**A Virtual Tomb for Kelvingrove: Virtual Reality, Archaeology and Education**
Melissa M. Terras
(The full model and article can be found at
http://intarch.ac.uk/journal/issue7/terras_index.html).

The use of computers as an educational resource in museums is becoming increasingly popular as more and more institutions realise that multimedia displays are very successful in imparting a broad variety of information. Although three-dimensional reconstructions of sites and structures have been used in archaeology for many years, the majority of museum computer installations have dealt with two-dimensional media because of the costs, equipment and labour involved in producing interactive 3D scenes.
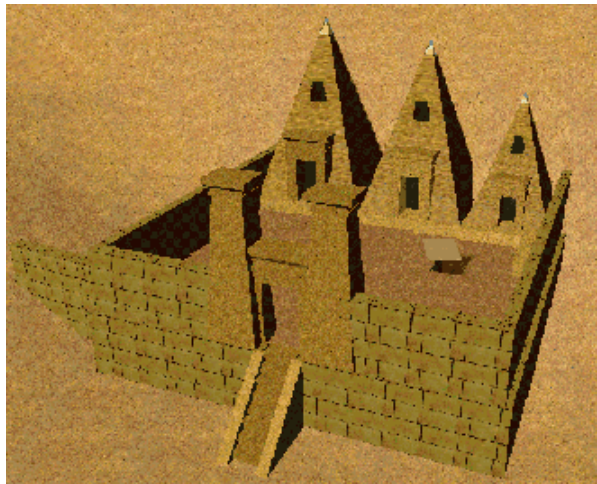
The birth of VRML (Virtual Reality Modeling Language) has changed the way virtual reality is implemented and viewed. As an internet protocol, VRML can be used on most major platforms and implemented by anyone with a word-processing package, an internet browser, and the relevant plug-in. There is no reason why this new technology cannot be adopted by archaeologists and museums to produce virtual reality models of structures, sites and objects to aid the research of specialists and the education of the public.

This project (undertaken at the Humanities Advanced Technology and Information Institute, University of Glasgow, Scotland, between May and October 1998) investigated the practicalities involved in using VRML to create a virtual reality model for use in a public space. A model of the Egyptian tomb of Sen-nedjem was developed for installation in the Egyptian Gallery of the Kelvingrove Museum and Art Gallery, Glasgow, in the hope that the introduction of this computer display would encourage the museum visitor's interest in the gallery's existing artefacts. Creation of the model would also investigate the possibility of using VRML to build accurate archaeological reconstructions cheaply and efficiently using publicly available software and existing archaeological resources.

A fully functioning virtual reality model of the tomb of Sen-nedjem has been created, incorporating interactive elements, photorealistic representation, and animation, and the model can be seen in this article. However, because of technical problems as well as the educational issues raised, it was felt that the model was not suitable in this format for inclusion in the Kelvingrove Museum. The project has illustrated that although it is technically possible to create an archaeologically based virtual model using VRML, technical issues prevent this format from being a feasible way of displaying 3D worlds in a museum environment at present. The project has also shown that the creation of the virtual reality world is only the beginning of developing a virtual reality display for use in education. Both the user interface and the informative aspects of a model have to be carefully designed to

ensure the resulting computer display has proven educational worth, and broad issues surrounding the nature of representation and reconstruction have to be addressed before such models will become commonplace in museums.

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1. The Problem Presented

The Egyptian gallery in Kelvingrove Art Gallery and Museum has remained almost the same for over thirty years. An injection of energy and life is needed to encourage visitors to the gallery to spend more time there, hopefully becoming familiar with more of the displays and exhibits as they do so. It was felt that a multimedia electronic display placed in the gallery could offer the solution to this problem. The display had to be interactive, educational, relevant to the Egyptian gallery, but not beyond the financial means of the institution. It was felt that with the growing technological developments in virtual reality (and complementary

public interest) a computer model of an Egyptian tomb could be used to give some context to the artefacts in the gallery, thus persuading the museum visitor to pay more interest to the existing displays.

The Curator of Ancient Civilisations at the gallery, Simon Eccles, had identified a tomb which was suitable for such a project; the tomb of Sen-nedjem at Deir el-Medina. This tomb was chosen for a variety of reasons. Firstly, the tomb is that of a workman on the royal tombs in the Valley of the Kings from the 19th Egyptian Dynasty. The reconstruction of this tomb would reflect the Egyptian collection of the museum, most of which comes from such individual tombs. Also, as Egyptian tombs go, it has fairly detailed, commonly available, archaeological reports which were thought to hold the information required to reconstruct the site in a virtual context (Bruyere 1959; Toda 1920). A third reason was that a 1994 publication by Abdel Ghaffar Shedid, Das Grab des Sennedjem (1994) contained comprehensive full colour images of the tomb, and, once copyright clearance was obtained, it would be possible to use these to produce a photorealistic reconstruction of the inner chamber of the tomb. (That is, if the hardware and software were powerful enough to cope with such images.) Thus it appeared this tomb not only had the necessary documentation which would allow a virtual model to be made, but it related to the collection at the Kelvingrove Museum.

The project (Terras 1998) was then an investigation into the use of virtual worlds for public education, constructing a virtual reality model that could be used in the museum. This would entail the production of the virtual reality model, the design of a user interface, and the evaluation of the model before installation in the gallery. VRML would be used as the means to generate the model; although a new development it seemed that it could provide the tools necessary to be able to implement the model at a low cost. In the process of building the display, then, the usefulness of VRML to archaeological reconstruction would be evaluated.

2. Contextual Information

Computers have been used in museums for many years, and the success of multimedia installations in imparting knowledge has led to an increase in the use of electronic displays for public education in the museum sector. Computers have also been extensively used in archaeology (Kvamme 1992; Ross et al. 1991) and computer reconstructions of sites have been shown to provide much knowledge about a structure. Virtual reality has always been popular with the public, but until recently archaeological computer reconstructions were too costly and difficult to produce and support to allow interactive public access to the models. The development of VRML as an independent three-dimensional modelling tool has created many opportunities for developing computer displays which allow the museum visitor to interact with a virtual environment, heightening the learning experience. Future developments may lead to the increased use of virtual reality as an educational tool (Mathur 1997; Mitchell and Economou 1997). However, the use of multimedia and virtual reality in a museum setting carries its own practical and theoretical problems.

2.1 The use of computers in museums

Interactive computer systems have been used in the museum sector since the 1960s (Economou 1997). Although the first projects merely converted museum records into digital format, over the last thirty years computers have become integral to the running and maintenance of museums. Today, multimedia systems are used in museums to support collection management, administration and the preparation of exhibitions. Increasingly, museums are using multimedia in public displays such as information kiosks, orientation devices, interpretation media, or even main exhibits.

Museum collections are often very complex, dealing with a variety of cultural phenomena. Artefacts and displays can be viewed from many different perspectives; often objects have aesthetic, religious, historical and emotional characteristics, and the museum curator has to try to present the information in a way that makes sense of the complex inter-related links between objects. Multimedia systems provide one tool with which the museum can store and deliver complex cultural information. Different media (text, sound, and the moving image) can be integrated with existing displays and information from external sources, providing a means of disseminating knowledge to the visitor. The interactivity of these displays generally means that the experience is individual to each user; often systems are structured to support different levels of knowledge, and the user is free to navigate through the system at will. Computer installations have the potential to invite active participation from the audience, stimulate interest in a subject, and increase accessibility of collections. Tests have shown that when presented with an interactive multimedia system, the user pays more attention to the existing collection, and recalls more information about the visit afterwards (Economou 1997).

However, although museums have experimented with multimedia, there are many factors that have inhibited the widespread use of technology in museums. Installations usually carry high development and maintenance costs, and require staff training. There is a lack of standards, both in the quality of subject matter and the technicalities of creating a multimedia system, and issues such as copyright need to be considered. It is only as costs of multimedia systems decline and museums become more aware of the potential of such systems that their use will become more widespread. Museums are learning from their experiences, and the standards of electronic displays are improving rapidly.

2.2 3D Computer representation and archaeology: a brief history

Archaeology is by necessity a very visual subject. Data collected are often large and complex, and the exploration of different configurations and interpretations of the evidence is possible through graphical representation, whilst at the same time displaying large amounts of information. Over the last thirty years, various computer systems have been employed by archaeologists to illustrate data and facilitate their interpretation. Computer Aided Draughting and Design has been used, adopted from the engineering industry, to automate the draughting of plans and drawings. In recent years, Geographical Information Systems have been used by archaeologists to provide the analytical engines necessary for the automated investigation of archaeological data. Since the 1980s, there has been a steady increase in the use of solid modelling applications to solve archaeological problems (Daniels 1997).

Computer modelling, as an attempt to understand the real world by the construction of a simplified representation, can facilitate the description and analysis of the large amounts of data associated with three-dimensional reality, and so is immediately attractive to archaeologists. Both surface and solid modelling have been used to create three-dimensional models, encouraging an awareness of how elements are related in a structure, and, in the case of the more complex solid models, providing scope for scientific analysis of the physical properties of structures. For example, solid modelling was used to reconstruct the temple of Roman Bath. The integration of data from plans and elevations into the computer model enabled the viewer to appreciate how the temple precinct builders had

made use of space to emphasise the symbolic relationships between various elements of the precinct. Similarly, a solid model of Furness Abbey was used to gain a stronger understanding of the monument's structural history, and to evaluate the need for repair and conservation in different parts of the building. A model of the Roman legionary bathhouse at Caerleon was constructed and used to create an animation which is on permanent display in the museum, providing information of interest to the public (Wood and Chapman 1992, 134).

The early application of solid modelling to archaeology is characterised by the reconstruction of elements of monumental architecture. Whilst it is possible to use solid modelling as a means of low-level hypothesis testing of possible reconstructions, the models created have mainly been technical showcases, reconstructing architecture such as Furness Abbey about which a great deal was known in the first place (Reilly and Rahtz, 1992). The commercial sponsorship of such models by large computer firms (both as a means of publicity and a way to test their developing technologies) has resulted in high-profile projects with perhaps little archaeological significance. Often, the final objective of the project was to create an animated fly-through of the site, which, generated from a solid model, is computationally expensive. Although animated fly-throughs prove popular with the general public, it seems that the technology behind these is not being used to its full potential. There is no doubt that solid and surface modelling can produce a means of interpreting a site by providing a three-dimensional reconstruction, but such modelling is very expensive, time consuming, computationally slow, and has been criticised for its unfriendly user interfaces which are more suited to calculation than visual design. Such models are also platform dependent, and run the risk of becoming technically obsolete in the future. Solid and surface models have their place as analytical mediums, but the use of these to create animated models is unsuitable, and provides no means of interaction for the user.

2.3 Virtual Reality as a learning tool

The use within education of models to substitute for those real physical environments that are too dangerous, difficult or expensive to experience first hand is not new. Throughout human history, people have found increasingly complex ways to capture the essence of an experience and relate this to others. Painting, storytelling, sculpture, theatre, music, books, radio, television and film all serve to stimulate the imagination and give an audience a sense of 'being there'.

In education, this 'cultural - data visualisation' is a recognised means of presenting data for increased comprehension. Text books and audio-visual aids, for example, provide a way of interpreting situations outside our knowledge. Virtual reality is the newest and most powerful medium of visualisation available, and this can be productively incorporated into the learning process (Auld and Pantelidis 1994, 29). Although military, scientific and government computer simulations of reality have been around in some form for decades, this technology is largely unexplored for education in the arts, specifically within archaeology, history and cultural heritage preservation (Sanders 1997).

The use of a virtual environment can offer the user first-hand experience otherwise not available, allow interaction with geographically or temporally remote locations, people and objects, and provide information at levels of detail tailored to individual needs. Subjects such as history, geography, archaeology, and astronomy can be taught using virtual worlds based on real-life situations and settings. Virtual reality, then, can provide the ideal means of presenting information about the structural qualities of a site whilst remaining in a museum setting. However, for educational purposes, the environments should be carefully vetted to ensure historical and archaeological accuracy:

> ...for virtual reality to have a positive impact on education, the content of virtual worlds should...be based on actualities, like the lifestyle on an ancient

Greek farmstead or the religious practices of an Egyptian priest, and not on fantasy and invention. (Sanders 1997)

2.4 Virtual Reality: a brief history

There is no generally agreed definition of the term 'virtual reality'. Taken to mean an interactive, self-directed, multisensory, computer-generated experience which gives the illusion of participating in a synthetic three-dimensional environment (Sanders 1997), virtual reality has been with us since the early 1960s. Ivan Sutherland first proposed the idea of stereographic head-mounted displays so that users could look around a computer-generated room simply by turning their heads. In the early 1970s, Myron Krueger coined the term 'artificial reality' and began developing computer-controlled responsive environments (Krueger 1993). In the 1980s, the drop in the cost of computers and the development in technology saw virtual reality become more of a possibility than a theoretical computer application. Jaron Lainier, of VPL Research Inc., is credited with coining the expression 'virtual reality', and created a glove for grasping computer-generated objects. NASA's research centres developed the modern head-mounted display (Gillings and Goodrick, 1996).

At this time there was much hype surrounding the concept of virtual reality. The entertainment industry latched onto the possibilities of the developing technology, but many people's experiences of virtual reality did not match up to their expectations. The displays were slow, movement was mechanical and unconvincing, the resolution of displays was poor and the field of vision very limited. The computer equipment required was expensive, and the displays were very platform dependent, inhibiting public access. As public interest diminished, it was obvious a critical re-evaluation of the way virtual reality environments were created and displayed was required if there were to be any further developments in the area.

To switch the focus from specialist use to mass market application, it was necessary to create a way of publishing virtual reality environments, or 'worlds', so that they could be experienced by all computer users, regardless of machine platform and practical experience. What was required, then, was a language to describe the physical attributes of the world which could be interpreted by different browsers to recreate the same environment on any machine, in much the same way that HTML (Hyper Text Mark-up Language), SGML (Standard Generalised Mark-up Language), and XML (Extensible Mark-up Language) can be used to transfer documents over the Internet. Indeed, the growth of the Internet spurred the development of Virtual Reality Mark-up Language, as advocates realised that the Internet would provide a powerful means of disseminating virtual reality.

2.5 VRML (Virtual Reality Modeling Language)

VRML, first known as Virtual Reality Mark-up Language, was conceived in the spring of 1994 at the first World Wide Web conference in Geneva as a three-dimensional web standard to parallel HTML. A mailing list, started by Wired magazine, soon became the on-line forum in which the first specification of VRML was developed. The name was swiftly changed to Virtual Reality Modeling Language to emphasise that the language was primarily concerned with three dimensions, not just text.

VRML 1.0 was based on the Inventor file format from Silicon Graphics, and could be used on a wide variety of platforms. Several browsers were created, but interaction and animation were not included in the specification, and work soon began on VRML 1.1, swiftly followed by VRML 2.0. Eventually a working group asked for proposals from individuals and industry to develop the software and language needed and these proposals were debated on the VRML mailing list. Silicon Graphics Incorporated won the battle that commenced (Microsoft's ActiveVRML failed to impress, although it has since been further developed and is part of Microsoft's ActiveX toolkit). Throughout the development of the language, interaction through the mailing list provided suggestions and comments from the on-line

community, and, as such, VRML 2.0 evolved from a collaborative effort of individuals and industry. In June 1996, VRML 2.0 was submitted to the International Standards Organisation, and adopted as the web standard for three-dimensional environments (Marrin and Campbell 1997).

A VRML document, identifiable from the suffix '.wrl', is an ASCII text file describing a three-dimensional scene. This text file contains a list of commands that instruct the computer to place objects of given forms in certain places within the 'world'. Basic objects can be constructed from primitives, such as box, sphere, and cone, which are simple, pre-defined, geometrical shapes. The use of primitives generates small, quickly rendered, files. It can take thousands of polygons to create a single building or landscape. Basic animation, lighting, and interactivity are supported, and the world can be linked using hypertext to other Internet worlds and pages. The files can either be scripted by hand, or written with the help of a 'world-builder', a WYSIWYG (What You See Is What You Get) application that facilitates the creation, placement and sizing of objects within the scene. Various conversion packages also exist which can generate VRML files from standard three-dimensional drawing applications.

The resulting file can be parsed by a browser into an intelligible, interactive form. All browsing is done on the client machine, resulting in low bandwidth requirements and hardware independent distribution.

2.6 Future developments in VRML and archaeological applications

Over the last three years, an increasing number of archaeological VRML models have appeared on the Internet. Early models are characterised by basic spatial modelling and no refinement of the user interface, as well as some navigational problems. However, the quality of new VRML models has improved rapidly over the past year for various reasons, including the increase in computer power, the acceptance of VRML as a standard, growing knowledge of the Internet and associated protocols, and the development of better and easier to use software. These models on the whole are static, i.e. cannot be fundamentally changed without reprogramming the model, but recent research into VRML and archaeological applications has focused on the use of databases with VRML to provide a cultural and historical context to virtual worlds, and also to support the creation of three-dimensional models from existing archaeological databases. This could eventually result in 'bi-directional databases into which excavated data could be fed, existing and emerging digital libraries could be linked, and from which new hypotheses could be tested and new computer environments constructed'.

Such dynamic database-driven VRML could provide great opportunities for the creation of interactive educational packages:

> Digital documentation methods will allow archaeological fieldwork to be entered directly into bi-directional databases as excavation progresses. Field archaeologists will be able to access virtual worlds based on this information during excavation, as well as feeding new data into the system, automatically updating the on-line teaching aids. Thus, eventually, architects, artists, archaeologists, engineers, computing technicians, software designers and telecommunications experts will collaborate in constructing multidimensional libraries that will become the foundations of virtual environments. The use of VRML and the Internet as the ultimate vehicles of this data and its interactivity now makes possible a globally integrated, symbiotic system for the enhancement of public education, public awareness, and interdisciplinary research (Sanders and Gray 1996).

Although such research and project work are currently in their infancy, continued exploration of virtual reality as an educational tool could well result in VRML becoming part

of the complex structures in place to ensure wide accessibility to both collections and history. The ability of the computer to transmute one form of information into another - data into pictures, pictures into scenarios - affords an amazing new mechanism for remembering the past. In a world consistently besieged by new technology, it is important to recall that the survival of culture ultimately depends on memory (Davis 1997).

2.7 Problems with VRML
Although virtual reality based installations and VRML ease the construction and access of virtual worlds, there are still problems with this new language. Technical, practical and theoretical issues need to be addressed before any virtual reality is used in a public setting.

VRML is not the best virtual reality system. It is rather a 'jack-of-all-trades', providing many basic functions that are designed to run on all platforms. It can never replace more sophisticated specialised VR systems optimised for specific tasks or configured to run on specialised hardware. It is, however, a standard, and the best standard that exists at the present time for the publication, construction and viewing of virtual worlds on different platforms.

One problem with VRML is its newness. There are VRML browsers for most common platforms (Macintosh, Windows NT, Windows 95, Windows 3.1, SGI, Irix, and Sun) but the browsers re not yet all consistent with the final VRML 2.0 specification, nor with each other. There is no way as yet to get standard colours in a VRML world and different browsers will display the same object with different hues and shading. Building an interactive VRML world requires the use of small snippets of code; whilst VRML has its own script it is very basic, and complex user interaction requires the use of another language. The VRML specification does not state which language should be used. Unlike other VR systems, VRML allows the user to interact with the world as it loads, and this means the designer has to develop interactive worlds carefully to ensure the world does not crash if partially loaded. VRML world files often run into thousands of lines of code which can be very hard to navigate, even with extensive remarks. VRML is very case and syntax sensitive and errors that may not produce obvious effects may result in errors in the rest of the file. Debugging VRML files is difficult and tedious, even with the use of some tools such as Vorlon which are being developed to check the code syntax. The future of VRML is also in question as a result of the developers of the associated software (Silicon Graphics, then Platinum) ceasing production of any further VRML-based systems. VRML may either evolve into a more sophisticated language or cease to be used (see www.vrml.org for updates). Granted, some of these problems are not applicable to museum installations which will run on a predefined platform using predefined software, but such issues need to be kept in mind whilst developing a world which should be usable on any platform yet remains future compliant.

Practical problems with developing archaeological reconstructions for installation in museums include the costs involved, and the time and effort it still takes to produce such an installation. Even though VRML provides the means to create a virtual world on a standard computer, the computer still has to be purchased, and the creation of such a world remains labour intensive. Additionally, there is often scepticism among curators and art historians towards the benefits of using modern technology in public displays (Economou 1997, 39). Even if the new technology is accepted, the lack of familiarity with virtual reality can mean it is impossible for institutions to supply a suitable set of requirements for the resource (Mitchell 1997). Other issues such as policy, procedures and copyright have become paramount in the creation of electronic displays, and the virtual world builder has to consider many legal issues before making the world publicly accessible.

There are also a number of theoretical problems surrounding the use of virtual archaeological reconstructions for public education. Electronic displays in museums have been shown to carry authority with the public; apparently just because the display is on a computer, it is assumed to be correct. Some virtual reality worlds found on the web are

very realistic, and some may appear realistic even though based on incomplete evidence, but nevertheless imply firm knowledge of the past:

> Archaeological evidence for a building may consist of little more than a few fragments of wall foundation, perhaps severely disturbed by later human or geological survey. A building may have been altered or rebuilt on several occasions, often with changes in its appearance and function. Unfortunately most current visualizations of the past provide a single view, representing not just a snapshot in time but also only one of many possible constructions of the surviving evidence. Much more is needed to capture the full range of both temporal change...and possible interpretations (Roberts and Ryan 1997).

It should always be remembered that:
> models are largely interpretative; they are working hypotheses and liable to change. It is not always obvious what the relation is between the recorded data and the interpretations which are built around them. There is a real danger of convincing the uncritical viewer that the model presented shows what the original really would have looked like (Reilly and Rahtz 1992, 157).

> Care must be taken to strike a balance between the desire to produce realistic images and the need to express the theoretical nature of an interpreted form (Ryan 1996).

3. Project Structure

The project was carried out over four months, and had several defined sections. The first stage was understanding virtual reality; what it means, how it has been used previously, and how current developments have revolutionised the genre. An overview of existing on-line virtual sites was undertaken, as was an investigation into archaeological three-dimensional modelling. Before embarking on the creation of the tomb model it was necessary to place virtual reality in a context, and become familiar with issues surrounding constructing a virtual world, or more precisely, constructing a successful virtual world. Background reading was also undertaken regarding the use of computers in museums and possible future uses of virtual reality.

The practical skills necessary to understand the modelling language were acquired by use of a 'teach yourself' manual. This procedure encouraged the beginning of the thought process required to implement the tomb model using VRML. At the same time, possible tools that would assist in the creation of the tomb model were investigated. General reading about Egyptology and Deir el-Medina was also undertaken to give a background to the tomb of Sen-nedjem, ensuring no drastic art historical or archaeological blunders were made during the virtual model's construction.

The functional requirements for the model were established through a series of meetings with Simon Eccles at the Kelvingrove Museum, who had already made decisions regarding the role and function of the model. The design of the system was completed before the construction of the model.

A collation of the archaeological evidence was then undertaken, and copyright clearance for the use of the tomb images was obtained. This information was incorporated into a series of drawings that gave the dimensions necessary for the creation of the model.

The model was then constructed. First a basic representation of the tomb was made, and then images were mapped onto the surface to increase its realism. The model was then refined and adjusted, and interactive elements were added to create atmosphere.

The user interface was then developed and implemented. Finally the model was tested and user feedback was used to redesign the user interface to aid the exploration of the model.

4. Design Documentation
The tomb model was designed as follows after consultation with the Kelvingrove Museum:

The system will provide a stand-alone virtual reality display of an archaeological reconstruction of the ancient Egyptian tomb of Sen-nedjem for Kelvingrove Museum and Art Gallery. Users will be able to interact with the model to explore the tomb by means of the mouse. The display needs to be easy to use, and secure so the system is not damaged by unauthorised access. The first view of the tomb will provide some context to the model by showing it from the outside. An animated fly-through will take the user inside the tomb, allowing exploration of the inner chamber. Only one user at a time can provide input but many users can watch the display. Interactive and animated elements will be used to increase the sense of reality of the model (see section 8).
Because of the time taken to produce the initial view of the tomb, the model needs to be rendered only once. However, the model should reset to the initial starting viewpoint when there has been no user interaction for a short while. The screen saver utility will be used to present a preliminary information screen. Information regarding the use of the model should be displayed on the screen.

The system should be easy to install and support and should have sufficient documentation.

The model will be made using VRML utilising Netscape, Word 2.0, CosmoPlayer 2.0 and CosmoWorlds 2.0. Image textures used in the model will be from Das Grab des Sennedjem (Shedid 1994).

This textual description was translated into the following technical specification. The Requirements Analysis specifies exactly what is required of the system, the overview of System Components (figure 1) provides a entity relationship diagram which notes how different elements in the system interact, the Data Flow Diagrams (figures 2-5 inclusive) illustrates how information passes around the system and the Entity Life History Diagram (figure 6) illustrates the order in which procedures are carried out.

4.1 Requirements analysis

- The system will provide a VRML display of an ancient Egyptian tomb for use in the Kelvingrove Museum and Art Gallery, Glasgow.

Functional requirements
1. The model will be a scale replica of an actual Egyptian tomb; that of Sen-nedjem in Deir el-Medina.
2. The model will maintain archaeological integrity at all times.
3. The initial view of the model will be the outside of the tomb; the user will be allowed to navigate inside by means of an animated fly-through.
4. The user will be able to explore the inner chamber of the tomb.
5. The model must be able to be viewed in real time.
6. The model will be navigated using one source of user input, the mouse.
7. The model will accept only one source of input at any time (i.e. the model will not be multi-user).
8. The model will incorporate interactive animated elements to add to the atmosphere of the display.
9. A user interface will assist the user in the navigation of the model.
10. The model will only be rendered once per session, and have the ability to be used by many different users in that session.

11.Animation and instructions will reset at the beginning of each new user's viewing of the model.

12.The screen saver utility will be used to provide an 'at rest' introductory screen to invite a new user to use the model.

13.The model will be thoroughly tested before installation in the gallery.

14.The model will be made available via the C drive of the computer installed in the museum or on a CD-ROM (the system will not be attached to a network).

15.Comprehensive documentation will be provided along with the model that will cover all aspects of the model and system.

Non-functional requirements

16.The model will be easy to navigate for a user unfamiliar with VRML and computers.

17.The system will be easy to install and maintain (having adequate documentation to aid technical support).

18.The model must be reliable, i.e. have a long mean time between failures and short 'up-time' (i.e. up-time being the time it takes a system to reboot after a crash).

19.The model and system must be secure from interference from unauthorised users.
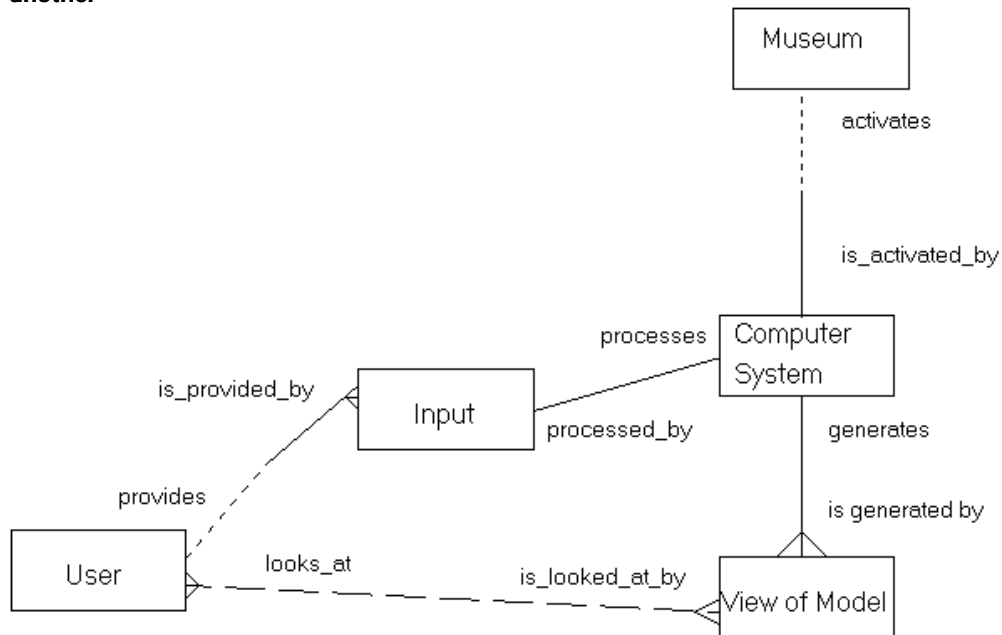
Design decisions

- The model will be constructed using VRML 2.0.

- The model will be constructed using a word-processing package and CosmoWorlds 2.0 on a PC system.

- Images will be digitised using Fotolook 2 on a PC system with scanner, and manipulated using Adobe PhotoShop.

- The model will be viewed using Netscape and the Cosmo Player 2.0 plug-in on a PC system.

- Images for the model will be taken from the publication Das Grab des Sennedjem, Ein Kunstlergrab der 19.Dynastie in Deir el Medineh, Abdel Ghaffar Shedid, 1994, ISBN 3-8053-1756-5. Other general reading about the tomb will be undertaken.

Design objectives

- The model must be simple to use.

- The model must be secure.

- The model must be easy to maintain.

4.2 System components
Figure 1: Showing how the different entities in the system relate to one another

Figure 1 diagram showing the relationships between Museum (activates / is_activated_by), Computer System (processes / processed_by), Input (is_provided_by / provides), User (looks_at / is_looked_at_by), and View of Model (generates / is generated by).

Data dictionary

- Museum = the institution which holds the computer system

- Computer system = the hardware, software and files required to run the VRML Tomb Package

- Input = the instructions the user gives via the mouse

- User = a museum visitor

- View of model = the current view of the model presented by the system

Assumptions
1. The museum holds the computer system but does not have to activate it
2. Only one system is in place to generate the tomb model
3. Many users can view the model
4. Only one user at a time can provide user input
5. The user input is the trigger that generates different views of the model
6. The system can generate many views of the model

4.3 Data flow diagrams

The following diagrams (figures 2-5) indicate the data flows in the system, showing how interaction by the user causes changes to be made in the view of the model presented on the screen.
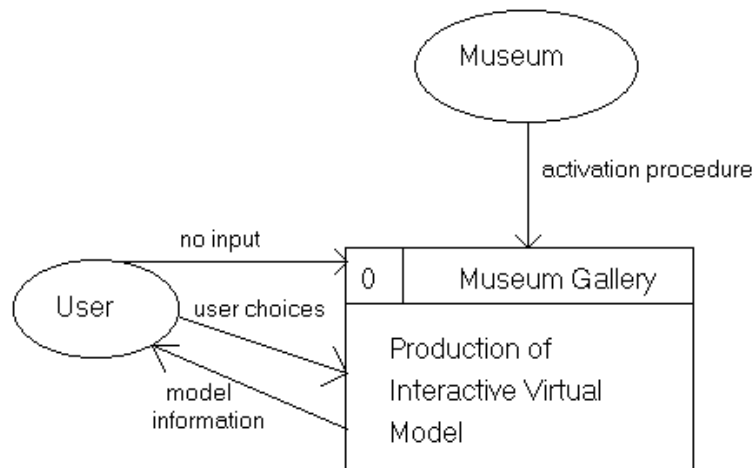
Figure 2: Initial level view of system

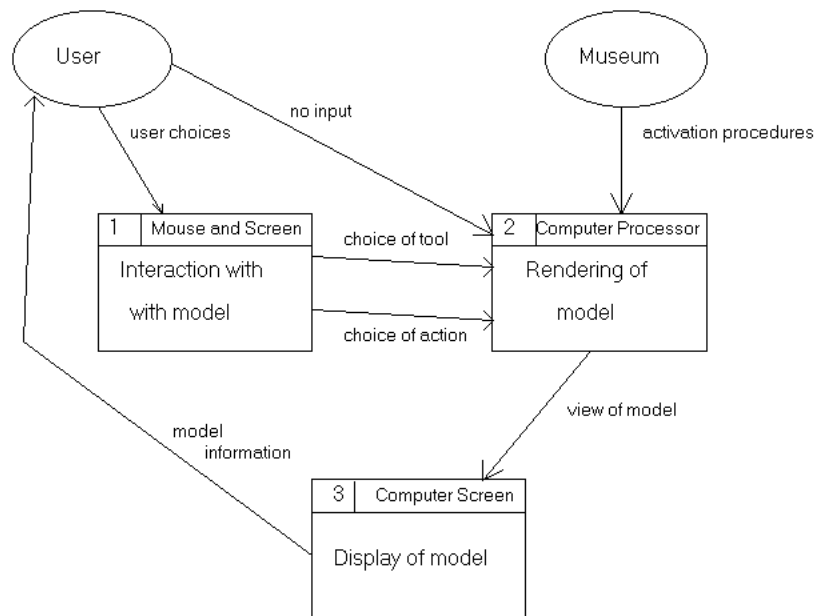**Figure 3: First level view of system**

Figure 4: Procedure 2: rendering of the model

activation procedures

2.1	Processor

Files Accessed

stored information

D1	Computer Files

no input

model data

choice of tool

2.2	Processor

Required View of model calculated

choice of action
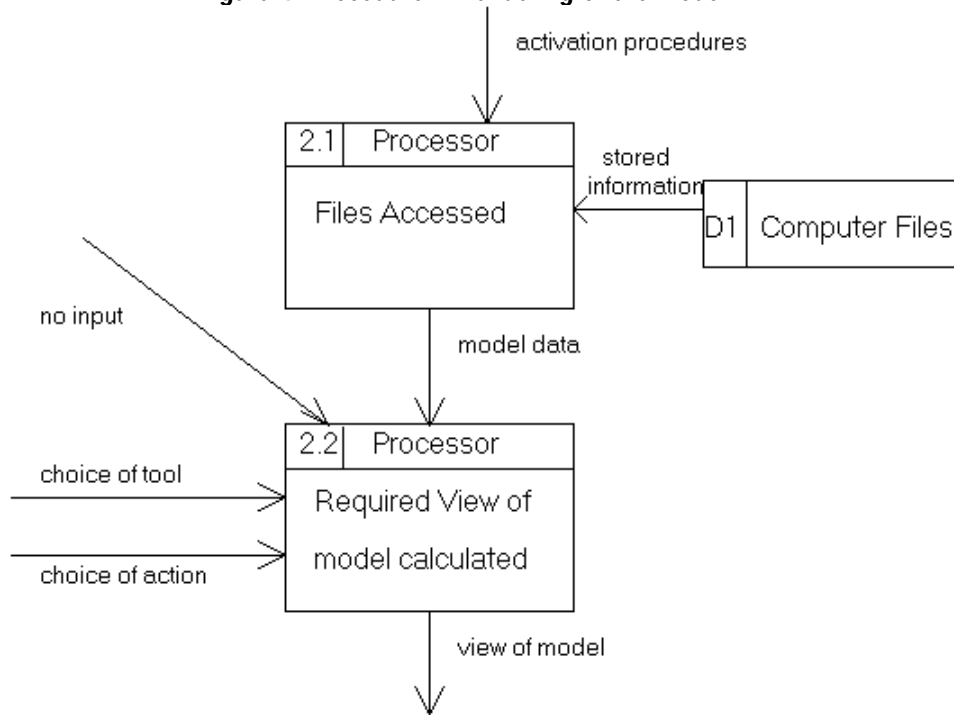
view of model

Figure 5: Procedure 2.2: Required View of Model Calculated

model data

no input

2.2.1	Processor

Preliminary View Created

choice of tool

2.2.2	Processor

Change to view calculated

first view

choice of action

changes

2.2.3	Processor

Changes made if necessary

view of model
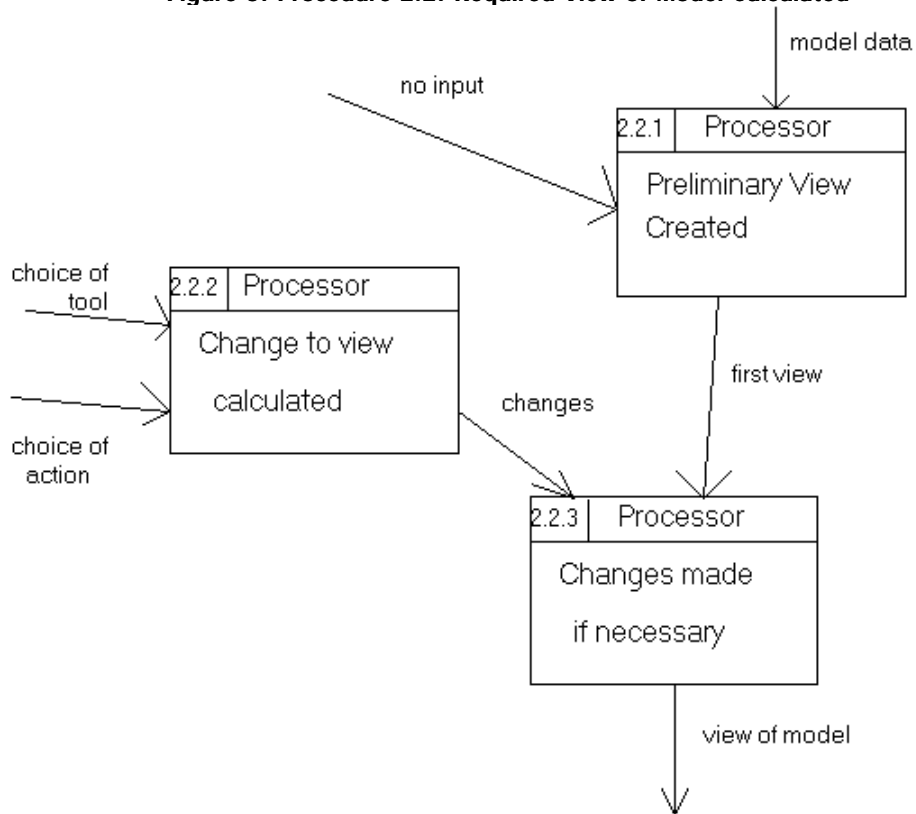
Data dictionary

Procedures

- 0. Production of Interactive Virtual Model = the overall procedure which allows a user to interact with three-dimensional model of the tomb
- 1. Interaction with model = the interaction the user undertakes with the model by using the mouse and viewing the model on the screen
- 2. Rendering of model = the process by which the computer generates the data necessary to present a view of the model on the screen
- 2.1 Files accessed = the process by which software calls the required stored files to create the tomb model
- 2.2 Required view of model calculated = the process by which the software interprets all the data given about the model and the user input given to produce a relevant view of it.
- 2.2.1 Preliminary view created = the process by which the first view of the tomb is created from the stored data, recreated when there is no input from the user
- 2.2.2 Change to view calculated = the process where the model interprets the effect user input would have on the current view of the model
- 2.2.3 Changes made if necessary = the process where the first view of the model is adjusted to accommodate user interaction.
- 3. Display of model = The process in which the data of the model is displayed on the screen

Data stores

- D1= The repository in computer memory for all software and world files.

Data flow

1.Activation procedure = the procedure by which the institution activated the system and produces the first view of the tomb model
2.Choice of action = the decision to move in any direction by the user by using the mouse
3.Choice of tool = the choice the user makes to specify which navigational tool is currently employed
4.Model data = the digital data regarding the model required to produce one view
5.Model information = the site and sounds of the model which are imparted to the viewer
6.No input = the signal given when the user does not interact with the system
7.User choices = the instructions the user gives the system via the mouse
8.Stored information = all the digitally stored information required to render the model (including software)
9.View of model = the data needed to produce a view of the model on the screen

External entities

- Museum = the institution which holds the computer system
- User = a museum visitor

4.4 Entity life history diagram

Figure 6: To show the order in which the system operates
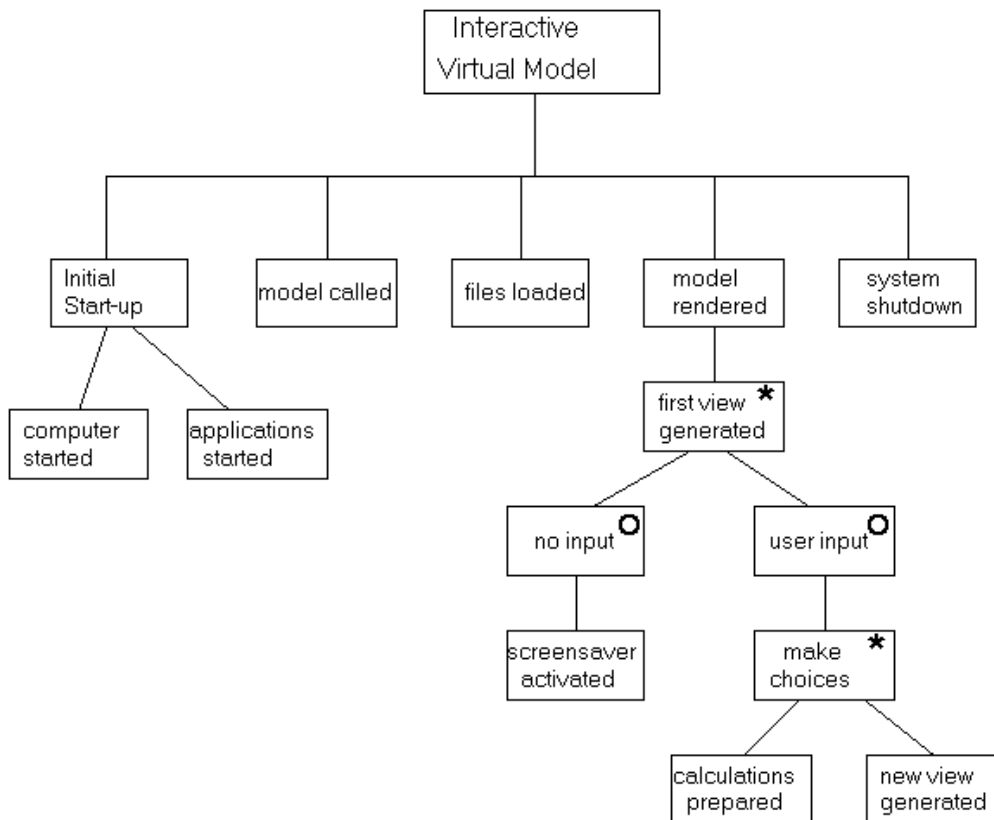
5. Archaeological Problems

As this was to be an archaeological reconstruction, it was imperative that as much information as possible was collected about the tomb before building the model commenced. This was to ensure that the model was as archaeologically sound as possible, with no glaring errors that anyone familiar with Egyptology would immediately condemn. As the model was to be an educational piece, it was necessary to try and rely on reality at all times, rather than make a virtual world which looked fantastic but had no real archaeological substance.

Access to relevant literature was limited. The three main publications that the model relies on are the two archaeological reports by Daressy (1920) and Bruyere (1959), and the photographic record provided in Das Grab des Sennedjem (Shedid 1993). Other reading about tombs at Deir el-Medina was undertaken, backed up by general reading on the construction of Egyptian tombs (Aldred 1996; Bierbrier 1982; Campbell 1912; Dodson 1991; James 1985; Lesko 1994; Romer 1984; Schafer 1986).

The major problem, after this was carried out, was that the tomb was not as well documented as first thought. The tomb was discovered in 1885, Daressy published the first reports in 1886, but the archaeological report was not fully published until 1959 by Bruyere. As a result there was much information which had not been included in the preliminary reports, and Bruyere could not rectify the omissions. These related to artefacts found within the tomb which were destroyed unintentionally by the tomb excavators, and parts of the tomb itself which were broken or smashed to increase access. Doorways, lintels, covering slabs and various artefacts were all destroyed without sufficient archaeological reference.

The reports failed to take comprehensive measurements of major surfaces, and there was little documentation about the courtyard and the main entrance. Bruyere, however, did create an artistic impression of the outer view of the tomb based on the archaeological findings, and this had to be referred to to gain an impression of the outer aspect of the tomb; a wholly unsatisfactory source of information in archaeological terms.

The plans of the tomb supplied were very basic. Drawn with a poor implement to a strange scale, they did not provide the information required for the construction of the model. John Baines, Professor of Egyptology at Oxford University, and Lynn Meskell, a specialist in Deir el-Medina also at Oxford, were consulted to investigate whether any modern plans exist. When new plans were not forthcoming it was decided that the best option would be to grid out the plans on architectural graph paper and use the scale given to calculate the relative measurements of walls and surfaces using the grid provided. The archaeological reports were also studied, and any measurements given were added to the plans. For the most part, these seemed to correlate with the scale on the drawings.

The possible inclusion of virtual artefacts within the computer model also posed some archaeological problems. The use of artefacts from Kelvingrove was discounted at an early stage, because there were none from a similar period, and would therefore prove educationally misleading as well as being archaeologically incorrect if included in the installation. Instead, it was decided to try and track down the actual artefacts found within the tomb. However, out of the twenty mummies noted in the archaeological reports only six could be identified and of those only four could be traced, the rest presumed destroyed (as noted in the reports) or lost due to the confusing and bloodthirsty art historical market which surrounded Egyptian antiquities at the turn of the century. It was decided to try and include the actual mummy of Sen-nedjem in the tomb. This would require good images of the coffin, mummy and canopic jars. The Egyptian Museum in Cairo, which holds Sen-nedjem's funerary artefacts, granted permission to use images from a catalogue detailing all the remaining artefacts of the tomb of Sen-nedjem. However, the catalogue was not published at the time the model was being created, and Cairo would not supply any images in the meantime. Although a few of the objects were available in various exhibition catalogues it did not prove possible to obtain enough views of any one object on which to base accurate virtual models. As a result, it was decided that the tomb would have to be presented without any artefacts.

Although the archaeological evidence was used wherever possible, it soon became evident that there was not enough information to make an entirely accurate model, a problem which will probably be encountered when using old archaeological reports for any type of model. This results in problems with representation and authenticity, as the user cannot tell which areas of the model are based on archaeological fact and which are an artist's impression.

6. Implementing the Basic Model

The measurements obtained from the reports and the plans were used to construct a basic model in VRML using Word 2, Netscape, CosmoWorlds and CosmoPlayer 2.0. (The computer used was a 330 MHz PII with 64 MB RAM, 6 GB hard drive, a 3-D graphics card with 8MB video memory, and was running Windows 95.) Any missing areas were based on Bruyere's reconstruction drawings and other information regarding similar tombs. The wire frame was completed before any textures were added to the model.

The wire frame (figure 7) was constructed taking the ground level in the virtual world as a starting point. First the courtyard was made, so that the overground and underground aspects of the model could be worked on separately to aid the construction process whilst ensuring that they would ultimately align. The underground part of the model was then constructed from ground level down, making sure each room aligned with the next. First

the pit, then room A, room B and room D were created. The pit shaft and doorway of room C were built and then room C itself. The overground part was constructed from ground level up, first implementing the walls and extra detail of the courtyard, then the pyramid plinth, he pyramids, the front doorway, the front steps, and finally the landscape and background.

Figure 7: The wireframe model viewed from the left before texture mapping. Room A is small chamber leading to Room B. Room C is the barrel-vaulted chamber that contains the frescoes and is accessed from a smaller pit shaft in room B. Room D is a small chamber that contained food and other articles thought necessary to sustain the mummies in the afterlife
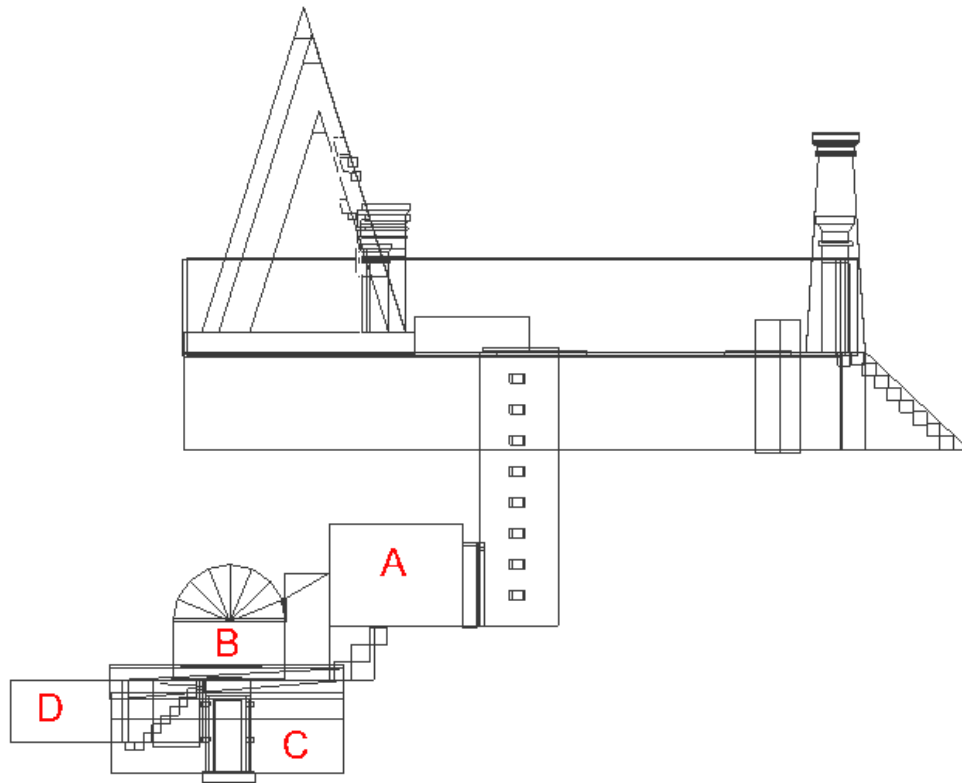

The structures were made by first identifying any large areas that could be defined using spatial primitives (cube, cone, sphere) and then adding any detail required using smaller shapes and faces. Some structures were very simple to make (for example the tomb covering slabs are merely simple boxes) whilst others required much use of the index face set node, where various points in space are identified then linked, for example the pyramids, which are made up of a great many different faces and complex shapes to define the sides and the cut-out entrances. Whilst making the structures, care was taken to ensure the files created were the smallest possible. For example, spatial primitives were used at every opportunity. Clones were used whenever possible to render similar surfaces such as stairs, and the three large pyramids. Copies of objects were rejected in favour of clones.

Figure 8: The basic model viewed from above before texture mapping
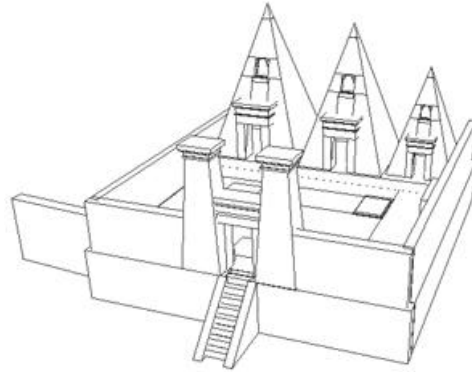
Before adding any textures this large wire frame model (figure 8) was split into smaller more manageable files, called from a single file as seen in figure 9. Each room and structure is called from a separate file allowing them to be worked on independently, speeding up the creation process. This structure also speeds up the final rendering process, allowing the model to be viewed as it is built up rather than waiting for the whole model to be processed before viewing. The model will also function if only partially loaded because of this.

Figure 9: High level view of the file structure of the completed model
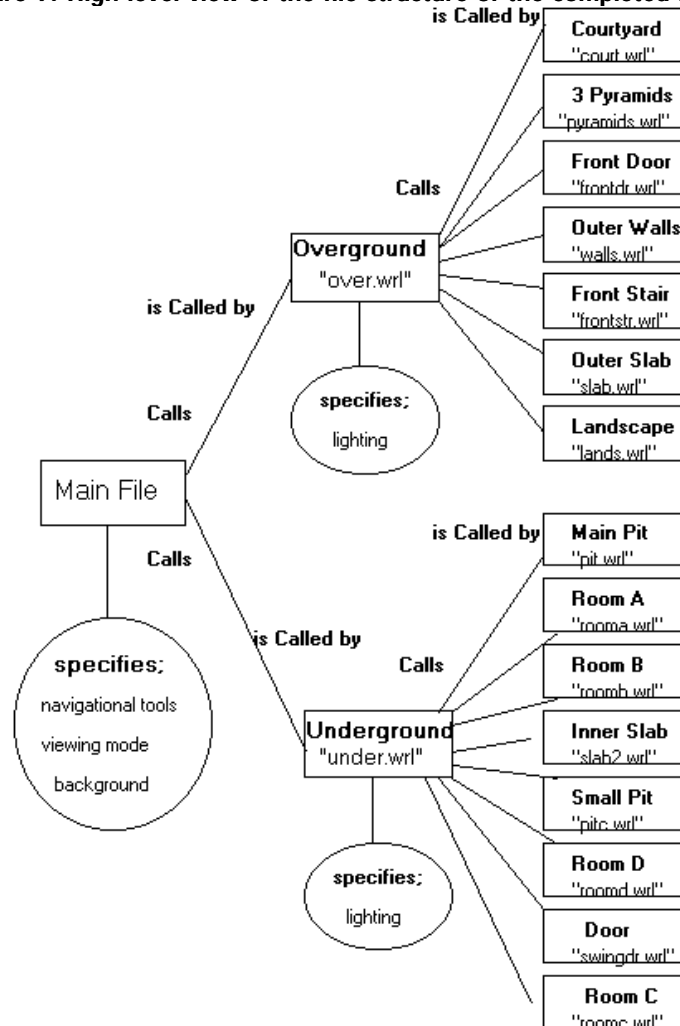
This diagram shows a high level view of the file structure of the model indicating how the calling mechanism works. The main file contains the navigational information required to view the model, i.e. by own exploration, guided viewpoints and animated fly-through. It also limits the tools provided by CosmoPlayer, turns off the default head lamp lighting, and implements the background. It then calls the files (by use of the 'inline' node) which contain the overground and underground information. These files specify the lighting that occurs in these areas, and call the various feature files to build up the structure of the model. The names of these files are quite self explanatory. The courtyard file contains the information needed to generate the courtyard, pit covering slabs and pyramid plinth. The pyramid file generates all the planes needed to create one pyramid that is then cloned to produce the others. The front door specifies the entrance pillars, outer walls, front stair (the set of stairs leading up to the courtyard). The outer slab file contains script which generates the slab covering the pit entrance, and contains the code which activates the movement of the slab when the user comes into its close proximity. The 'Landscape' file contains information required to construct the desert scene.

The files called from the underground file are self explanatory. The inner slab file generates the slab covering the second smaller pit and the animation script that makes this move. The door file contains code that governs the creation and movement of the door to the inner tomb.

All files are VRML files, created in ASCII text, and suffixed by '.wrl' to indicate this. Image textures are called by each individual file as it renders each object in the file separately. The files are called in order, so the first object to be rendered is the courtyard, and the last room C. This means that as the model is loading the viewer is first presented with the overground area to stimulate their interest and convince them to wait until the whole model is loaded.

Throughout the construction of the model, care was taken to keep a record of any areas which were not archaeologically sound. Although the final model does not show these areas, the documentation provided stressed that some parts of the final model were hypothetical.

6.1 Model plans and problematic areas

These views were created using the 'wire frame' option in CosmoWorlds that allows the model to be rendered showing the outer edges of each face only, illustrating the structure of the model. The shaded areas in the figures illustrate parts of the model for which there were no measurements given in the archaeological reports, or where those measurements conflicted with those given in the plans.

Left view

Figure 10: The completed basic wire frame model from the left.
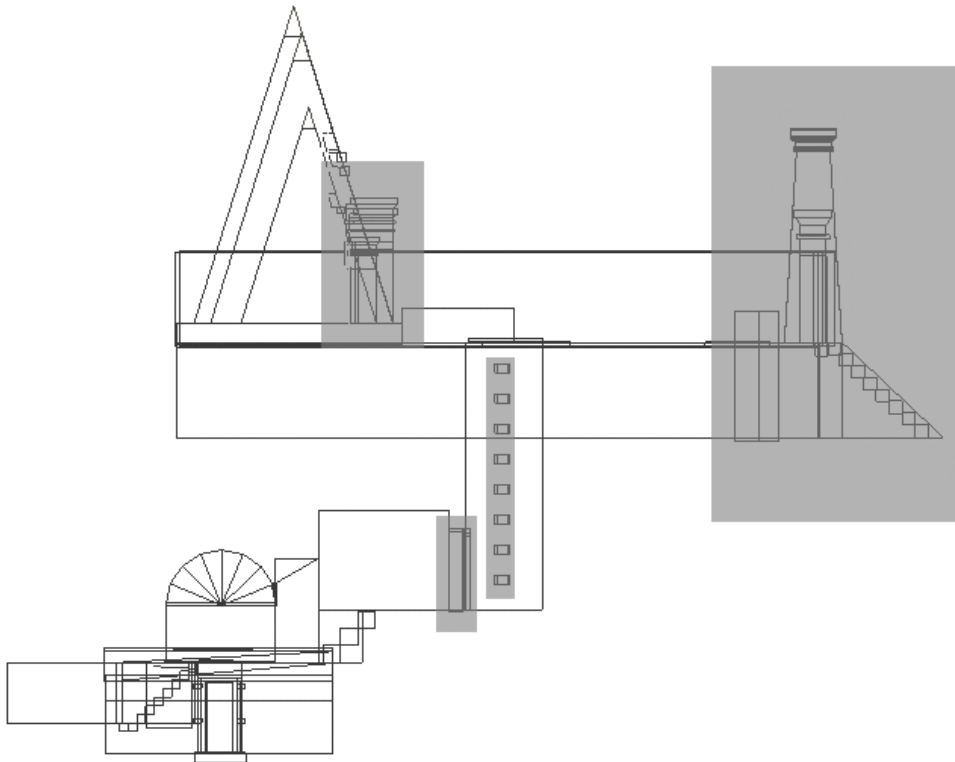
All faces are shown here (figures 11, 12 and 13), indicating how the model was made. For example, the ends of the barrel-vaulted chamber in room B (see figure 7) is made of many triangular polygons to create a semi-circular end to the roof. The stairs on the entrance way and from room B to room D are made of a series of identical boxes. The front doorway and stairway are based on an artist's impression, although there was evidence to suggest a structure such as this had been in place. The doorways of the pyramids, too, are based on an artist's impression. The brick steps in the side of the pit differ in number and placement in the archaeological reports and the plans. The doorway into room A was destroyed by the excavations and no trace of it exists.

Top elevation

Figure 11: Showing the courtyard from above
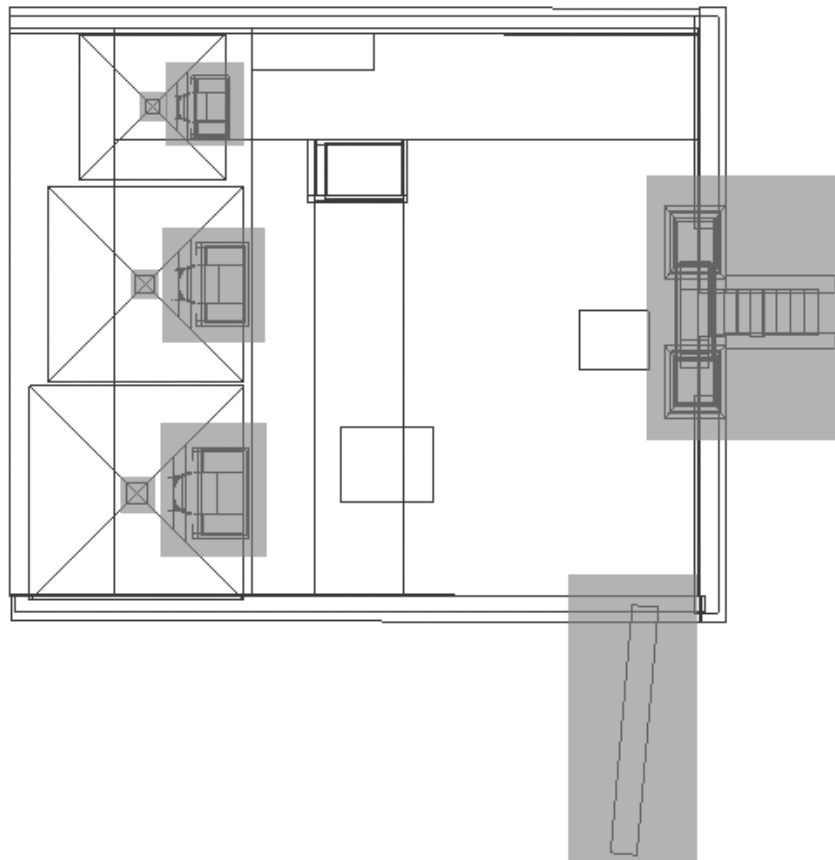
The courtyard square had to be split into four large sections to accommodate the gap for the entrance to Sen-nedjem's tomb. The pyramids can be seen to be fairly complex structures because of their doorways and portals. All three pyramids are identical, merely scaled to different sizes. The front stairway and doorway are based on an artist's impression, as is the wall on the left (although there was archaeological evidence to suggest such a doorway and walls had existed). The front doorways of the pyramids are based on the artistic impression, but consistency in dimensions is maintained between all three and, again, there was some archaeological evidence to suggest this construction. The Pyramidia (on the top of the pyramids) are correct in size but would have been painted and covered in hieroglyphs. Only fragments of these were found and so they could not be reconstructed.

Top elevation (lower model)

Figure 12: This view shows the lower portion of the model from above
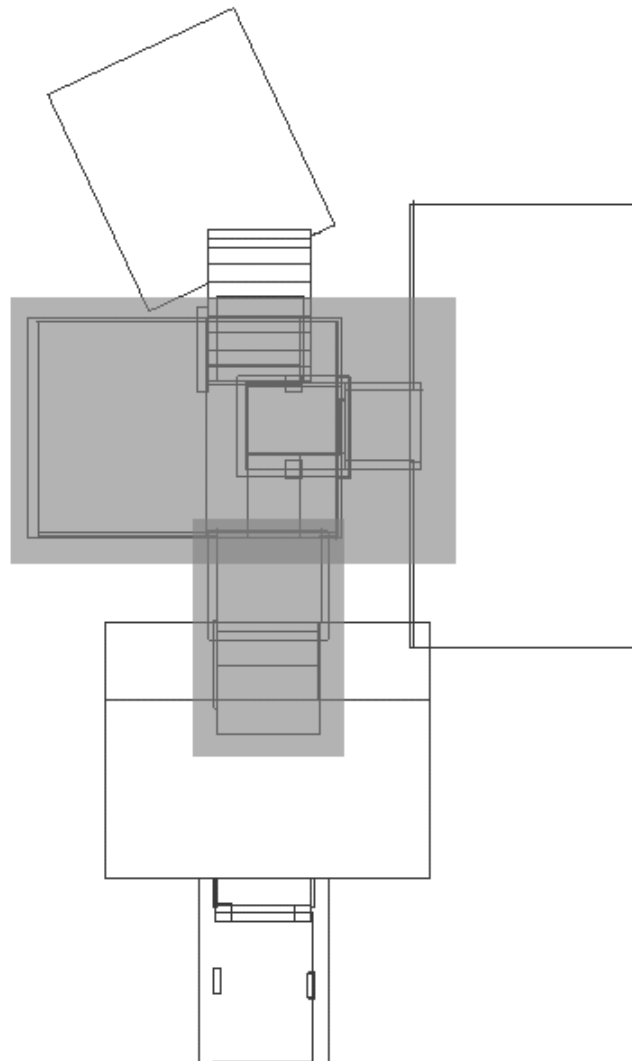
The pit entrance is shown at the bottom of the illustration (the two rectangles either side are the series of brick footholds embedded into the walls down the whole depth of the pit). The first room is A, then stairs to B are shown (see figure 7). The smaller pit to room C, on the right, again shows footholds. Rooms C and A do not overlap in the model because of the large difference in height. The angle of the rooms in relation to each other was contradictory in both reports and the final plans. It is suspected that they are at more of an angle than is represented here.

Front view (lower model)

Figure 13: View of the side of the barrel-vaulted inner chamber; room C
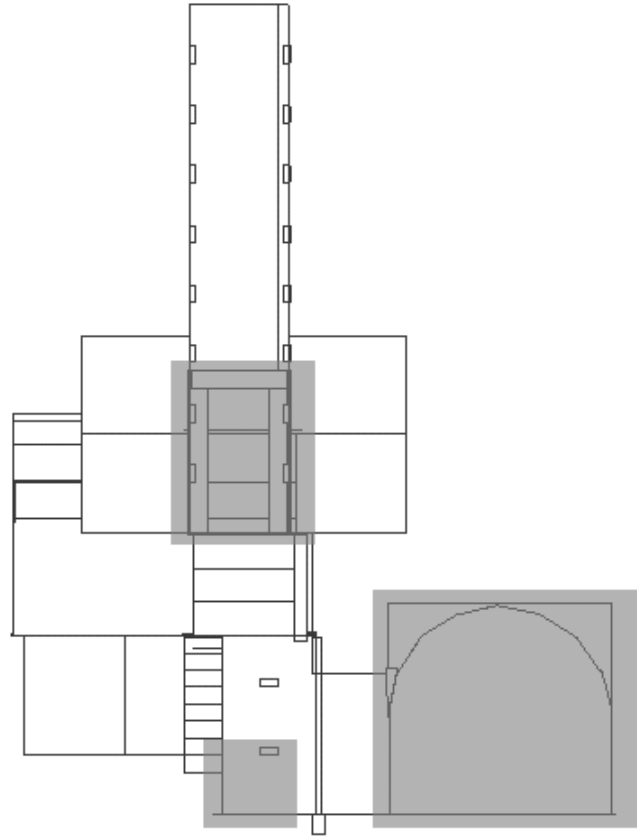
This gives a sense of how deep room C is below ground. The doorway to room A is a reconstruction, as discussed above. There was a large step at the bottom of the smaller pit; this had to be removed as the avatar could not crouch and turn to get into room C, so the inner tomb was effectively blocked. The end walls of room C are presented as two large squares separate from the rest of the chamber: this was to aid the texture mapping of the images onto the surface. From the inside they appear as part of the barrel vaulting. The barrel vault is also shown as a perfect symmetrical shape; in reality the two ends are of slightly different dimensions.

7. Image Development and Texture Mapping
Before any image development took place, care was taken to acquire copyright clearance from the publishers of the art historical publication which contained a comprehensive photo documentation of the tomb of Sen-nedjem; Das Grab des Sennedjem, by Abdel Ghaffar Shedid (1994). This was necessary to avoid any legal disputes that could result from the unauthorised use of published images. Thanks are expressed to Verlag Philipp von Zabern for allowing these images to be used in this project. All copyright remains with the owners.

One of the features of VRML is that it allows images to be 'texture mapped' onto surfaces, meaning photorealistic models should be created. Usually this involves using small images that are tiled over a larger area to give a repetitive surface. This cuts down on file size and therefore rendering time, and if images are carefully constructed it appears little or no repetition has occurred. In the model, it was decided to try and make the tomb complex as realistic as possible. This then involved two procedures; small images for the application of textures such as stone, sand and grit and, where possible, larger images to make the painted barrel-vaulted chamber as photorealistic as possible. Although images used in texture mapping are generally small, it was decided to produce an optimum model of the tomb using large images derived from Das Grab des Sennedjem. This would test the boundaries of the facilities provided by VRML, the competency of the world builder package, and the ability of CosmoPlayer to cope with large photorealistic images. If archaeological reconstructions are to become more realistic, VRML and its browsers should be able to cope with large image file sizes.

To retain some kind of authenticity, the smaller texture images were created by scanning pictures of the site as it exists today, and taking samples of the dirt, sand and stone found at the tomb site (figures 14 and 15). These were scanned at 75 points per inch, the Internet standard, using Fotolook and Adobe PhotoShop. They were adjusted and manipulated in PhotoShop to create tiling textures with an average file size of 10k.

Figure 14: Image files created from photographs of the site used to add texture to the model. These are used to create sand, stone and dirt textures. They were carefully created so that the fact the image repeats is not apparent.

Figure 15: A view of the tomb complex from inside the courtyard.
This shows the use of the image textures to give the background and courtyard ground their texture. Unfortunately, because of the triangular shape, the image mapping does not work very well on the pyramids, giving the stripy appearance at the front.

Preparation of the larger images was much more complex. As each wall surface in the inner tomb was covered with individual frescoes, the tiling mechanism available in VRML was not applicable, and so images had to be prepared which would cover each wall surface fully. This took a long period of trial and error to complete.

The first issue confronted was the resolution and size of the images needed to cover such a large virtual area. Again, it was decided that the optimum model required photorealistic surfaces, and accordingly much investigation had to be carried out to ensure the images applied to the wall surfaces did not pixelate or distort when viewed in place in the tomb. VRML browsers allow the user to 'zoom in' to surfaces, and because each wall painting contained so much detail, it was important that this manoeuvre did not produce a pixelated unintelligible mass of colour when the images were viewed at close range. After much trial and error, it was discovered that the minimum resolution needed for the wall surfaces was 150 points per inch when the images were scanned to 100% scale. This resulted in a file size of over 2 MB for each wall surface (in index colour mode), and although various attempts were made to decrease the file size, this size of file was required to ensure the visibility of the tomb paintings in the computer model.

There were also problems with the photographs themselves, including the technique used to take the photographs and the size of the images. The tomb, being underground, is of course dimly lit. In the photographs, instead of a diffused light being used to illuminate the surfaces, there is much evidence of flash photography that causes discoloration over different parts of the image. This is not really a problem when the images are destined for a coffee-table type book, but when placed together in the virtual tomb the unsuitable lighting of the images became all too obvious. Some were overly dark, some too light, and larger images with two or more panels showed that the colours within the paintings were different between separate images. Eventually, scanning techniques were employed to try and eradicate this problem. A Gamma tone curve of between 1.2 and 1.8 was applied to different images, and PhotoShop was relied on to blend in different areas of lighting and colour.

The mapping of the images was not a straightforward scan and apply process either. Many of the walls were photographed in two or more segments, and the roof was recorded by a series of ten images (figure 16). This required that a composite image for each surface be constructed using PhotoShop, giving a roof, right wall, left wall, long lower wall, two shorter lower walls, and eight images for faces surrounding and on the door. This involved much work.

Figure 16: The composite roof image.
This consists of eight main panels and many fragments of hieroglyphs that were laboriously pieced together in PhotoShop to create the whole representation of the roof that is overlaid onto the bare model.

It was also discovered that some surfaces on the tomb had not been photographed. At least half of the hieroglyphic inscriptions had been cropped out of the photographs. One whole panel, the hieroglyphs regarding the book of the dead beneath the image of Anubis and the mummy (figure 17), was missing. Edges of panels were missing, and often details of the images had been cropped too. When trying to piece together the panels, then, an archaeological issue became apparent. The missing areas of the tomb could either be left blank, giving the most accurate but not convincing model available from the sources available, or recreated using techniques in PhotoShop, resulting in a model which gave the impression of the tomb as it would have been (fully covered in wall paintings), but which surrendered some archaeological integrity. It was decided to go for the latter, because the tomb had been fully covered with images, and as an educational model this would give the best impression of the structure of the tomb, rather than having missing strips throughout. However, any missing areas such as hieroglyphs were copied from other areas in the same tomb to retain a semblance of archaeological integrity. (There was a major attempt to find an image of the hieroglyphs beneath the image of Anubis and the mummy. Even with the help of the Oxford Topographical Bibliography staff, only a poorly grained black and white image was acquired which proved unsuitable for the purposes of the model. This area, again, was constructed using areas of hieroglyphs from other parts of the tomb - figure 17.)

Figure 17: The reconstructed hieroglyphs beneath Anubis and the mummy.
Although some repetition is evident in the hieroglyphs, it was considered that it was necessary to try and reconstruct the panel to blend with the rest of the model rather than leaving it bare. The hieroglyphs were taken from other parts in the same wall.

These images were then mapped onto the surfaces of the tomb. After much trial and error, a more realistic final model was thus created. However, the major drawback with using such large images was the time taken to render the model. Once loaded, the browser copes admirably with the large images, allowing smooth movement within the tomb. Unfortunately the model takes five minutes to render, even running from the C drive on the authoring platform. A further attempt was made at file size reduction, but this caused great distortion to the images. Comprehensive views of the model can be seen later. Figure 18 shows a view from inside the inner tomb.

Figure 18: A view of the inner chamber of the tomb model.
This illustrates the left wall, the barrel-vaulted ceiling and the lower long wall. The viewer is standing just in front of the entrance to the chamber. The two large figures illustrated on the wall are that of Sen-nedjem and his wife Eineferti.

7.1 The completed images and problematic areas

All images are taken from the art historical publication which contains a comprehensive photo documentation of the tomb of Sen-nedjem (Shedid 1994). The images are scaled down to appear in this article : the original images are much larger. All images were colour adjusted and had a Gamma tone curve applied to even out areas of light and dark. Any shaded parts highlight areas where some reconstruction of the image took place.

Figure 19: The composite roof image.

Figure 19 shows the areas of archaeological inconsistency which have been blocked out in grey. These areas are for the most part hieroglyphs which were not photographed when the main panels were recorded. The missing hieroglyphs were replaced by copies of other hieroglyphs from the roof. There was also a lot of adjustments to be done along the edges of the main panels as there were some missing parts in the photographs. However, the main panels are generally as shown. No attempt was made to adjust areas where the plaster is crumbling.

Figure 20: The right wall

The right wall (figure 20) is shown as a quadrilateral to aid the texture mapping process. The greyed out area above the curve was filled with the background texture from the rest of the painting. Only the edge of this is seen in the tomb. Areas down each side were cropped by the photographer and so have been shown to be strictly incorrect.

Figure 21: The left wall

The left wall (figure 21) shows the area above the curve as added. This too was the background texture.

Figure 22: The lower right wall

Figure 22 was not adjusted (save for being lightened). However, the photographer had cropped over four inches of painting from the right of the picture.

Figure 23: The lower left wall

Figure 23 was not adjusted (save being lightened) but again the photographer had cropped a large section, this time on the left of the image. The right-hand side remains very dark because of the poor lighting.

Figure 24: Lower long wall

The composite image that is figure 24 posed the most problems in the tomb. All grey areas had not been photographed and had to be reconstructed using hieroglyphs from other parts of the tomb. The boxed area had been photographed in three different sections (with different scales, angles of view and lighting) which were painstakingly mapped together to reconstruct the panel as it is. Even with tone adjustment, the far right of the image remains very dark.

Figures 25 and 26: Door to tomb: front and back (l-r)

Figures 25 and 26 of the outer door of the tomb did not have to be adjusted from the originals.

Figure 27a/27b (l-r): Inner doorway: left and right panels

Figure 27 (a and b), the panels of the inner doorway, required much work. The only photographs of these panels were taken at very oblique angles. The upper images had to be reconstructed, and the majority of the hieroglyphs copied from other parts of the tomb.
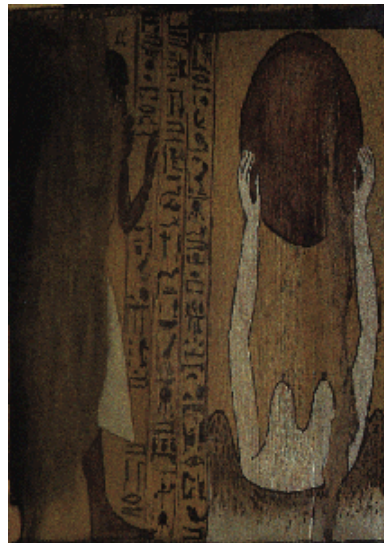
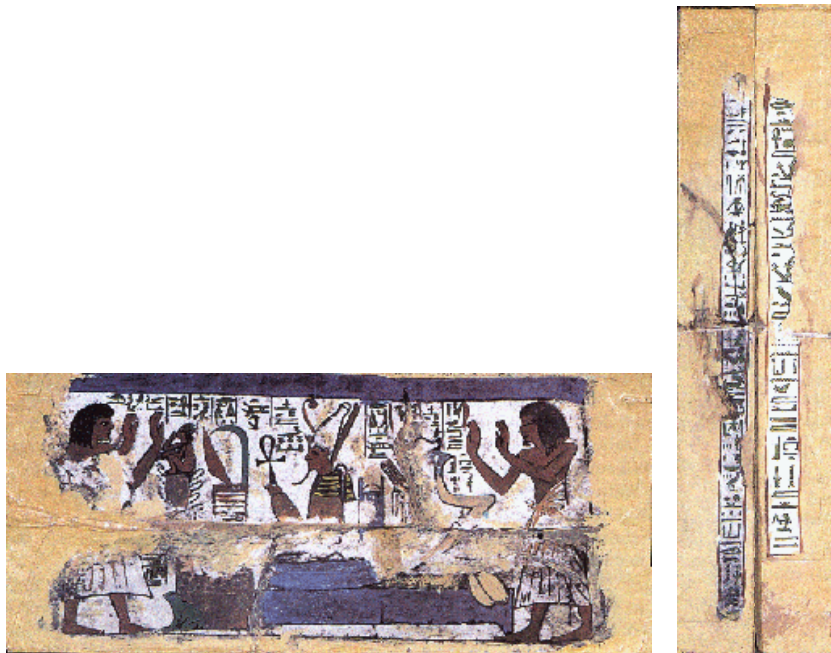**Figure 28: Inner doorway: upper panel**

Figure 28, the upper panel of the inner doorway, had to be reconstructed for the model from a very oblique photograph. The left of the panel shows deterioration where the door has brushed against the roof.

**Figures 29, 30 and 31 (l-r): The lintel of the outer doorway, and outer left and right side of the doorway.**

Figures 29-31, photographs of the outer doorway, did not have to be adjusted to be used in the model.

8. Refining the Model

After the basic construction of the model (see section 6), it was then decided to add other features that would improve the presentation and user experience. Interactivity was added with the moving door and tomb covering slabs. Lighting was experimented with. A series of viewpoints were defined, and a seventy-second animation of the model was constructed. These are all extended capabilities of VRML 2.0, and added some interest to the model. A sky and sun were added, with the external lighting adjusted to make the experience more realistic. A landscape was added to place the model in some context (figure 32). An attempt was made at constructing images of the Deir el-Medina tomb complex to place the model in the correct setting, but this was found to slow the rendering of the model down a great deal, and so the detailed background was abandoned for the time being. Other issues considered though not used were the use of sound to create atmosphere, and the addition of information boxes to explain to the user points of interest about the tomb. The image below shows the final model in its desert setting as viewed through Netscape using the CosmoPlayer Plugin. Other views of the model are available in section 10.1.

Figure 32: The Tomb of Sen-nedjem in its desert setting.
The courtyard of the tomb holds the entrance and chapels of three family tombs; the largest pyramid on the left may be that of Taro, Sen-nedjem's father, the middle Pyramid is that of Sen-nedjem, and the smallest that of Khonsou, Sen-nedjem's brother. The pit opening leads to the inner tomb of Sen-nedjem. Sen-nedjem's tomb was used for approximately 120 years by his offspring and their families.
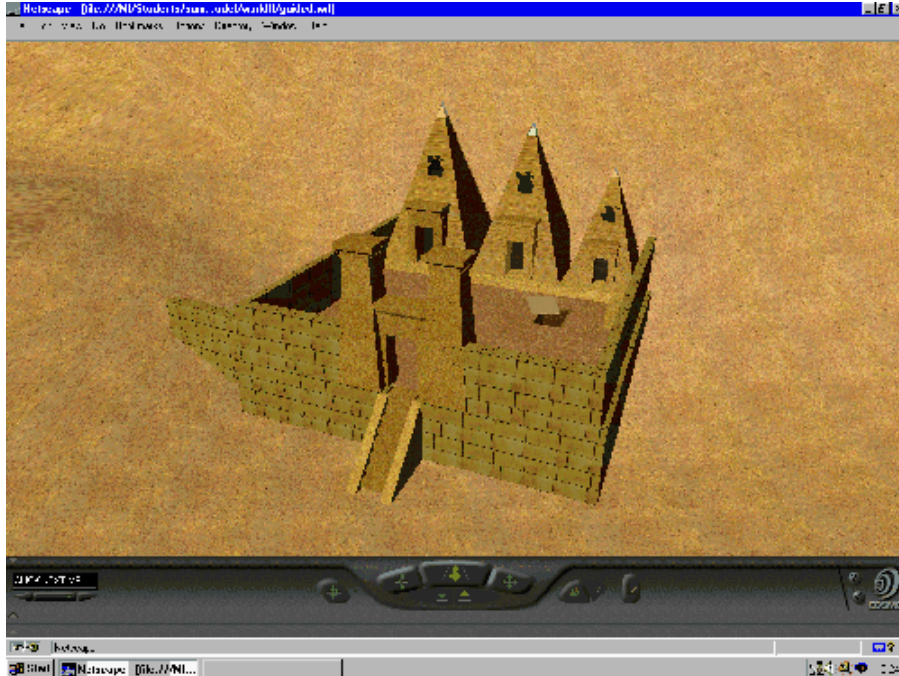
9. The User Interface

There were many things to consider when designing the user interface. Essentially, this was to be a stand-alone electronic display for use in a museum (section 2.1). Of necessity, the interface had to be intuitive, suitable for users of different ages, easy to use by those with no technical experience, and interesting enough so that those with some knowledge of virtual reality did not feel that they were being patronised. The design of the interface was limited by the browser used to view the model, which provided pre-defined functions. This tool had to be integrated with some user information to allow any user to view the model.

The model is viewed using CosmoPlayer 2.0, which has its own set of pre-defined tools. This gives a confusing area of options for the user, and has only a basic help mechanism integrated into the system.

Figure 33: The CosmoPlayer toolbar

On the far left of the toolbar (figure 33) is the drop down viewpoint menu. The central panel holds the navigational tools required to explore the model (the user has to select a tool then click and drag to move). On the far right are the preferences and help buttons and the link to the Silicon Graphics Site indicated by the CosmoPlayer logo.

The toolbar, as well as the five primary options shown in the centre, offers another five tools by which to view the model. There is the option to use 'gravity on' or 'gravity off', various tools to navigate, and different options to control the speed and lighting of the model. To limit this greatly, and hopefully make the toolbar less confusing, as many of the advanced options as possible were disabled to provide a basic set of navigational tools; go, tilt, slide and seek. Gravity was not imposed to allow users to climb up and down the two pits and stairs in the model, and collision was turned on to stop the disorientating effect of walking through walls. Transparent screens were also erected in the model to prevent the user from accessing areas which were of no interest, such as inside the three pyramids (which had no interior decoration and so were not archaeologically sound), or inside Room D, a small repository for refreshments for the dead in the tomb (which was very difficult to get into or out, and had no real significance to the user). This hopefully made the user interface more intuitive from the outset. Unfortunately there were still some buttons that could not be disabled, such as the CosmoPlayer icon, preferences and help menu, which posed some problems during testing.

The museum wanted to incorporate three different ways of viewing the model into the package, and there needed to be some way of connecting all three (although technically all three can be combined into one it was felt that this gave too many confusing options for one user). Three basic versions were created; the animated fly-through, the model with some guided viewpoints, and a version that gave the user no help at all in navigating the model. Having these three versions also meant that it would be easy to test the average user's ability to navigate a virtual structure, and the level of help required to do so.

Initially a frame mechanism was set up which presented the user with an opening screen. Subsequent screens were linked to this by means of a button on the lower frame, meaning whatever version of the model was being used, the user always had the option to return to the start and try another. Also, hopefully, a new user, when confronted by a model which had been left in progress, would be able to return to the start of the package. This opening screen showed a large image featured in the tomb to attract the interest of the viewer (figure 34), and also some copyright and creation data. The large image was hyperlinked to the rest of the model. The image of Anubis preparing the mummy was used as it was felt to capture the overall function and stylistic quality of the inner chamber.

Figure 34: The opening screen to the first design of the display.
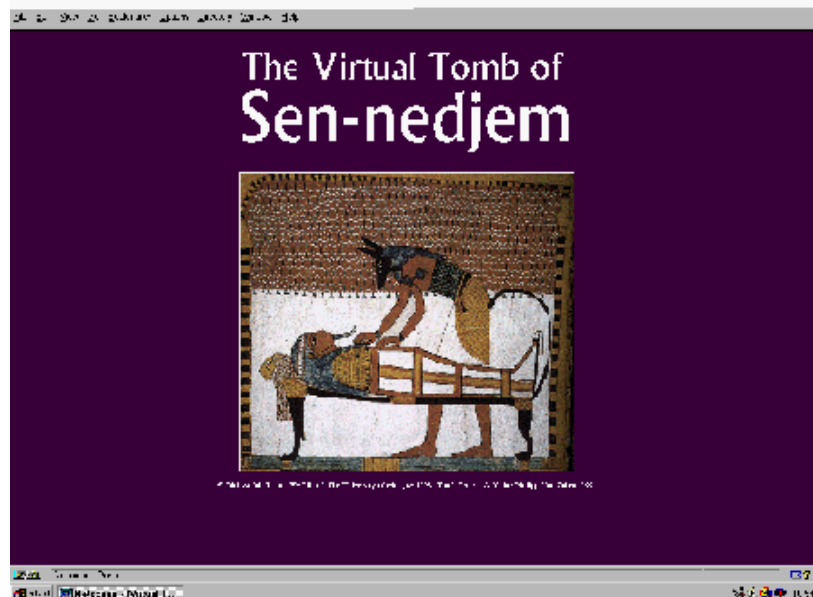
This opening screen was initially connected to a second one that gave the user a brief introduction to the tomb, and provided the three options for the user to view a model (figure 35).

Figure 35: The introductory page to the three versions of the tomb.
This uses an image of Sen-nedjem. The three buttons were created from hieroglyphs found in the frescoes in the tomb.
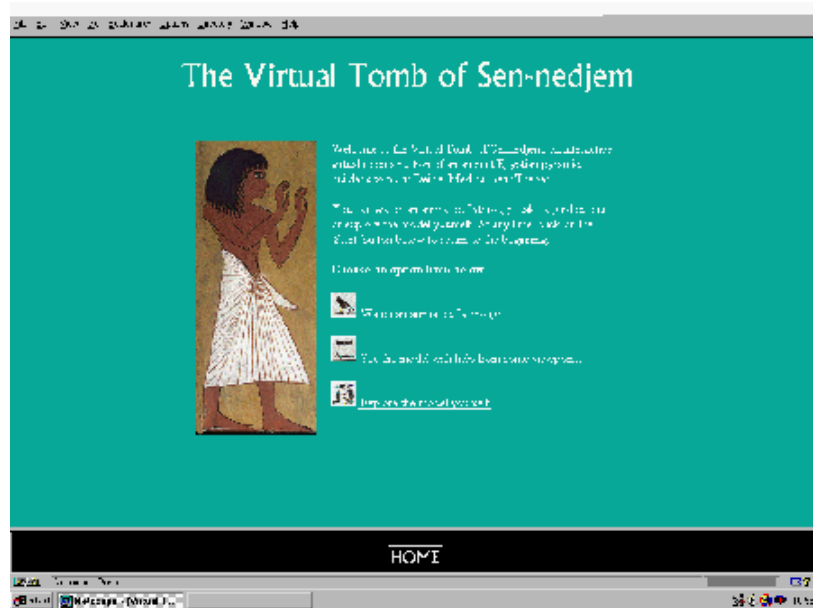
There were obvious problems with using three versions. They all required instructions to tell the user how to begin the animation, or use the viewpoints, or use the buttons on the toolbar to navigate. Another major problem was the time the model took to render every time a different version was loaded. The design of the system also presumes that the user is au fait with hyperlinks, the mouse, and the concept of returning 'home' to the start.

There was still the problem of giving users basic information regarding the tools. The initial version of the user interface consisted of three more screens, accessed prior to the loading of the model, which gave the user some indication of how to use the interface (figure 36). The model is activated by means of a hyperlink on each instruction page.

Figure 36: The introductory screen to the animated fly-through

This screen attempted to provide the complex instructions needed to activate the animation. There were problems with this, as described below and in the section on testing.

This version of the model was then tested to see how users navigated around the different models, and how they understood the user interface. Unfortunately, there were found to be major problems with this design, as documented in the section on testing. Although some resulted from the toolbar provided by CosmoPlayer, the frame system was found to be unsatisfactory for a variety of reasons. The fact that the model takes five minutes to render meant that the user had forgotten the often complex directions in the time elapsed since reading the instructions. Users were not prepared to wait five minutes. The frame used to allow the user to return to the start wasted valuable screen space, and users unfamiliar with multimedia did not understand that the 'home' button led back to the start. It was obvious from initial testing that this version was not a suitable end product.

There were also problems with the three different versions. It was found after testing that even the most experienced users could not manipulate the package well enough to be able to see the tomb without any assistance. The viewpoints provided were an alien concept to many, and understanding how to implement them was a problem.

Understanding how to start the animation also caused difficulties. First attempts had tried to start the animation automatically on loading, but VRML allows the user to explore the model before it is fully loaded. This meant that because of the large size of the tomb images, the animation had completed before the tomb paintings were in place. A button was added to the model to try and implement the animation from within the scene, but this could not be made to work satisfactorily. The animation, as a result, had to be triggered manually after the model was loaded, which led to another major problem common to all three versions; how did the user know when the model was fully loaded?

Several options were discussed, as explained in the conclusion in the testing section. A second stage of the design was planned as follows.

> The model needs to remain fully rendered to cut down on the time wasted by each user waiting to begin using the model. Help, and the animated fly-through, need to be integrated into this version of the model. Help and instructions need to be displayed on the same screen as the model to enable the user to understand how to use the CosmoPlayer toolbar, and how to start the animated fly-through. All other options presented by the Netscape interface should be hidden to prevent the program from crashing (but unavoidable in the case of the link to the CosmoPlayer website in the CosmoPlayer toolbar which could not be disabled).

> A version of the model with the animated fly-through and the viewpoints needs to be displayed in a Java window to stop any other Netscape options being visible. Information needs to be presented on the screen by a set of Java windows. On start-up, a Java pop-up window explaining how to trigger the animation will appear. During the animation there will be a voice-over that imparts information about the model. Sound will also be used to give atmosphere to the model. When the animation reaches the tomb door, another pop-up window will appear explaining the tools in the toolbar. The model needs to be able to reset itself for the next user, i.e. return to the outer view without causing the whole model to be re-rendered. This could be implemented using a Java routine after a short period of time elapsed without any user input. Animations need also to reset at this point. The Java window containing the instructions to trigger the animation will then reappear ready for the next viewer. To save the need for an introductory screen that causes the model to be rendered again, the screen saver facility on the computer

could be utilised to provide an opening title page. This would mean that the user only need touch the mouse and the model would be apparent, and reset to its initial position. This should mean that the museum need only start the model once and it should function securely for the whole day. Java pop-up windows could also be used to impart some information about the model should the museum require this. An associated database could be built to hold information about the images and this could be accessed whenever the tomb images are clicked, returning information about the wall paintings.

Unfortunately, there was not time to implement this version and carry out the required testing before the submission of the project, but it was hoped that this would solve a lot of the practical problems associated with the user interface. Documentation of the system specification and functional requirements regarding this system can be seen in section 4.

10. The Completed Model

The completed model of Sen-nedjem's tomb can be viewed in two ways. The fully functioning model is provided, and can be viewed using your browser and the CosmoPlayer 2.1 plugin from Silicon Graphics/Platinum. The full model contains very large files (20 MB in total) and, as well as taking a long time to download, can take an equally long time to render on most machines. The large file size for the full model is due to the large images which are used in the inner tomb. For this reason a second version of the model is provided in which the images in the inner tomb are switched off, meaning the model is reduced to 1.5 MB, which may allow some systems to download and view the basic model.

For those who cannot view the model on their machine or do not wish the long download, a series of screenshots that take the user through the path of the animated flythrough has also been provided.

10.1 Views of the tomb model
For readers who do not have the memory capacity to view the model itself.
This section has been designed to show several different views (figures 37-45) of the tomb as experienced
in the animated fly-through generated by the model.

Outer view

Figure 37: The tomb complex from above.
The outer view was part of a larger group of tombs and so would not appear to be alone in its real setting. However, this proved too computationally expensive to show using current technology.

Pyramids

Figure 38: Left to right: the pyramids of Taro(?), Sen-nedjem's father, Sen-nedjem, and Khonsou, Sen-nedjem's brother. Each were decorated inside in the same style as the inner tomb. The user is prevented from entering the pyramids as the interiors are not reconstructed and essentially the point of interest is the inner tomb. The white triangular shape on the top of each is a Pyramidion, which would have been covered in a variety of images and hieroglyphs. Sadly, these have not survived. There would have been other votive offerings of plaques and statues in the courtyard but again these were no longer in place when the tomb was excavated. The tomb covers are shown to be visible here to indicate that there are other pits in the courtyard, but in reality all would be very well hidden under packed earth and gravel to deter tomb robbers. The entrance to Sen-nedjem's tomb is shown to be open; at the start of the animation this is closed and as the user approaches the tomb cover slides open.
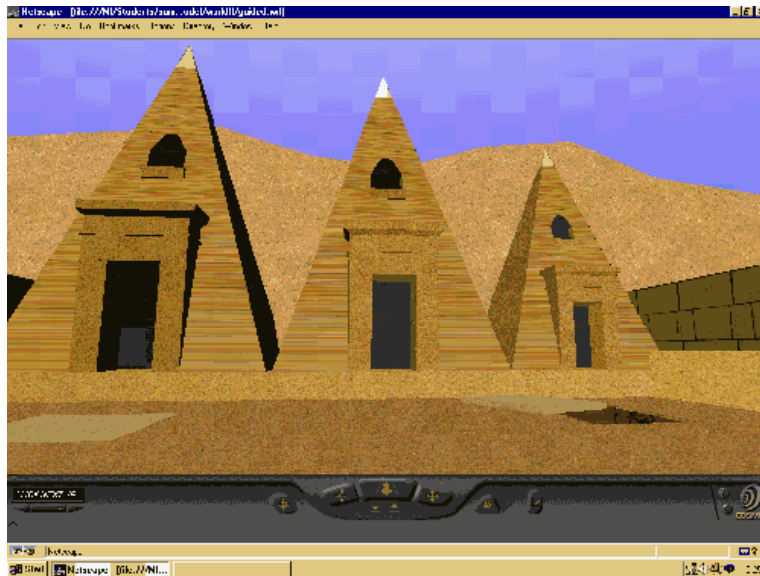
Top view
Figure 39: The courtyard and Pyramids from above. The open pit is the entrance to Sen-nedjem's tomb.
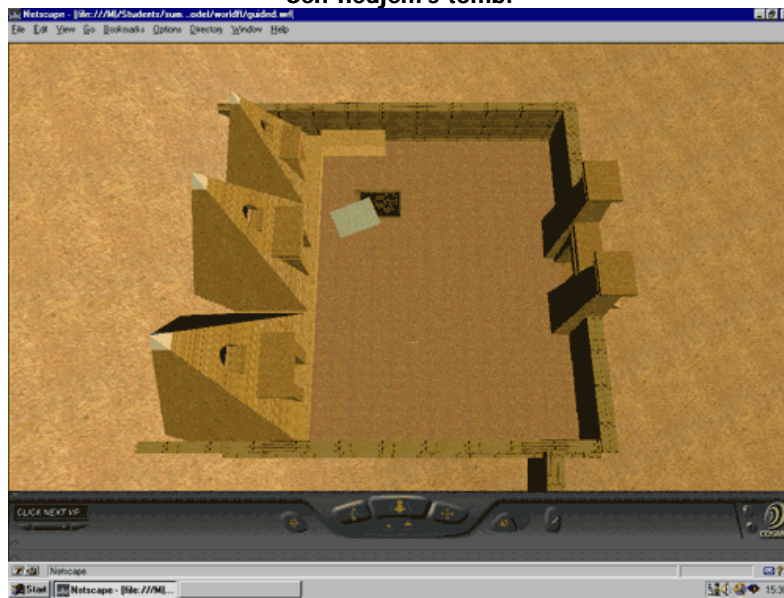

Pit opening
Figure 40: The view into the lower chambers. Note the footholds on either side of the pit.

Entrance to inner tomb

Figure 41: The smaller inner pit and entrance to room C. Again, the smaller pit entrance is covered by a slab which slides across to reveal the pit opening when the user is in close proximity to the pit. The stairs to the left are those that go down to room D, a small chamber which held food and funeral goods of Sen-nedjem. These stairs are small and the avatar cannot go down into the chamber (although it is modelled as found in the archaeological reports). The door to the inner tomb is shown slightly ajar. When the user first encounters the door (at the end of the animated fly-through), it must be clicked on to make it open and reveal the inner tomb chamber. Light sources have been employed throughout the model to make the tomb chambers visible.
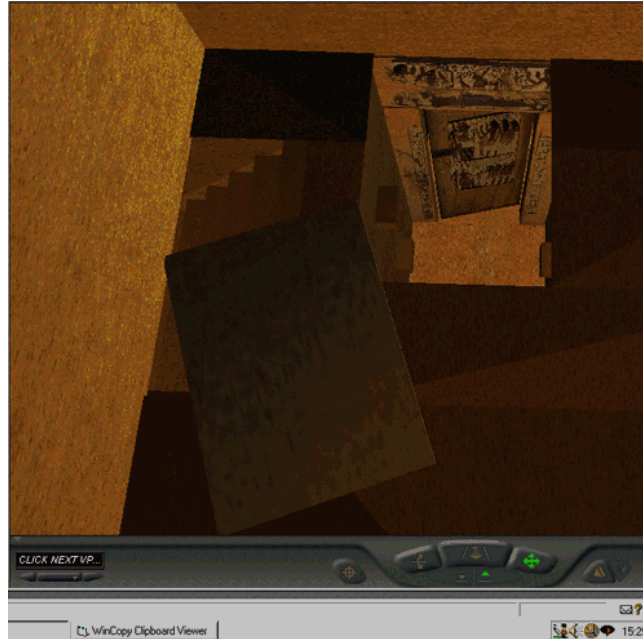
Inner chamber, left wall
Figure 42: This view shows the barrel-vaulted chamber of room C. Sen-nedjem and his wife can be seen on the left of the end wall. This image clearly shows how the barrel-vaulted chamber is rendered, allowing the viewer to see the painted chamber as a whole. The diagonal lines are lighting effects caused by light coming through the tomb door.
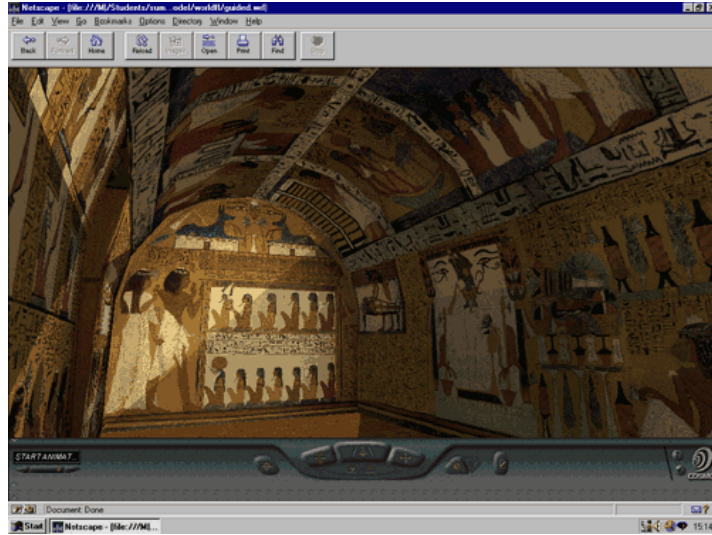
Roof, looking right
Figure 43: This image shows the barrel-vaulted roof chamber. At this angle it is apparent that the chamber is made from rectangular faces pieced together, but from below the vault is smooth enough to appear almost spherical. This view gives the spectator a good idea of how the images are laid out in the tomb.

Longer lower wall

Figure 44: This shows the difficult image of the longer lower wall in place within the tomb. Because of the lighting, the troublesome areas are darker than the authentic ones, which hopefully masks any real problems with the image.

Shorter walls and doorway

Figure 45: An image showing the doorway. Again, the diagonal lines are caused by the lighting algorithm, but this was the best that could be obtained. This image shows how the barrel vault joins the lower structure.

10.2 The completed VRML model

To view the completed model of Sen-nedjem's tomb you will need a browser that supports VRML (Netscape recommended), and have installed the CosmoPlayer 2.1 Plugin. This can be obtained from Silicon Graphics if you are using Irix or from Silicon Graphics' CosmoSoftware arm or Platinum if you are using Windows or Mac. It may be quicker and easier to download from Netscape Plugins. Note that Silicon Graphics are no longer

developing VRML and Cosmo software, and so it may be difficult for you to get the download either from their site, or even, in future, from Netscape. There are, however, plenty of individuals on the web who have a copy of CosmoPlayer 2.1 on their websites for download.

Internet Explorer Users: Microsoft products did not initially support VRML at all (they had set up their own and totally different alternative called Liquid Motion), so early IE browsers will not run the model. However, later versions of Internet Explorer (4 onwards) now have their own VRML-supported viewer (see http://www.microsoft.com/VRML/default.htm) but also support the Cosmo plugin, so the model should still work. However functionality using either may still be erratic. Ultimately the model will work best with Netscape.

Follow these instructions to view the model:

- Ensure you have CosmoPlayer 2.1 installed.
- Click on one of the links below to download a version of the model (the full model is 20 MB, the smaller version 1.5 MB).
- Wait for the model to render fully. This may take five minutes or more in order for all the images files to download. You can tell when the model is completed when the Netscape symbol in the top right of the browser stops revolving, or the stop button is dimmed.
- On the bottom left of the Cosmo navigation bar there is a viewpoint list. Click the downward pointing green arrow to show the other viewing options. Select the 'start animation' option by clicking on it.
- The animation will start.
- N.B. When you reach the inner tomb door you will need to click it to open the door to the painted chamber.
- Use the tools on the toolbar to navigate yourself around the room.
- You can navigate around the model without using the pre-programmed animation.
- If you want the animation to start again, select 'start animation' in the viewpoint list again.

Many users experienced problems with the tools provided by CosmoPlayer: it can be quite difficult to navigate around a scene. If you have problems please don't be disheartened, it's all part of the experience provided by the model and system.

Choose a model from these below: [hyperlinks inserted in web original]

- The complete model (20 MB)
- The model without inner tomb images (1.5 MB)

WARNING! Depending on your computer, the models may take a long time to download (you will require 16Mb of RAM although it may be possible to get by with 8Mb). Pentium or PowerPC class machines and 3D graphics cards are recommended. To improve the response speed, try making the VRML browser's window smaller.

11. Testing and Evaluation
Problems in developing a testing strategy

There are many problems involved in evaluating a virtual reality electronic display, mostly because of the fact that 'there is a distinct lack of methodologies that can be readily applied to the development of virtual environments for museums' (Mitchell 1997). Very little research into the evaluation of such systems for educational worth has been carried out, affording little framework upon which to base a comprehensive testing strategy.

The testing of such a device requires much observation of the user, ideally in the environment in which the final system is to be placed. Care has to be taken that test volunteers have a variety of computing experience to take account of the fact that a large proportion of museum visitors will have little or no computing knowledge. The person collecting the data has to be as unobtrusive as possible to allow for the reality that museum visitors do not often operate or understand an exhibit in the way those responsible for developing the display wanted them to.

Because of these basic facts, it was decided to carry out a series of formative evaluations on the virtual tomb of Sen-nedjem. By using systematic observation of a small sample of potential museum visitors, clarifying any issues raised and collating data, formative testing brings empirical evidence to the design process, testing the developer's ideas and informing the developer of the visitors' opinions (Economou 1997, 124). It was felt, with the lack of any proven methodologies for testing virtual environments, that formative evaluation would provide the means necessary for evaluating the system.

Aims of testing
The Virtual Tomb of Sen-nedjem aimed to present a virtual archaeological reconstruction, allowing the form and function of such a structure to be understood and interpreted by a wide audience. The model, however, did not carry any information regarding the tomb and the period of Egyptian history to which it belongs. Also, the means of viewing and exploring the tomb was already understood to be quite complex due to the nature of viewing virtual worlds constructed in VRML (see section 9). It was thought that a period of formative testing was necessary to;

Test the construction of the model
- Test the navigational tools used to explore the model (provided by CosmoPlayer)
- Test the navigational functions, i.e. animation, available to explore the model
- Observe the behaviour and needs of users
- Provide feedback about the user's understanding of major aspects of the model
- Provide feedback about the user's understanding of the procedures required to view the model, i.e. hyperlinks, load time, instructions given on different screens etc.
- Assess the overall impact of the model.

Method of testing
The model itself was thoroughly technically tested as each part was implemented, to ensure that the VRML was free from bugs and that each part functioned according to plan. This meant that when the model was fully rendered, each section would be sure to be completed and working, and any glitches were a result of the file structure or the way each part was called. The model, then, was continually tested from its creation to ensure that it functioned fully. The remaining tests would concentrate on how the user would be able to view the model.

It was not possible to carry out the evaluation of the user interface in the actual setting where the model would eventually be installed. However, in an attempt to rectify this, the user was supplied with some information regarding the possible use of the system to try and give some context to the display.

The first phase of testing involved 'think aloud protocols' (where users discuss exactly what they are doing and why) with three different volunteers from varying backgrounds. The subjects were observed whilst using the interface, and an informal discussion took place during and after their use of the interface. Care was taken to ensure that the users knew it was the interface that was being tested, not themselves, and the subjects were urged to be honest about their views on the model and user interface. They were then asked to explore the model using the three different navigational methods, and were given no help from the observer.

Further testing, building on these findings, involved the use of a semi-structured interview after viewing the model. Another five test subjects were shown the model, and encouraged to discuss their views.

More informal testing was carried out by showing the model to friends, computer specialists and archaeologists. Any comments were recorded and used to re-evaluate the design of the model and user interface further.

Problems with the testing

Unfortunately, it was not felt that those testing the interface would give a fair representation of the average museum goer. Although not all had experience with virtual environments, most had extensive experience with computers, were used to using the mouse, and were familiar with terms like 'load' and 'home'. To test the final version of the interface, it was acknowledged that a broader spectrum of people would be required, including those from different age groups and social strata. However, for initial testing of the user interface, it was thought that the users chosen would spot major flaws in the electronic display. They came from a wide variety of backgrounds, having experience in primary education, Egyptology, archaeology, computer graphics, three-dimensional computer gaming and the development of multimedia interfaces for museums.

Results: first phase

The purpose of the first three 'think aloud' protocols were to indicate the ease of use of the user interface, and compare how effectively the different options enabled the user to navigate around the model. This was done by asking each of the three users to describe exactly what they were doing (and what they understood they were doing) at each stage. Each was asked to start with a different model to evaluate what the user learnt from each. Results of these first tests showed that whilst the model itself was interesting and functioning to a high standard, the user interface explaining how to use the tools provided and allowing the user to switch between models was far from ideal.

One problem was the frame mechanism used. Although this allowed the user to alternate between instructions and the model, and provided some introductory information, every time the model was accessed it took five minutes to render. If any of the navigational functions were used before the model had finished loading the resulting views were stilted and jumpy. There was no way of telling exactly when the model had finished loading, unless Netscape's toolbar was retained on the screen, but this gave the added problem of providing the user with another row of buttons, some of which would crash the model if pressed. The use of Netscape also meant its basic menu bar at the top was displayed, and the mail preferences in the lower right hand corner were active. These, too, could be accessed by the user and crash the model.

Another problem with the frame mechanism was that the instructions required to start the animated fly-through or use the viewpoints were given on the page before the model. With the five minute delay, the user had forgotten the complex instructions before the model had even fully rendered. A final problem with the frame mechanism was that, using Netscape v3.01, every time the user pressed the 'home' button to return to the start a new browser was initiated. With two browsers running, the model did not function smoothly and with three or more the model crashed because of the extra pressure placed on the processor.

Once the model was fully loaded, there were other problems. The toolbar provided by CosmoPlayer was found to be wholly unsatisfactory for users both unfamiliar and familiar with the use of virtual reality. All three found it non-intuitive, with one commenting 'The worse thing about it is the toolbar'. Only rudimentary help is given, and it is not clear that the buttons require the user to click and drag to instigate movement. That said, after all three users grasped the basic concept, they were quick to use the tools effectively, or as

effectively as they can be used. One user noted that whilst the model was in three dimensions, the tools only allowed travel in two, meaning that the user has to switch between all three tools to move, for example, to the top left of a space. Movement was deemed to be very clumsy and difficult. It was noted that the experience of the model was greatly affected by the poor tools provided. The inability to disable the link to the CosmoPlayer site and help site was also noted; these brought up separate sites which filled the screen, giving no indication of how to return to the model.

Due to the problems with the toolbar, it was found that the version giving no navigational help through viewpoints or animation proved impossible to navigate by even the most experienced user. Without any help the user did not know what they were trying to do, where they were trying to go, and why they were trying to get there. Although the animated slabs gave some indication of where to go next, the tools provided made it impossible to get there, and after a few seconds all three users gave up. One found it 'irritating', another 'unplayable', and the third commented that it was 'no fun'.

The version using viewpoints also proved tricky; first the user had to understand the concept of viewpoints, then understand how to implement them, then be prepared to follow the list of viewpoints in order. Because the viewpoint mechanism is constructed linking the easiest path between two specified points, if the user chose a viewpoint not consecutive to the current position there was often the sensation of passing through walls and glimpsing the partially rendered model outside the field of allowed vision. There was no way to disable this unwanted, disorientating effect. The viewpoints often did not give the feeling of a fluent transition between each, merely jumping to the next, meaning that areas of interest were not seen by the user, and the experience of understanding the structure of the model was lost. Again, two left the model without seeing the most important part, the painted tomb. This was deemed 'too difficult to use', and 'disorientating', by those tested.

The animated fly-through was thought to be the most successful of the three options by all three users. This integrated the use of the animation and solo exploration by taking users to the inner tomb door, and allowing them to explore the tomb chamber. 'The animated fly-through was the most enjoyable. The fly-through wins', commented one user, another said it was 'cinematic', and the most advanced they had seen, the third merely said 'wow'. It was generally agreed that the combination of guidance and then opportunity to explore the model yourself gave the user some context before having to experience the CosmoPlayer toolbar, and the use of the images on the moving door made them try harder to use the tools to see the rest of the model.

However it was noted that the model gave no information about what it contained, why it was of interest and what they were expected to draw from the experience. One of the three believed that as there was no interactivity (in the provision of information sense) the model would be better presented as a continual fly-through, including the inner tomb chamber in the animation which could be on continuous rotation in the museum, even shown on a video and television screen: 'it's not worth being interactive as there's nothing to discover'. The other two believed that having the opportunity to explore the model yourself was paramount to the learning experience.

The actual model was found to be of high quality, and very advanced for its type. The inner tomb chamber was especially commented on for its realistic appearance and the real feeling of being there the model imparted. There were a few areas noticed which could be tidied a little, but no drastic flaws were spotted.

Conclusions drawn from this initial testing were:
- The model itself is fully functioning
- The animated fly-through is fully functioning

- The tools provided by CosmoPlayer are very hard to manipulate, and whilst this is not the fault of the model developer it affects the impression people have of the display
- Of the three versions of the model, the animated fly-through is the best and, indeed, the only workable option
- The frame mechanism hinders the display of the model because of the time taken to render it every time it is accessed. The model should be rendered once and reused
- The frame mechanism does not help in explaining to the user how to use the toolbar provided
- The whole model needs to be displayed in such a way that the Netscape functions are not shown
- Information should be given during use of the model, on the same screen
- Some contextual information needs to be provided regarding the tomb and the wall paintings.

Results: phase two

Testing with the five others confirmed the above findings. The model was very well received in general, aside from the technical problems of the frame system and instructions. There were various positive comments: 'I like it', 'It's like Doom!', 'makes you want to see the real thing', 'fascinating to look at', and 'cool as hell!' One volunteer, a former primary school teacher, commented that 'kids would love finding things and getting around on their own, especially if there was some puzzles or items to find'. Another, who had actually visited the tombs in Deir el-Medina and the surrounding district, observed that it was 'as realistic as you are going to get, especially if you never get to Egypt'. He also commented on the fact that the real tombs are now in such bad repair because of the number of tourists visiting them that in such sites the wall paintings are protected by sheets of opaque plastic and very dimly lit: 'it is actually possible to see more detail in the model than in the real thing', highlighting the conservation aspect of virtual reality. However, there was a general feeling of wanting to know more, and most asked 'is that it?' One volunteer commented that it 'looks quite cool but doesn't tell you anything about it', another said 'yes, it was very pretty...' All were questioned on what they had learned; most had no concept of the time scale of the model, how it looks today, what the purpose of the structure was or if they had 'completed the task'. A general conclusion was that some information needs to be integrated into the model to tell the viewer exactly what they have been seeing.

Various suggestions to improve the model were made, including the use of a continuous animated loop, the use of Java pop-up windows, the addition of a voice-over to the animated tour, the use of mouse-overs, the use of a compass so users could orientate themselves within the model, the presence of a small map so users could tell their present position, and the use of interactivity to impart knowledge about the tomb paintings.

Conclusion

The model itself was thought to be of very high quality, showing that it is possible to build a realistic archaeological reconstruction using VRML and commonly available resources and software packages. However, it is acknowledged that the first design of the user interface is unsuitable for installation in the museum, for reasons specified above. Testing has shown that a complete redesigning of the user interface is necessary to incorporate the necessary information and tools into the model in such a way that the user will understand how to use the model and the purpose of the installation. Unfortunately, the second phase of the design was not implemented in time to be tested. It is hoped that this design will incorporate the necessary characteristics needed for users to view the model easily.

12. Conclusion

Discussion of status of model

The computer-generated model of the tomb of Sen-nedjem successfully reconstructs the archaeological evidence available into a cohesive whole, which illustrates how the tomb could have looked in its heyday. Although this tests the limits of current hardware and software, it shows that VRML can be used to achieve archaeological reconstructions, and the photorealistic virtual structure created could be used as the basis of an educational experience for installation in a museum. However, there is still considerable work to be done on the user interface before the package could be deemed fit for installation in a public environment, and the authenticity of the model remains in doubt because the user cannot differentiate between areas based on archaeological evidence and those devised by the model's creator.

Problems found

The major problem regarding the model is the lack of information provided about the structure. Questions need to be asked regarding the function of the display; what learning outcome is to be fulfilled by experiencing the model? Without an integrated information system, for example to provide an interpretation of the wall paintings and explain their detail and significance, the model becomes a technical showcase which allows fairly photorealistic archaeological reconstructions to be shown, but gives little real educational benefit. Virtual reality is only one of many multimedia tools and should be used alongside others to provide information by all means available.

There were major problems found with the design of the user interface, and perhaps too much emphasis was placed on developing the model in the time-scale given, neglecting issues concerning how the public would actually access it.

However, in saying this, the groundwork has been done to implement a successful virtual display. The technical issues encountered in creating the model were wide and varied, and a great deal of ingenuity had to be applied to reach its present state. Although there are a few areas in the model which could be tidied up (the backdrop could be improved, the sky could perhaps show night and day, a few faces in the structure need to be re-aligned to ensure they are flush with other walls), the general consistency of the model is of a high quality, and essentially any other adjustments are small refinements. The virtual reality model is ready to be viewed by the public; it is the means by which it is viewed that needs to be improved.

Future work

The VRML model itself, as stated above, is in a finished state. With any project of this type there are always additions that could be made - for example improvement in the background to indicate the tomb's place in the complex at Deir el-Medina, and the use of sound within the tomb to improve the multimedia experience - but essentially the model successfully renders the structure required to a high standard. Future work will concentrate on developing the user interface to make it more intuitive, interactive and informative to the viewer, as specified in section 9.

Other possibilities that could be looked into include having the model assessed by experienced archaeologists to gauge how authentic the reconstruction actually is. With the publication of the catalogue relating to the tomb of Sen-nedjem, and the permission acquired to use the images in the catalogue, authentic virtual exhibits could be placed in the tomb model. These too could be linked to a database, providing the technical means necessary eventually to link existing museum catalogues with virtual reality worlds to place museum artefacts into an authentic context.

Summation

Building the virtual world is only the start of implementing an archaeological reconstruction for public education. Care needs to be taken to ensure that the virtual world actually provides some information regarding the time-scale, form and context of the structure, whilst stressing that the representation is merely an impression of what the scene could have been like, even if based on archaeological evidence (early archaeological reports do not provide the information necessary to implement a virtual structure). Due to the public's lack of familiarity with the technology, extra care must also be taken to explain how to use it. That said, VRML has been shown to be capable of dealing with complex archaeological data, and the software involved is capable of rendering photorealistic surfaces. VRML does provide a means of supplying archaeological reconstructions for public education more cheaply and efficiently than other available alternatives, but until methodologies are put in place regarding the creation and evaluation of such packages, their development will be hindered and their educational worth remain unassessed. A great deal of work needs to be undertaken before virtual reality becomes a common feature in public spaces.

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Other Web Sites of Interest
Dynamic Timelines - Visualising Historical Information in Three Dimensions
http://robin.www.media.mit.edu/people/robin/thesis/

Egyptian Reconstructions, University of Chicago,
http://www-oi.uchicago.edu/OI/DEPT/RA/ABZU/ABZU_REGINDX_EGYPT_IMG.HTML

Egyptian Tomb of Menna, Manchester Metropolitan University
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