

A different sense of interactivity is explored by Kadobayashi et al. They introduce the idea of Meta-Museum, which is a new environment where experts and novices can easily communicate with each other so that they can share broad knowledge related to all aspects of humans and nature. A practical formation of Meta-Museum would be a combination of traditional museums that have physical objects and virtual museums that have digital information. Kadobayashi et al. have developed the VisTA and VisTA-walk systems based on the Meta-Museum concept. These systems simulate the transition process of an ancient village. Users (here it may refer to experts) can visualise the transition process through real-time 3D computer graphics after they interactively set the value of each building's lifetime. Users intuitively learn the ancient landscape of the site because they can walk through the reconstructed 3D computer graphics village. The systems provide intuitive information access through the selection of objects such as buildings in the 3D computer graphics scene. Hence, VisTA will serve the users as a tool for helping them research and easily make effective presentations. They propose a new interface, a full-body and non-contact gesture interface, for exploring cyberspace that does not require visitors to wear extra devices; it is easy to use and at the same time can provide an immersive walk-through and information accessing capabilities. The name of the system with the new interface is "VisTA-walk." The expected users of VisTA will be archaeologists, and the users of VisTA-walk will be museum visitors, although this is not a strict definition.

It is interesting to compare the Meta-Museum concept with the Nu.M.E. concept in the paper by Bonfigli and Guidazzoli. Here virtual interaction is obtained through the Internet and a series of web documents. Interacting with the Nu.M.E. interface the user begins with the virtual reconstruction of a city as it is nowadays and travels backward in time using the time-bar. As the user travels back in time, recent buildings dissolve into the ground and ancient buildings that no longer exist pop up. To make sure that the visitor understands that he/she is seeing only as much as the historical sources can justify, each building is accompanied by an HTML document compiled by a historian. These hypertexts contain references to the historical resources and can be consulted at any time during the visit. Bonfigli and Guidazzoli offer a detailed examination of the Virtual Historic Museum of the City of Bologna as an example.

Internet interactivity by means of VRML documents is also considered in the introductory papers by Sanders and by Mitchell and Economou. Sanders describes three types of archaeological publications (excavation reports, research resources, and educational materials) that can be created as VRML documents, thus allowing them to be accessed via the Internet. The advantages include their immediate accessibility as well as the ease with which they can be updated as new data is collected and analysed. In Mitchell and Economou, the Tomb of Menna project is presented to investigate how the Internet can be used to provide access to archival material from the Griffith Institute at the Ashmolean Museum, Oxford. A web site was constructed based on information about the Egyptian noble Menna. The site included a 3D walk-through of the tomb as well as supporting pages containing text and photographs. A related project, also explained in the paper, is the Kahun project. Its aim is to investigate how an Internet-based resource can be used to support the work of the Education Service at Manchester Museum. The project would allow children to make the most of their time in the museum and allow
and studying the volumes in order to make detailed three-dimensional models of the monument through time in architectural aspects of the monument (plans, sections, views), analysing and comparing the historical sources, with Gurri and Gurri). The authors have projected the first virtual 3D reconstruction of the castle, starting from the presented, but also a general multimedia approach to reconstruction and historical evolution of the Castle of Este (Italy). Here not only general objectives and methodologies are possible.

The paper by Forte and Borra proposes a virtual model to produce images and animations representing the medieval town of Turku (Finland), and Junyent and Lorés present the virtual model of the Iberian hillfort of Els Vilars (Lleida, Spain). In all these cases, the goals of reconstructions and the methodologies are explained. Hixon et al. use a similar strategy to recreate ancient Yodefat (Israel). Martens et al. propose a virtual model of Sagalassos (Turkey), from the third century BC until the seventh century AD. Louhivuori et al. offer a model of the Byzantine city of Emmaus-Nicopolis (Israel). Uotila and Sartes deals with the medieval town of Turku (Finland), and Junyent and Lorés present the virtual model of the Iberian hillfort of Els Vilars (Lleida, Spain). In all these cases, the goals of reconstructions and the methodologies are explained.

Among the other papers, Feihl explains how to integrate an entire visualization project, beginning with the need to procure on site an image that is as close as possible to reality and to use advanced spatial information acquisition techniques. Further, it is necessary to work out the restitution of space and to produce synthesis images in order to illustrate the results of studies or restoration alternatives. Several Medieval examples are used for this explanation. Hixon et al. use a similar strategy to recreate ancient Yodefat (Israel). Martens et al. proposes a virtual model of Sagalassos (Turkey), from the third century BC until the seventh century AD. Louhivuori et al. offer a model of the Byzantine city of Emmaus-Nicopolis (Israel). Uotila and Sartes deals with the medieval town of Turku (Finland), and Junyent and Lorés present the virtual model of the Iberian hillfort of Els Vilars (Lleida, Spain). In all these cases, the goals of reconstructions and the methodologies are explained.

The paper by Forte and Borra proposes a virtual model to produce images and animations representing the historical evolution of the Castle of Este (Italy). Here not only general objectives and methodologies are presented, but also a general multimedia approach to reconstruction and augmented reality approach (compare with Gurri and Gurri). The authors have projected the first virtual 3D reconstruction of the castle, starting from the architectural aspects of the monument (plans, sections, views), analysing and comparing the historical sources, and studying the volumes in order to make detailed three-dimensional models of the monument through time in immersive interaction in the paper by Kadobayashi et al.

Frischer et al. give an account of the Rome Reborn project. Rome Reborn is producing its model of the ancient city of Rome in reverse chronological order, starting with Late Antiquity, and in concentric circles starting from two centres: the old civic centre in the Roman Forum and the new Christian quarter of the city in the southeast sector of the city, between S. Giovanni in Laterano and Santa Maria Maggiore. The project short-term goal is to connect the individual sites modelled and to recreate an itinerary from the pagan civic centre to the Christian religious centre. In this paper, the Basilica of Santa Maria Maggiore model is presented. The authors explain how they have built the model, integrating all archaeological and art historical information, and the different interactivity approaches designed, from video editing to Internet access. Specially interesting is the CAVE approach to total immersion, very similar to that proposed by Kadobayashi et al.

A different approach to interactivity within a virtual model is Panoramic VR. Here the user is able to induce some movements on a virtual scene, but the model is passive; it is the user who changes points of view: the model remains in its place. Louise Krasniewicz offers in her paper some examples of this technique. The alternative approach, that is, a fly-through of a landscape, is presented in the paper by Ruiz Rodriguez et al. In this case, the user does not move around a static image but sees how a dynamic representation of a landscape model moves in some directions. These computer animations with a photorealistic aspect allow the territory to be overflown.

This territory is considered as a three-dimensional space that is the basis of a historical hypothesis based on the interpretation of the archaeological documentation, in this case the Iberian population patterns in the Upper Guadalquivir basin (Spain). Travel to the time of the Iberians is based on the design and the implementation of a New Virtual Environment of the landscape of Jaén (Spain) as a virtual multidimensional environment characterised by efficient and effective navigation and orientation tools, using virtual reality and interaction techniques to represent real scenarios (the landscape of archaeological areas of interest as it is nowadays), artificial scenarios (the recreated landscape of the past in 3D reconstruction) and their integration. In particular, the multimedia navigation is based on the 3D reconstruction of the landscape, with the introduction of tools to show 3D reconstructed models interactively by addition or removal. Josep Gurri and Esther Gurri offer a good example of the current move towards enhanced or augmented reality (see also Sanders, in this volume). That is, computer animated models where the user not only moves within the model, but obtains information about different aspects of the model. Gurri and Gurri present a virtual model of the Roman city of Baetulo, nowadays Badalona (Spain). The system was approached as a didactic tool that allows the user to acquire textual as well as visual knowledge. It starts with a main menu from which the user can go directly to the ancient buildings (the Roman baths, for example) or to an introductory screen that describes ancient Baetulo. The graphic part is very important in all the screens, although there is always a voice-over that tells users more about what they are seeing. Furthermore there is the possibility of another voice-over and a text that explains the subjects with more detail. This text is referenced with hypertext, associating some concepts to images in order to aid comprehension. The main goal of this multimedia project was to provide the general public with an idea of what the Roman baths were like, how people lived, how things were done and which objects and tools were used in that historical period all in all, to reconstruct the different parts of the baths as accurately as possible.

The reader should compare this evaluation of an Internet virtual world with a similar evaluation of a full-body immersive interaction in the paper by Kadobayashi et al.
the four periods of building. Considering the complexity of the project, it was very important to use different 2D-3D metaphors so as to obtain the best cognitive impact compared to many didactic approaches to multimedia information. In fact a visualisation in multiple levels permits every user to choose the best multimedia path in accordance with his own knowledge: therefore the system must school the user, having a high regard for key-concepts and key-words, but using images and animations for communicating information. The project development emphasized the distinct information layers of the architectural periods correlated with the multimedia aims, as well as how to create a model, and the necessary interaction in the development team between the Scientific Tutor, the Modeller and the Communication Manager.

In his concluding paper, Maurizio Forte addresses some general and philosophical questions about virtuality, and the proper meaning of the virtual archaeology concept.

Virtual Reality techniques in archaeology as presented in this book (reconstructions, 3D graphics, immersive imaging) promise an accessible, highly visual, and interactive means of representing difficult-to-see data, opening up new ways of presenting research. Virtual Reality models allow us to put all of our contemporary knowledge and thought about an object into a user-interactive presentation. Maurizio Forte points out that such models are important because, "above and beyond its strong popular impact, computer reconstruction allows the presentation of complex information in a visual way that enables it to be used to test and refine the image or model that has been created" (Forte 1997:110).

The advantage of virtual computer models in comparison to traditional analysis is evident. The visualising process resulting from solid modelling can sometimes reveal relationships within an archaeological reconstruction more clearly than any other current methods of display (Fletcher and Spicer 1992, Molineaux 1992, Miller and Richards 1994). Consequently, those models permit spatial queries such as "what is next to, what surrounds, what is above, below, to the side of, etc." (Harris and Lock 1996), or the provision of complete physical properties (mass, volume, centre of gravity, moments of inertia, radii of gyration etc.), as well as the ability to generate section views, add full visual physical properties, and detect interference between adjacent components (Daniel 1997). By constructing detailed models of the excavated material, archaeologists can re-excavate the site and search for evidence which escaped attention during the actual dig (Reilly 1990). Computer models of archaeological buildings or artefacts can be linked to text, image, and sound databases permitting self-guided educational or research virtual tours of ancient sites in which users can learn about history, construction details, or daily life with a click of the mouse. As suggested by D. Sanders (1999 and this volume) alternative publications can supplement or supplant traditional paper-based source material. In this sense, archaeological virtual reconstructions can be used, for instance, to determine how much material would be required to construct walls of an architectural feature, or to evaluate different theories of how a roof might have been built, or to evaluate other archaeological hypotheses, identifying inconsistencies in the actual archaeological data and rectifying incorrect assumptions about the appearance of prehistoric features.

Some virtual models are intended for use in exploration and analysis in which the user has some ideas about what he/she is looking for, but is not fully sure. Other computer representations are often prepared for presentations intended to communicate one's findings to others. The key difference here is between the need to understand the data better, versus the desire to communicate a particular understanding that has already been reached. To date, the catalyst for visualisation in archaeology has not been the search for improved techniques for discovering new knowledge but rather for improved ways for presenting existing knowledge to the public (Miller and Richards 1994), but in the next years we look forward to new applications in many different domains.

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Applications of VR (also known as virtual reality) can be found in fields as diverse as entertainment, marketing, education, medicine, construction and road safety training and many others. They provide numerous possibilities for users to explore virtual realities for various purposes. Several virtual reality head mounted displays (HMD) were released for gaming during the early-mid 1990s. These included the Virtual Boy developed by Nintendo, the iGlasses developed by Virtual I-O, the Cybermaxx. We often associate virtual reality (VR) with thrilling experiences we may never be able to have in real life – such as flying a jet fighter, exploring the oceans or going on a spacewalk. But researchers are also starting to use this technology to study and open up access to archaeological sites that are difficult to get to. An archaeological site can be inaccessible for a range of reasons. It might be in a remote location or on private property, the archaeological remains may be fragile, or it might just be difficult or dangerous to get there. Just over an hour’s drive north from Los Angeles are various of monuments that could be seen on their land, so as to recover the architectural remains and other objects of artistic value, which they then classified in accordance with stylistic logics. The birth of archaeology, as we know it, can be situated in the 19th century when the age of the human being was recognised and demonstrated and the bases for current research techniques and methodologies set. Despite an obvious evolution (in part caused by ICT), the concept of archaeology and its publicising continues to be closely linked to objects and monuments and their artistic value. This can be seen if we analyse examples of the virtual reconstructions of archaeological
This article describes a study at the Allard Pierson Museum, the Archaeology Museum of the University of Amsterdam the Netherlands, where Virtual Reality was used to re-contextualization various archaeological objects. Based on a case study called 'Etruscanning' the article explores how User Interface design, visualization quality, and integration of the virtual environment with the physical collections on display influence the visitor experience.