VIRTUAL REALITY USER INTERFACES FOR THE EFFECTIVE EXPLORATION AND PRESENTATION OF ARCHAEOLOGICAL SITES

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ABSTRACT: Archaeological virtual environments are computerised simulations allowing the study and exploration of archaeological sites. For architecture students and researchers at the University of Auckland they provide several advantages compared to traditional methods of study and exploration such as site visits, illustrations and books. Advantages include that there is no physical travel required, greater amounts of information can be provided in a more accessible manner than with maps or diagrams, and different representations of the site can be created, e.g., before modifications and expansions. The sites that archaeological virtual environments represent can contain many structures and thousands of artefacts distributed over a wide area. As a result users find it hard to get an overview of the site or to focus on particular aspects. Furthermore data on these sites is often gathered over a long period of time using different processes and media, which makes it difficult to present effectively to a student body.

In this project we present solutions to these problems tailored to the needs of different user groups such as archaeologists, architects and architecture students. The requirements of different user groups were analysed and Virtual Reality technologies were developed to facilitate the exploration of archaeological sites, in order to retrieve information effectively and to gain new insight into the site and its inhabitants. These technologies are demonstrated within a new reusable archaeological virtual environment framework, which is used to create virtual environments for archaeological sites. The framework is built upon a game engine, resulting in a quicker development cycle and more realistic rendering than would be feasible if it were developed from the ground up. In contrast to previous applications our framework enables the integration of a wide variety of media. This dramatically facilitates content creation, which is usually very time consuming, expensive, and requires skilled modellers and/or animators. Our framework provides simple interfaces to create a 3D context (terrain and simple models) and then integrates more easily obtainable representations such as images and movies for providing visual details.

The technologies designed and implemented included the integration of QuickTime VR into a game engine, which allows a commonly-used medium for recording scenes to be used within a virtual environment. The two media integrate well and, while not seamless, the new representation enables a focus-and-context style exploration of the domain. We also present a data model for archaeological sites that supports a wide variety of information types including multimedia. It is independent of the rendering engine used, allowing archaeological virtual environments to be extended and upgraded more easily. Using these representations we investigated new metaphors for navigating and interacting with archaeological virtual environments, including interactive maps, guided tours, searching mechanisms, time-lines and time-of-day settings for controlling sunlight direction.

The techniques afford users a richer, more informative experience of archaeological virtual environments. They can be adapted to a broad range of archaeological sites, even where data was gathered by multiple differing methods.

KEYWORDS: virtual environments, novel interaction interfaces, game engines, archaeology, data representations

1. INTRODUCTION & BACKGROUND

Three-dimensional virtual environments have been investigated since the 1990s for use in the study of archaeology. Their uses range from purely research-oriented tools to aid in the visualisation of archaeological data through to explorable digital renditions of full archaeological sites for uses such as education and virtual tourism. Whichever the application, virtual environments provide a number of advantages:

- They allow people to visit sites without having to physically travel to them.
- They improve the ability of the observer to visualise and understand a site compared with traditional media such as photographs and maps.
- They provide a more interesting and immersive view to the casual observer than such traditional media.
- They allow a wider range of viewpoints from which to study a site, including in a temporal sense; for example, an observer can watch a site develop over time
- They can present additional information on features of interest in a coherent, easily accessible manner; for instance, an observer may examine details of an archaeological artefact presented in the virtual environment without having to refer to a separate text. This is especially useful if the description refers to the object's location and its relationship the environment and other objects.
- They allow users to interact with the environment, e.g. by moving, adding and removing objects and structures or by changing scene properties such as lights and materials. This can help understanding the motivations for an existing architectural design and its changes over time.
- They allow people in separate geographical locations to work collaboratively on a single site.
- They can easily be distributed to the general public.

Archaeological virtual environments may be roughly divided into two classes; research aids and historical reconstructions. The former represent the site as it exists today and provide the means to explore and study it; the latter attempt to recreate the site as it was at one or more points in history. Both types of environments exist, although historical reconstructions have been more widely publicised.

Virtual environments can be greatly beneficial for archaeological research. Before the advent of computer technology, visualisations of archaeological data were created in the form of two-dimensional diagrams or illustrations (Reilly and Rahtz 1992). The immense quantities of data generated from archaeological excavations and surveys are often very difficult to adequately display in these formats, however. For example, stratigraphy – the representation of the layers of earth on a site and the objects and soil types contained within – is represented using two-dimensional diagrams called "sections" (Renfrew and Bahn 2004). This data is inherently three-dimensional (Barceló et al 2000), and would be better presented using three-dimensional visualisation methods. Two-dimensional methods also struggle to adequately represent the associations between finds on a site because of the limited information that can be displayed (Barceló et al 2000). Interactive three-dimensional visualisations such as virtual environments greatly ease this restriction, and provide an increased number of ways to visualise and work with data. For example, neighbouring objects can be computationally analysed to determine whether they might actually be fragments of a single object. Examples of these kinds of archaeological virtual environments include ARCHAVE (Acevedo et al 2001), which allows the analysis of stratigraphy and the finds within an archaeological site, and GeoSCAPE (Lee et al 2001), which facilitates the recording of the position of the features of an archaeological site including artefacts, structures and other finds, and their later visualisation.

Virtual environments depicting historical reconstructions have often been aimed towards the general public, but they can still be helpful to archaeologists. They may, for instance, be used to formulate and evaluate hypotheses about questions such as how the site was used. They also allow a broader variety of ways to present information more richly than earlier technologies: any number of viewpoints is possible in a virtual environment, features of the site such as buildings and artefacts may be "hyperlinked" to relevant information such as bibliographic resources, and querying can be used to locate and concentrate on important details (Renfrew et al 1996 and Barceló et al 2000). One of the strongest advantages of these kinds of virtual environments is their usefulness for the dissemination of research: archaeological research is normally published in a printed journal, and all too often a long time passes between the actual fieldwork and analysis and its publication (Barceló et al 2000 and Renfrew and Bahn 2004). Virtual environments can be distributed via electronic means such as the Internet. Furthermore, they can easily be updated as new information emerges, increasing the frequency of the publication of this information as well as reducing the delay. Virtual environments have the additional advantage of being easier to interpret than a series of disparate diagrams and explanatory text, improving their accessibility to both academics and laypeople.

The use of virtual environments for "virtual museums" or tours aimed at the general public is also very common (e.g. 3D Rewind Rome (2009), and the work of Gaitatzes et al (2001) and Kim et al (2006)). These are gradually advancing in complexity and capabilities, with continuously improving graphics and some featuring sophisticated animations as well.

Significant challenges are still faced in the development of virtual environments to represent archaeological sites, especially as the scope and detail of the information presented increases. It is necessary to capture and digitize 3D data before it can be used in a virtual environment, and it is difficult to achieve this cost-effectively while maintaining high visual fidelity. Furthermore, information-rich virtual environments must merge data collected from often disparate sources such as photographs, 3D models, GIS data and reference texts into a cohesive whole. This data can be incomplete, tends to contain uncertainties, and may change over time as more information is collected. The large quantity and complexity of the data available for an archaeological site necessitates careful consideration of the representation of that data and how it is accessed. Our project has investigated methods to allow archaeological virtual environments to present this data in a coherent, informative and easy to use manner, while remaining cost-effective to create and maintain.

2. SELINUS CASE STUDY

During the development of our project we created a virtual environment of the ancient city of Selinus – a Greek colony in Sicily – as a case study. The University of Auckland's School of Architecture and Planning, in conjunction with its counterpart in the Università degli Studi di Palermo (University of Palermo), runs a joint program every few years in which students from Auckland and Palermo visit archaeological sites including Selinus, and work together on architectural projects (Milojevic 2007).

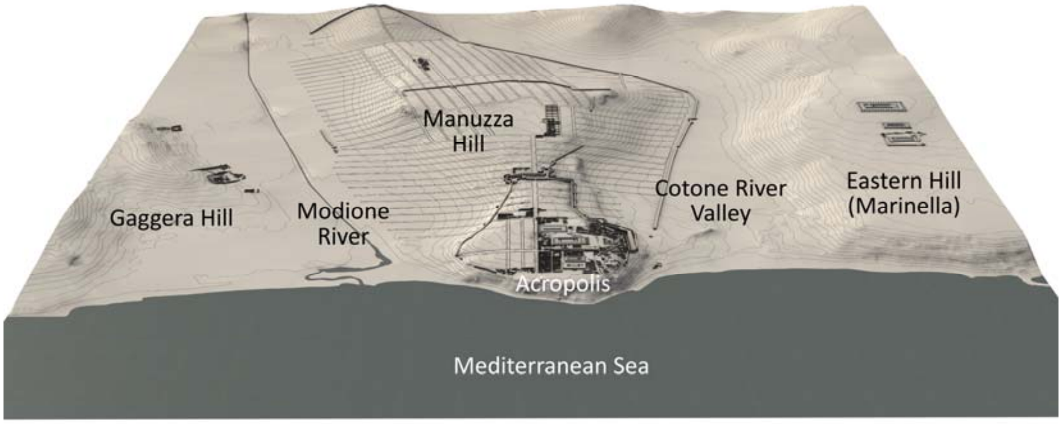


FIG. 1: Overview of the Selinus site.

A multimedia DVD containing photographs, maps, 3D models, QuickTime VR panoramas, and textual resources has been created to give these students an introduction to the Selinus site, its contents, and its history. However, it is not as effective or as immersive as a virtual environment would be, and thus its authors wished to create such an environment to improve the quality of their learning resources. We have used this project as an example to help guide our decisions in the design of a virtual environment creation system that can be used for a broad variety of purposes, which may not even include archaeological research.

3. REQUIREMENTS

In order to design a broadly-applicable virtual environment system we needed to consider the needs of the wide variety of users it would have. These included:

- creators of virtual environments, such as researchers and other academics from the archaeological and architectural fields;
- users from the architectural field who would be using the system to explore archaeological sites; and
- users from the archaeological field who would be using the system to study an archaeological site.

Users wanting to create virtual environments of a real location may have varying levels of computer skills, and are often not programmers. Content creation tools such as level editors of game engines and modelling and animation applications have made this task easier, but do require some artistic skills, reasonable technology skills (e.g. use of scripting languages), and are time consuming and expensive. Most large-scale Virtual Reality application we are aware of use professional designers and animators. A suitable application for laymen is “Second Life”, which, however, does not have any tools for creating archaeological content. In order to make content creation more efficient and effective we must utilise pre-existing data such as diagrams, 3D models, contour maps, and the like.

We surveyed users of archaeological environments and evaluated the literature and found (Keymer 2009) that users of virtual environments from the architectural field tend to be most interested in the aspects of a site that could be considered more “artistic”; its spatial features, its form, its appearance and so on. They are particularly interested in the structures on a site, and thus are often responsible for creating historical reconstructions or visualisations of an archaeological site or ancient building. In order to appreciate the form and shape of a site, they prefer to be able to view them from as many vantage points as possible. Views from the ground are important, as they reflect the site from the perspective a common person may have seen it; however views from the air can also be particularly informative. Human activity is important to architects; this is one of the main reasons that the archaeological artefacts on a site are interesting to them. The most important aspects of these artefacts are, again, largely artistic; their minor details are less important than their presence, spatial attributes such as their arrangement, and what they indicate about the human presence in the area. Thus architects may tend to browse through areas rather than study particular groups of artefacts in detail.

Users from the archaeological field, by contrast, study sites from an anthropological perspective; they seek to understand the people that lived there, not just the artefacts, buildings and other features that make up the site (Renfrew and Bahn 2004). For this reason the crucial information from an archaeologist’s perspective is the cultural significance of an artefact or a structure – for example who used it, how they used it, and what it indicates about the society that created it. How this information should be presented depends on whether the virtual environment is being used for presenting past findings or for original research; if the former is true an interpretation of the significance of an object can be provided directly, but if the latter is the case as much information as possible should be presented about each feature of the archaeological site to maximise the chances that a researcher will be able to draw useful conclusions (Renfrew et al 1996).

These requirements can often conflict with each other; an environment that is useful for an archaeologist is likely to contain a great deal of information which would be unnecessary or even distracting to an architect. Therefore a virtual environment creation system that is useful to both would need to be able to tailor the resulting virtual environment to present the level of information required.

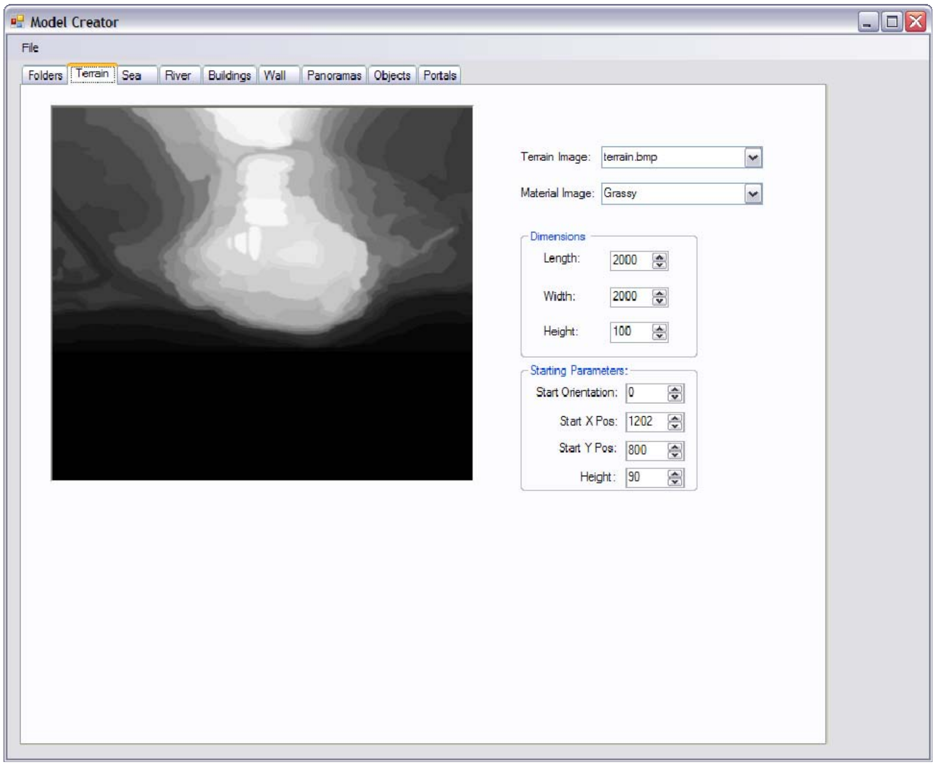
4. PROJECT DESIGN - GAME ENGINE

The rendering framework was the first stage of the development of the project as it would form the foundation for later work. We elected to build it using a pre-existing framework or technology as a base. There were three main reasons for this. Firstly, the development of a new framework would not address any of the goals of this project; it focuses on user interface techniques, and features such as a custom rendering engine were considered to be unlikely to add significant value to these. Secondly, the use of a pre-existing framework would accelerate the development of the system overall, and the features that would add value in particular. Thirdly, the disadvantages and limitations of such an approach are minor; although it may limit the flexibility of the overall system somewhat, this can be largely mitigated with careful choice of a technology appropriate to the project.

We analysed a variety of options when choosing a basis for our virtual environment rendering framework, including general-purpose 3D visualisation technologies, previously developed archaeological tools, and game engines (Keymer 2009). Game engines fulfilled our requirements best since they are cheap, are optimised for consumer level hardware, are frequently updated to use the latest graphics technologies, provide intuitive interaction tools, and have a large user base resulting in well tested and stable code. We eventually settled on Esperient Creator (2009), as we received access to the SDK, had previous experience with it, and because it is highly flexible, had excellent tools, strong plug-in support, multi-player support (for collaborative visualizations), and is targeted at the development of non-game virtual environments such as those we wish to support.

Even with a well-suited engine, however, we still needed to create our own pipeline for creating, rendering and exploring archaeological virtual environments. We achieved this through the use of two major components: one of these is a stand-alone program to collect various types of archaeological data, compiling them into a computerised description of the archaeological site. The other component is a plug-in for the Esperient Creator engine which interprets this description and uses it to display and facilitate interaction with the virtual archaeological site.

This plug-in is designed to be re-usable and extensible, in order to support a wide variety of kinds of archaeological sites. It has a two-layer, modular architecture which separates the concerns of the data model from the engine used to represent it – making the data easier to work with and more portable – and separates distinct blocks of functionality into their own modules, which helps to make new functionality easier to introduce.



Terrain Image: terrain.bmp
Material Image: Grassy

Dimensions
Length: 2000
Width: 2000
Height: 100

Starting Parameters:
Start Orientation: 0
Start X Pos: 1202
Start Y Pos: 800
Height: 90

FIG. 2: Virtual environment creation interface: terrain loading and modification.

4.1 Data Model

Archaeological data sets can be extremely large, diverse and feature rich. In addition some data, such as building structures, can change over time. We have created a custom data model which supports dynamic scene generation, efficient data access and manipulation, and interaction with other systems or APIs. The data is imported from an XML scene descriptor file, which facilitates interchange of data, extension of the model, and integration with web interfaces. The data model is divided into the following components which have different attributes and functions:

- Environmental components (terrain, seas, rivers, vegetation)

- Man-made structures (buildings and other structures such as walls and moats)
- Archaeological artefacts
- Multimedia components (e.g. photographic images of the site and objects, including QuickTime VR panoramas and object movies.)
- Temporal entities (eras)

All of these components can be interrelated. For example, man-made structures and artefacts can be associated with one or several eras and multimedia components can be associated with positions in the terrain or artefacts. Each of these data entities contains attributes describing it, such as size, shape, age, date created, date found, bibliographic references, multimedia descriptions (photos, object movies tec.), and relationships with other elements of the archaeological site. More details of the data model and attributes are found in (Keymer 2009).

Different data entities are generated and loaded using different tools using common interfaces. For example, figure 2 illustrates the terrain generation using a digital elevation map (DEM) representation where height values correspond to gray scale values of an image. We have also developed an application for creating DEMs by drawing and semi-automatically labelling contour lines or importing them from GIS applications (Xie and Wünsche 2009).

FIG. 3: QuickTime VR within the game environment.

4.2 QuickTime VR support

Supporting some types of data used to create archaeological sites can be more difficult than others; one of the most difficult was QuickTime VR panoramas. These allow a user to view a 3D scene from a single point by wrapping a photograph or series of photographs onto a virtual cylinder or sphere. The user can click and drag with the mouse to rotate their view of the scene. QuickTime VR panoramas are widely used by a number of archaeological projects, including the Selinus project, because they can be produced relatively easily and inexpensively, and allow an immersive view of a site that is otherwise difficult to obtain.

We allow the user to transition from a view of the virtual environment to a view of the QuickTime VR panorama, retaining the same control system from the environment, which is also drawn around the border of the QuickTime VR panorama to provide a frame of reference. The QuickTime VR panorama provides an interactive feature rich representation without expensive and time-consuming creation of 3D content. Note that 3D content can be created automatically from video images, but this is computationally expensive, heavily influenced by environmental parameters (illumination, shadows), and requires expensive well calibrated hardware. In addition the resulting scenes usually contain many small errors which severely reduce viewing pleasure.

This process was challenging to implement; QuickTime is normally designed to be used by embedding a player in an appropriate place inside an application window, but due to issues in timing the rendering of the player with the in-built rendering cycle of Esperient Creator, we had to introduce an extra stage of indirection into the process by rendering the player to a non-visible section of memory, the contents of which were then copied into an Esperient texture buffer. Details are given in (Keymer 2009). While this process is more complicated and less efficient than drawing directly to the screen, it does allow us more flexibility with the use of the QuickTime player's output. The results are illustrated in figure 3. The view direction inside the virtual environments changes with the view of the QuickTime VR movie such they are always aligned. Small offsets are unavoidable due to inaccuracies in the modelled scene and lack of information about the exact camera position for the QuickTime VR movie.

4.3 Navigation

Another important concern is how users move through and navigate the virtual environment. Architects – as we discovered – are particularly interested in being able to view a site from the ground, but also find it helpful to view it from the air. Thus our system had to handle both, allowing the user to switch between them quickly and easily. Ground-based movement had the higher priority of the two.

The size of large sites – such as Selinus – also has impacts on navigation. It will take some time to cross a large site if the user can only move slowly; however if movement is too fast the system will be less usable and less immersive, and disrupt the user's perception of the scale of the site. The system had to allow the user to move at a normal walking speed, but also provided methods for crossing large distances that do not disrupt perception of scale or immersion. The portal concept from computer games is a suitable method to jump quickly between logically connected positions, e.g. buildings which related functions spread over a wide area. The Strider concept, which we introduced in (van der Linden et al. 2004), allows exploration with smoothly varying speed, context and perspective.

A major difference to games and other virtual environments is that archaeological sites change over time. The user should hence not only be able to explore a site in the spatial domain, but also in the temporal domain. The time period displayed in the virtual environment is controlled by a "timeline" slider as illustrated in figure 4. The slider is manipulated using the mouse, and the adjacent text provides a visual indication of the currently selected era. Only objects valid during that era are rendered. In order to achieve this each data model entity – presently artefacts and buildings – that is affected by the timeline system contains a list of the eras it is present in and absent from. Terrain is less likely to change over time, but the system could be extended to support terrain if such changes are later found to have been significant.

Guided navigation methods – such as tours – allow users to become acquainted with a site quickly. While non-essential we believe they would be a valuable addition to our system. Tours should utilise both the spatial and temporal domain and should be easy to find, easy to use, and effective at improving understanding of the site.

The system should also support a mechanism that allows artefacts and other important elements of an archaeological site to be found quickly. This would be especially important for archaeologists – to allow them to locate related finds, for instance – but it would also be helpful for anyone who is particularly interested in one location or artefact on the site. This kind of "search" mechanism would therefore need to be designed to identify individual entities based on a variety of commonly-required constraints, whether by individual object attributes, groups of attributes, or relationships to other objects on the site.

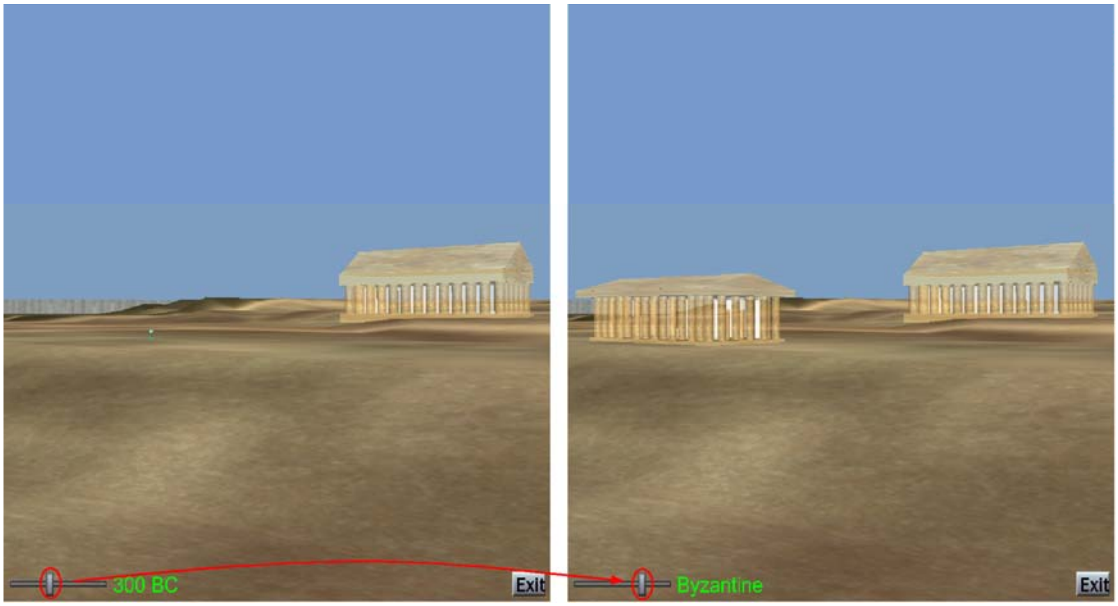


FIG. 4: Timeline control to filter site view.

4.4 Artefact display

There are a number of key requirements the artefact handling features of the virtual environment system had to satisfy. These include abilities such as being able to represent the artefacts on screen, conveying as much information about them – especially important details – as quickly and concisely (such as in visual form) as possible, allowing the user to easily interact with them as necessary, and managing situations where artefacts are distributed quite densely.

We chose to represented artefacts within the virtual environment by small 3D objects, or “icons”, which indicated the type of the artefact; for instance an individual amphora may be represented by a generic “amphora” icon. Because there are relatively few artefact types, only a few models need to be provided, which reduces the amount of time and resources necessary to build virtual environments containing large numbers of objects.

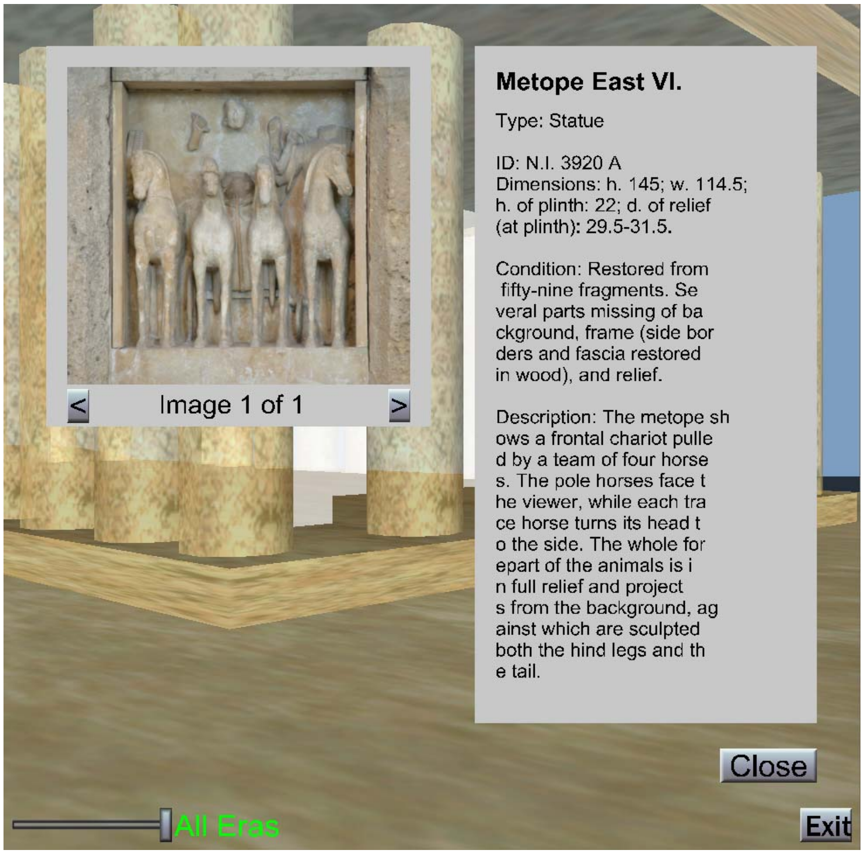
When the icon is clicked a “detail view” is shown which displays more information about the selected artefact. This view displays material that cannot be easily displayed in the virtual environment – such as textual information and visual media – and information that may be represented in the environment but cannot be accurately interpreted there – such as its dimensions and significance.

The detail view consists of two “panes” as in figure 5. The left pane displays a selection of visual media, while the right contains exclusively textual information about the artefact. Media in the left pane need not be static images; QuickTime VR object movies are shown here as well, and the system is constructed to be extended to support other media types including animations and movies as needed. This is demonstrated by the QuickTime VR integration which is essentially an advanced movie format.

5. RESULTS, CONCLUSIONS AND FUTURE WORK

We have presented a system supporting the display and exploration of archaeological virtual environments that can be created from a broad range of types of media. This work was motivated by our observations that much existing data recorded for archaeological sites is difficult to use in existing virtual environments, and that they could be improved if these types of data were supported. After analysing the problem and user requirements we identified key features to incorporate into our system, then developed designs for these features and implemented them into a working application.

We have evaluated technologies and found that game engines are best suited because using they provide multi-player capabilities, intuitive interfaces, tools for content creation, and they support common 3D data models. Our system separates the content of a virtual environment from the system used for the presentation of that environment. This helps it to achieve the objective of supporting a wide range of archaeological sites. We created a conceptual "meta-model" of an archaeological site describing the kinds of features and information that can make up an archaeological site; this information is used to create collections of data files that can be used by the same environment. One of the most effective features of this approach is that it allows pre-existing data that has been collected for an archaeological site to be used for creating a virtual environment. This data may be stored in a diverse range of formats, such as GIS data, photographs, models and QuickTime VR movies. By using this data as-is rather than requiring custom-designed content be used for the site, we have created a system that allows virtual environments to be created more easily, quickly and efficiently. Furthermore it can be updated simply by adding new content, without requiring an expensive and time-consuming conversion into a 3D representation.



Metope East VI.

Type: Statue

ID: N.I. 3920 A
Dimensions: h. 145; w. 114.5;
h. of plinth: 22; d. of relief
(at plinth): 29.5-31.5.

Condition: Restored from
fifty-nine fragments. Se
veral parts missing of ba
ckground, frame (side bor
ders and fascia restored
in wood), and relief.

Description: The metope sh
ows a frontal chariot pulle
d by a team of four horse
s. The pole horses face t
he viewer, while each tra
ce horse turns its head t
o the side. The whole for
epart of the animals is i
n full relief and project
s from the background, ag
ainst which are sculpted
both the hind legs and th
e tail.

FIG. 5: Object icons in the game environment and the detail view.

Integrating QuickTime VR movies into the rendering of the scene provided rich content with suitable context. Identifying the precise camera position for a QuickTime VR view is difficult without additional data such as its GPS position. However, even without seamless integration the media blended well and allows a focus-and-context style exploration of the domain. The game environment provides an overall context for QuickTime VR movies and enables users to get an overview of the entire scene and the QuickTime VR movie's camera position within it. Vice versa the QuickTime VR movie is content rich and provides a more realistic representation than the modelled environment and hence provides a better context for understanding the terrain, e.g. how the architecture blends into the natural environment.

We also performed a basic usability study and found that navigation is easy, although the existing Selinus virtual environment is relatively simple. More challenging scenarios are required to test how well the system performs in complex environments. Interaction with QuickTime VR panoramas works quite well. They are easy to see and activate, and view rotation is synchronised accurately. Rotating the view with the mouse results in sluggish handling, however, which needs to be improved. Interaction with artefacts is relatively easy, but they can be difficult to see at a great distance due to their size. The planned inclusion of a top-down map should alleviate this problem. The Selinus site takes a long time to move around at present, and this could become frustrating for users. This may be partly due to performance issues that slow down movement, but in any case it is likely that faster movement, e.g. by using the previously mentioned Strider interface, will be required.

Overall our results indicate that the developed tool is intuitive to use and provides an easy way to create content rich multi-media supported 3D representations. More detailed user studies are required to test the effectiveness of the tool. In particular we want to test whether our tool helps users to explore an environment more efficiently, whether users' memory of scene content and spatial relationships improves, and whether users can solve archaeological problems more effectively. We also want to do add more capabilities for automating the creation of scene content, e.g. modelling of 3D objects and structures from images using photometric stereo, integrating GIS data (if available), and automatically creating guided tours based on spatial, temporal and semantic relationships.

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