

# Providing Multimedia Tools for Recording, Reconstruction, Visualisation and Database Storage/Access of Archaeological Excavations

J. Cosmas, T. Itegaki, D. Green, N. Joseph,  
Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom,  
Email: john.cosmas@brunel.ac.uk  
L. Van Gool, Eidgenossische Technische Hochschule Zurich / Katholieke Universiteit Leuven  
A. Zalesny Eidgenossische Technische Hochschule Zurich  
D. Vanrintel, Eyetronics NV  
F. Leberl, M. Grabner, K. Schindler, K. Karner, Graz University of Technology  
M. Gervautz, S. Hynst, Imagination Computer Services GesmbH  
M. Waelkens, M. Vergauwen, M. Pollefeys, K. Cornelis, T. Vereenooghe, Katholieke Universiteit Leuven  
R. Sablatnig, M. Kampel, Vienna University of Technology  
P. Axell, E. Meyns, Axell Communications

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## Abstract

*Over the years archaeologists have been swift to embrace new advances in technology that allow them to more comprehensively document the results of their work. Today it is commonplace to find information technologies, in the form MS Office-type tools with some CAD and GIS, deployed for primary data capture, analysis, presentation and publication. While these computing technologies can be used effectively to record and interpret archaeological sites, the radical developments in 3D recording, reconstruction and visualisation tools have had relatively limited impact upon the archaeological community. This is unfortunate as these new technologies have the potential to (a) enable the archaeologists to record their unrepeatable experiments to unprecedented levels of accuracy, (b) enable the archaeologists to reconstruct artefacts such as pottery from sherds, textures and sites from different eras (c) visualise the wealth of excavated information in dynamic new ways away from the archaeological site during post-excavation analysis, (d) make this wealth of detail available to the scholarly community as part of the publication process and secure its digital longevity through its deposition in a trusted digital library/archive and (e) communicate the excitement and importance of their archaeological site and its finds to an interested non-academic audience. This paper describes the overall concept of the EU funded project, 3D Measurement and Virtual Reconstruction of Ancient Lost Worlds of Europe (3D MURALE), that has developed and created a set of low-cost multimedia tools for recording, reconstructing, encoding, and visualising archaeological artefacts and site.*

## Keywords:

*Recording, Reconstruction, and Visualisation of Multimedia Tools, Archaeology, Replicated Database.*

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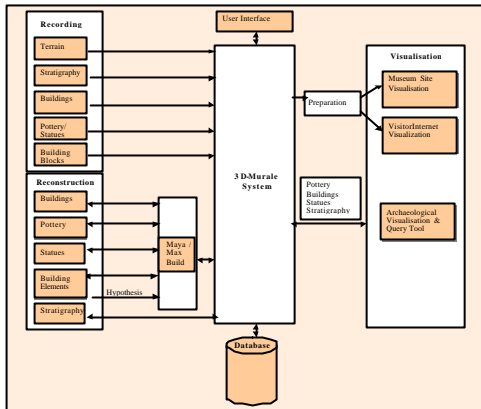
## 1. Introduction

A large archaeological site excavates hundreds of thousands of artefacts annually and during this process destroys its own evidence. The largest sites, covering tens of square kilometres, are actively excavated over hundreds of years. Therefore the logistical effort to digitally record both artefacts and building finds is enormous and access of the finds for the purpose of scientific study is very difficult. Accurate records of the excavations are crucial in order to study the finds within their context, and to allow for later reassessment where necessary. The stratigraphy is bound to disappear as the excavations proceed, and physical access to the

finds is often restricted in practice, as pieces are locked into depots. Novel technologies to improve the quality of the excavation records therefore are of potentially great help to archaeology, but they must not reduce the speed of the excavations and the cost of the equipment involved should be reasonable.

The 3D MURALE system [1] consists of the Recording, Reconstruction, Database and Visualisation components as shown in Figure 1. The 3D MURALE project, in close cooperation with the Sagalassos Archaeological Research project of Katholieke Universiteit Leuven, has developed a modular set of Multime-

dia tools for recording, reconstructing, encoding, and visualising archaeological artefacts and sites that are easy to use, affordable, and that require minimal expertise in the underlying technologies. This enables archaeologists themselves to efficiently use the tools in situ.



**Figure 1: Archaeological Process Flow**

It has developed generic recording tools that can record a variety of shapes and object types, ranging from landscapes, over buildings, to ornamental structures and statues. Furthermore more dedicated tools have been developed to record and model for example pottery sherds or stratigraphic layers. Virtual reconstruction of both the original shapes and surface textures yield impressions of how these structures once looked like. In addition to existing 3D graphics tools, software tools have been custom-built for the automatic matching (puzzling together) of 3D pieces, with the aim of building completed 3D models (virtual anastylosis). In parallel, a database has been designed, that allows the finds to be linked to a site's stratigraphy, that supports the retrieval of the finds, and that helps to visualise them within a freely selected spatial and/or temporal context.

This paper describes the overall concept of this multimedia system for archaeology and then briefly describes the functionality of the tools provided by the project.

## 2. Description of 3D MURALE Tool Set

### 2.1 ShapeCam-part of ShapeWare

A first system for the capture of 3D shapes, developed by Eyetronics is ShapeCam. ShapeCam is based on the principle of structured light: a predefined grid or pattern is projected on an object or a scene and is viewed at by a camera from a (slightly) different point of view. ShapeCam generates 3D models based on the use of a single image taken by an ordinary camera

(Canon EOS D60). The shape extraction is achieved by analysing the grid deformation while the texture is extracted by filtering out the grid lines of the image. Alternatively, a second image is taken without the grid projected that directly yields the corresponding high-resolution texture. ShapeCam comes with an easy calibration procedure. It is used to capture objects of small and medium sizes, from cm-large pottery sherds to m-sized statues. It is also portable hence can easily be taken on the site. The limitation is that the projected grid has to dominate over the ambient light.

### 2.2 Shape from Video

The shape from video technique retrieves both the structure of a scene and the motion of the camera from an image sequence. Not only video but also sequences of photographs can be used. The processing is in principle fully automatic, although a limited user interaction can allow a more robust and flexible use of the software tool. In a first step features are extracted and matched or tracked over consecutive images. Geometric constraints exist on where feature points can go in the images with respect to each other if they are part of the same, rigid structure. Based on these constraints, both the settings and motion of the camera, as well as the 3D positions of the feature points can be determined. This only yields a point cloud. To obtain a full surface reconstruction of the observed scene, the images are rectified so that a stereo algorithm can be used to determine dense depth maps. Using a volumetric technique, these are then integrated into a single 3D surface. By making use of texture mapping photorealistic models can be obtained. A more detailed description of this approach can be found in [2, 3, 4, 5]. The flexibility of the approach allows this technique to provide a solution for many of the 3D modeling demands found in archaeology.

Since the Shape-from-Video software is based on the tracking of features between images that look alike (short baseline), motion blur will inhibit this proper tracking of features, as a feature looks very different in a blurred frame and a non-blurred frame. Motion blur occurs if there is fast camera motion during the recording of the video. The features would therefore be lost or at best the blurring will severely diminish the accuracy of the feature position in the image. For this reason, blurred images are detected by the software and removed to avoid these problems. However, as this eliminates the faulty feature tracking between a sharp image and its consecutive blurred image, the removal of the blurred frames will increase the gap which exists between sharp frames which are separated by a section of blurred frames. As blurring is normally a phenomenon that extends over multiple frames, the gap between the sharp frames that delineate this blurred region can be quite large. This gap can require corresponding features to be sought no longer in more or less the same

place in the images (short baseline) but in image regions which can be far apart from each other (wide baseline). An experiment with wide baseline feature matching as an addition to the Shape-from-Video software has been constructed during the 2003 excavation season in Sagalassos (Turkey). Wide baseline feature matching is based on a methodology that has been developed by [6], which identifies affinely invariant features, which make use of their geometric and colour invariance for easy matching.

In the context of this project Shape from Video is used to record and reconstruct stratigraphy, building parts, statues, and terrain geometry.

### 3. Reconstruction Tools

#### 3.1 Stratigraphic Layers Matching

Once the different stratigraphic layers have been reconstructed, it is important to transform them to the world coordinate system. At least three theodolite points are measured by the archaeologists to be visible in the 3D reconstruction of a stratigraphic layer. This positioning is crucial to allow the Strat Tool to read in the model and automatically position it at the correct place. In theory, the theodolite points should be sufficient to place each reconstruction independently in the absolute framework of Strat tool. However, noise and errors on the theodolite points and the 3D reconstruction will cause the 3D reconstruction of neighbouring layers to be somewhat misaligned with respect to each other. This can be ameliorated by loading in the two neighbouring layers at the same time, indicating in each layer the theodolite points and on top of that indicating corresponding feature points between both layers such as structures that have been reconstructed in both layers (e.g. standing walls).



**Figure 2:** *Stratigraphy alignment tool in action. Two different layers (top) are aligned (bottom).*

The Layer Matcher will then look for the optimal positioning of both layers keeping in mind both the

absolute theodolite data and the relative corresponding feature data. Figure 2 shows two neighbouring layers that were registered in this way. The tool also allows to make length measurements and to compute volume between layers.

#### 3.2 Shape Matcher

The ShapeMatcher software, part of ShapeWare, is a tool to combine different patches obtained with Shape-Cam in order to obtain a complete all-around 3D model. It distinguishes itself from other approaches in the fact that:

- The matching procedure between different patches is automated and can be performed on more than two patches at the same time.
- There is no need for prior knowledge about the relative positions of the separate patches,
- Even patches that do not match perfectly or do not correspond can be integrated into a single surface.
- It takes into account specific information about the data acquisition (Shape from Structured Light's calibration file) to optimise the matching process.

The automatic tools can be called for the matching proceeds in three consecutive steps:

- Alignment;
- Blending;
- Integration of the different patches into a single model.

Overall the process is time consuming and can take up to a week depending on the complexity of the object. For example each block of the “Dancing Girls” frieze shown within Figure 13 which is a complex object took a week to complete.

#### 3.3 Building Reconstruction using Enhanced Maya

The reconstruction of a building is done in three steps [7]:

- Stones are typically broken and weathered therefore the existing building blocks from the recording stage are completed;
- The hypothetical blocks are assembled like 3D puzzle elements to construct the original building;
- Finally, the missing parts are added by creating additional hypothetical objects or by cloning existing ones.

All three tasks require a great amount of expert knowledge from an archaeologically trained operator.

The process of reconstructing statues is very similar to the one for buildings reconstruction previously described. First the existing parts of the statue are put together, then the hypothetical statues is created. In order to implement the outlined process, a data model has been defined describing the objects as shown in

Figure 3 and their relations where data can be organised for building reconstruction as shown in Figure 4.

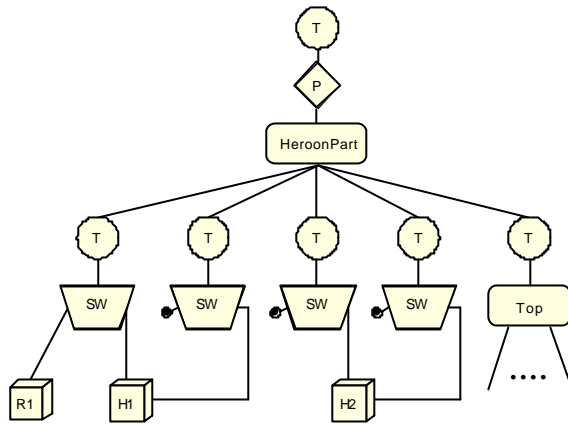


Figure 3: Scene graph for archaeology

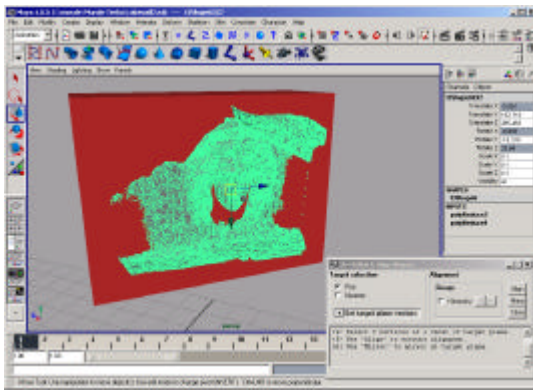


Figure 4: Placing the dancing girls mesh onto the wall of the Heroon

### 3.4 Pottery

Classification and reconstruction of archaeological pottery fragments is based on the profile that is the cross section of the fragment in the direction of the rotational axis of symmetry [8], [9] and [10]. In order to segment the profile into primitives like rim, wall and base rules based on expert knowledge is created. The input data for the estimation of the profile is a set of points produced by the acquisition system, as shown in Figure 5.

A function fitting this set is constructed and later on processed to find the characteristic points necessary to classify the original fragment.

- Automatic Orientation
  - Determination of the axis of rotation
  - Registration
  - Profile generation
- Automatic Profile Selection

- Determination of shape characteristics
- Determination of description
- Curvature based segmentation
- Generation of primitives
- Generation of a description (archive database)

- Automatic Reconstruction
  - Automatic classification
  - Reconstruction of missing parts of profile
  - Reconstruction of vessel
  - Search for already archived fragments of the same vessel

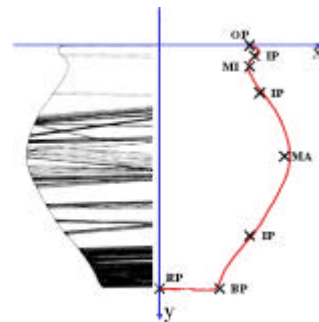


Figure 5: S-Shaped Vessel: Characteristic Points

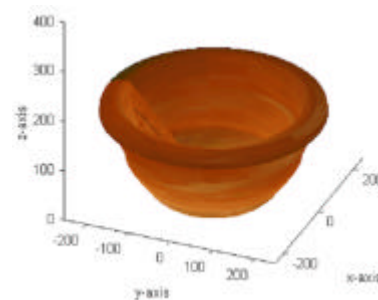
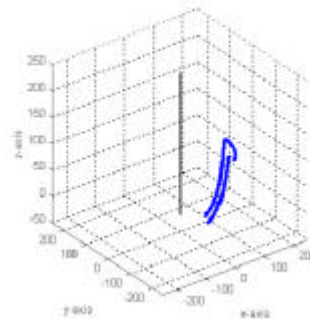


Figure 6: Rotating the Oriented Profile in order to get a 3D Model of the Object

By rotating the oriented profiles, a 3D model of the object can be obtained, Figure 6.

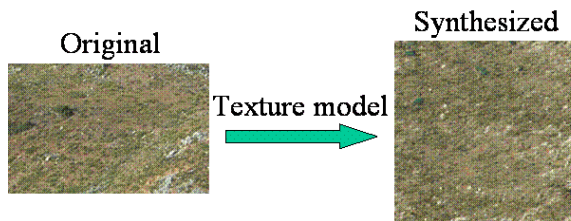


### 3.5 Synthetic Texture Generator

So far, the focus of attention has been on the acquisition of 3D shapes. Almost as the other side of the same coin, good surface texture is also needed. This cannot always be captured together with the shape. Building materials, for instance, will change their appearance over time, due to erosion and degradation effects. Similarly, the terrain may have been covered by different vegetation at different periods. This means that shapes may have to be covered by textures different from the existing ones. A tool has been developed to create these alternative textures, mimicking original materials and vegetation.

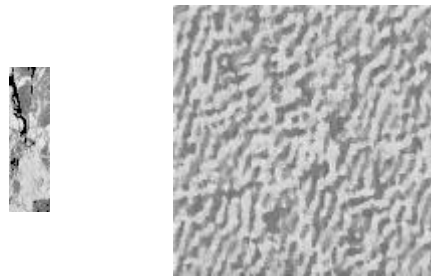


**Figure 7:** Simplified trial mapping of the synthetic limestone textures onto the 3D model of the Antonine Nymphaeum.



**Figure 8:** Learning and Synthesis of Homogeneous Textures

As with the other 3D MURALE tools it is important that the texture generation tool is as easy to use as possible. Starting from example images of the desired texture, a statistical model is generated automatically. Such models are then used to generate synthetic textures [11]. The models contain information on the pair-wise relations between pixel colours. For flat surfaces, a single, perpendicular view of the example texture suffices. An example is shown in Figure 8. This single view was used as the only input to the texture modelling procedure, creating the texture model Figure 9.



**Figure 9:** Black-white. Composite with 2 subtextures



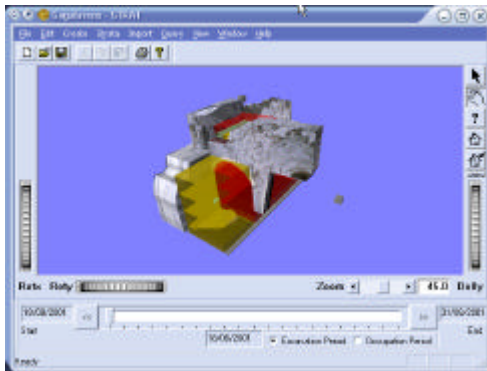
**Figure 10:** a) mountain slope behind Sagalassos in its current state, b) Virtual reforestation and irrelevant object removal

It shows the relative pixel positions that are involved in the pair-wise colour relations contained in the model. Rough surfaces need more. In that case the texture appearance will strongly depend on the lighting and viewing directions. Self-occlusion and self-shadowing effects will change the appearance drastically. The same approach can be extended. Given a set of example views now taken under a sufficiently wide set of viewing conditions, a texture model is again learned automatically. This model can be used to synthesise arbitrary amounts of texture for user-selected viewing and lighting directions. This extended model is hardly any larger than the one for a flat surface Figure 10a, b.

## 4. Visualisation Tools

### 4.1 Stratigraphy

The stratigraphic visualisation tool generates a textured or wire-frame 3D representation of the stratigraphic layering of archaeological excavations as shown in Figure 11, through a set of data entry interfaces and provides plan, profile and perspective views to the data [12].



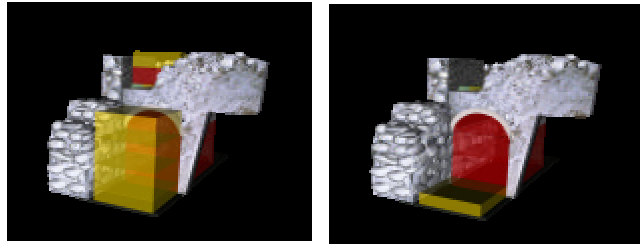
**Figure 11:** Wireframe 3D representation of stratigraphic layering

Artefacts discovered in a layer can be represented by a symbol or by a 3D representation of the found artefact. Each layer can have an arbitrary shape. The tool:

- Enables three types of possible stratigraphic data to be entered in the database for 3D reconstruction: notebook data, theodolite data and photogrammetric/laser scanned data. The quality of the reconstruction improves with each method stated.
- Enables the archaeologists to more readily visualise the relative positioning of the stratigraphic layers
- Enables archaeologists to correlate layers of stratigraphy correlation. Layers are selected with the mouse, and then correlated with the four temporal relations (earlier than, later than, contemporary with and equal with). This interface is very similar to that of ArchEd [13].
- Allows stratigraphic data to be exported as a Harris Matrix file [14];
- Allows for the data entry of a broad range of archaeological data, namely: building elements (features), artefacts, stratigraphy, plan and profile drawings and photographs;
- Allows the data entry of hypothetical data, as illustrated in Figure 13;
- Selectively accesses and queries an particular group of artefacts (Building Parts, Pottery, Statues, Bone, Coins) to be visualised within the stratigraphic layers for the purpose of analysis;
- Visualises each stage of the excavation using a time slider thus establishing the chronological sequence of stratigraphic layers, as shown in Figure 11;
- Visualises the occupation period of each stage of the excavation using a time slider;
- Visualises user defined cross sections of the stratigraphy;
- Highlights through visualisation the inconsistencies in the dimension of adjacent

stratigraphic layers;

- Corrects through user interaction the inconsistencies in the dimension of adjacent stratigraphic layers.



**Figure 12:** Replaying an excavation, strata by strata with textured building elements made visible



**Figure 13:** Hypothetical data Entry

During the development of the stratigraphic data-entry module of the STRAT system, the central issue that came to light was that of the incomplete and inconsistent recording of the stratigraphic data by archaeologists. This difficulty was strongly reinforced in November 2001, when Harris emphasised the need for Geographical Information Systems (GIS) to force the archaeologist to acknowledge the pre-eminent position of surfaces, rather than deposits, in stratigraphic analysis and recording [15]. Due to field difficulties, stratigraphic data is often recorded in a haphazard and incomplete fashion. This prohibits the accurate and convincing reconstruction of the original stratigraphic surfaces [16]. On analysis of contemporary stratigraphic data recorded by archaeologists it becomes apparent that if the noble desire of the archaeologist to generate detailed maps from this data is to be fulfilled, an improvement of the procedures by which archaeologists record stratigraphic data is necessary. The future strength of GIS systems such as the one developed in this project is dependent on a comprehensive consistent approach to the 3D recording of stratigraphic layers by surveyors.

## 4.2 Museum

For the museum-based visualisation system, the user can navigate through textured models of the excavation site Figure 14 and visit some of the main buildings such as the Heroon and the Nymphaeum. However, anyone who has already tried to navigate through a city model using a normal vrmf-browser knows that navigation is not a simple task. Therefore developing an intuitive and easy to use navigation interface seems important to enable all types of users to use a museum system. Displaying a 3d-reconstructed scene to the user, regardless how realistically it is rendered, is not enough. No serious museum would present its exhibits uncommented to the public – however this is exactly what is done in most present visualizations. Therefore the integration of various kinds of interactive multimedia content into the scene, adds educational value without disturbing the appearance of the visualization.



**Figure 14:** *Virtual Reconstruction of Sagalassos (Axell Communications)*

Since the users of a standalone museum installation can not be expected to be experienced with computers, navigation is a vital issue. The visitor should be able to freely explore the ancient city on his own, otherwise there is not much difference to just watching a documentary movie. However, navigation needs to be restricted in a subtle way so that the visitor is not allowed to navigate to parts of the scene, which are not relevant or is not able to rotate the viewpoint about virtually any angle in 3D-space. Any of these two cases would quickly leave the user lost in hyperspace. Furthermore collision detection has to be used to avoid visitors passing through objects. A terrain following map has been developed where a colour code is used to restrict navigation for avoiding collision and to restrict camera motion for helping viewer stay on the ground.

A proof of concept “display” was made out of a cardboard frame with a back-projection foil inside the frame and was mounted on top of a space-mouse, as shown in Figure 14. A projector was used to project the image onto the foil from behind. By means of turning

and pushing the display with its handles the user can navigate through the scene. During tests this handling proved to be very intuitive, indeed since everyone was able to operate the system immediately and there was no need for explanations which is very important if used in a museum context. Currently a more robust material than cardboard is being sought for the “display” frame.

In order to avoid getting lost, free navigation is complemented with predefined camera animations, where the visitor can take virtual tours through the site [17], as shown in Figure 16. Like on a real tour he/she is lead through the city and the sights are explained to him/her as they come into the visitors view. In the first visualisation – the upper agora – signposts were used so the user could choose to start a tour to the most important “virtual sights”. On the lower agora, an avatar is used as a virtual guide to accomplish the same effect. While both methods work fine and also can be easily combined, virtual guides seem to be more effective because following a guide seems to be a more active process and text/sound output can be integrated more logically – i.e. it is the guide who speaks to the visitor.

For the integration of interactive multimedia, on the selection of an object (be it an artefact or a building), a semitransparent plane with explaining text/image/movies/3D object slides out of the object and stops in front of the user, as shown in Figure 17. By clicking the plane it slides back to where it came from and disappears. Of course it would be easier to use a separate 2d-window for text/image/movies/3D object output instead of displaying it as fully integrated into the 3d-environment.



**Figure 15:** *Proof of Concept Display System*

But apart from esthetical considerations the main advantage of this approach is that due to the animated effects the user gets visual clues to what exactly the text relates to. The viewer can zoom in and rotate the 3D objects interactively, to get a 360-degree view of the find. Panoramic images can also be accessed, as example of which is the Doric fountain as shown in Figure



18, where a 360-degree panorama taken from the actual site is smoothly faded with the reconstructed 3d-scene. By being able to control the transparency of the panorama overlay the user can compare reality with hypothesis in a very intuitive way.

To match the specific needs of the application, two different types of audio output can be integrated into

the scene: background-sound and speech. one speech While there can be several background sounds running at a time (e.g. birds, opening doors, music ...), there can only be output active which can also be muted if the user doesn't want to listen anymore.



Figure 16: The user can select guided tours, view real photos from the actual site and examine artefacts in detail



Figure 17: Accessing Interactive text/image/movies/3D object media



Figure 18: 360 Panorama with reality merged with virtual reality

### 4.3 Internet

An internet-based portal to the database has been provided to allow access from anywhere in the world for the public. We cannot make any assumptions about the user capabilities, graphics capabilities and network connectivity, the Internet visualization system must be designed for use by non-experienced users on old machines without graphics hardware and with just a dial-up modem connection to the Internet.

A new data structure called "Compressed Adaptive Multiresolution Encoding" (CAME) has been developed for efficient storage of adaptive multiresolution non-manifold triangle meshes [18]. This offers data compression by a factor of 25 over the original meta-node concept [19]. View-dependent simplification (as in principle already proposed by Clark [21]) is used to select only those parts of the virtual world with the highest contribution to image quality, thus saving



transmission and rendering time while minimally degrading visual appearance. Our remote visualization system utilizes client-server architecture. The server provides the compressed data, the client receives and interprets the compressed geometry and displays the scene to the user. The client is encapsulated in a browser plug-in to allow embedding 3D MURALE scenes into regular web pages (Figure 19).



Figure 19: Viewing window with LOD processing embedded into a framed web page as a browser plugin

5. Database

The 3D MURALE database handles storage and retrieval of text, 2D and VRML image information of archaeological content such as excavation units in the site, specifications of the strata, buildings, artefacts, parts of artefacts, photographs, stratigraphic drawings and documents. The 3D MURALE Database follows a replicated system design where the data is maintained in a central PostgreSQL database and during an excavation season, the new data is entered into the local Access databases in the laptops or personal computers of archaeologists. Once the season ends, the new data is uploaded to the central database. Due to the remoteness of the sites and the non-availability of a high bandwidth Internet connection, this is the only plausible option. PostgreSQL was chosen of the central database, which has the advantage of being free and open-source, thus making this system as low cost as possible and is the most advanced and well-supported open source and advanced object relational databases. The Stratigraphy Data Model has been implemented both in the PostgreSQL and Access. The Strat tool is used for data entry in the Microsoft Access database and a Replication Tool has been developed which selectively uploads and downloads data from the central database to the Access database, as shown in Figure 20. It also has the facility to remotely connect to the central PostgreSQL database and selectively upload the data from the local Access database.

For migration of both database schema and data from Microsoft Access to a PostgreSQL database, software such as pgAdmin, Access2PgConverter, exportSQL, the MDB Tools could have been used. However, none of these supports replication of data on a selective basis. That is to say, the user cannot specify a particular record in a table and any related information regarding that row to be replicated into another database. The 3D MURALE System has developed a tool that allow for the selective replication of data in the local database to the central database and the selective downloading of data in the central database to the local database. This system has been designed so that it only permits users (excavation site foremen) with the appropriate user id and password to login to the central database and download/upload data associated for a chosen archaeological excavation campaign. The interface of the replication tool is shown in Figure 21.

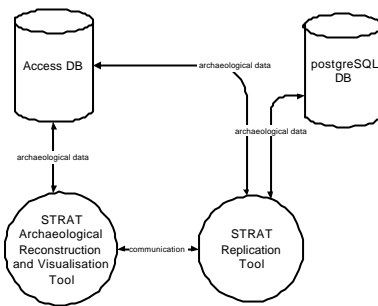


Figure 20: Process of replication between the Central PostgreSQL database and the local Access Database

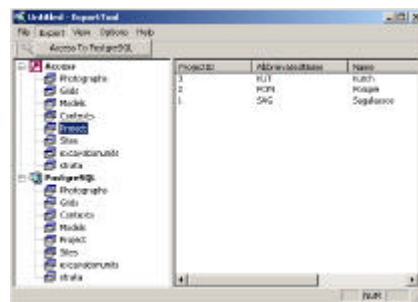


Figure 21: Selective replication tool between PostgreSQL and Access

In the Strat tool data entry and query tools have been developed to store and access data for the stratigraphy and pottery as well as Building Parts, Statues, Bone and Coins. The database follows current CIDOC data model guidelines [20] for representing the final museum artefacts. The work done in the 3D MURALE project may be used to extend the CIDOC data model to address the archaeological excavation process.

## 6. Conclusions

3D MURALE provides tools to the archaeological community, in order to support the recording, reconstruction and visualisation and database storage of 3D content. Ease of use and applicability *in situ* by the archaeologists themselves are central goals of the project. The tools not only produces good-looking results that can be shown to the general public – however important that is in its own right – but also allows archaeologists to keep records that are more complete and accessible.

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