# Designing Virtual Reality Reconstructions of Etruscan Painted Tombs

Mirko Rao[1], Davide Gadia[1], Stefano Valtolina[1],
Giovanna Bagnasco Gianni[2], and Matilde Marzullo[2]

[1] Dip. Informatica e Comunicazione, Università degli Studi di Milano,
Via Comelico 39, 20135, Milano, Italy
{gadia,valtolin}@dico.unimi.it
[2] Dipartimento di Scienze dell'Antichità, Università degli Studi di Milano,
Via Festa del Perdono 7, 20122, Milano, Italy
giovanna.bagnasco@unimi.it, matilde@infinito.it

**Abstract.** The application of Virtual Reality technologies is becoming largely widespread in the Cultural Heritage field. Digital restorations, virtual reconstructions, interactive navigations, are just some of the possible applications. In this paper, we present a preliminary Virtual Reality reconstruction of the Etruscan painted Tombs in Tarquinia. Only a part of these tombs are open to the public: using Virtual Reality it could be possible to visit all the Necropolis, with the possibility to interact with the environment, and to visualize additional information.

The application has been designed in order to be modular and flexible. To test the application, we have used the Virtual Theater of the University of Milan, a Virtual Reality installation based on a large semicylindrical screen and passive stereoscopic visualization.

**Keywords:** Virtual Reality, Cultural Heritage, Virtual Reconstruction, Etruscan Tombs.

## 1 Introduction

The application of Virtual Reality (VR) technologies in the Cultural Heritage (CH) field has shown a relevant growth in the last years. In fact, the flexibility of VR allows archaeologists and historians to experiment with new approaches and validate different theories through simulations and digital reconstructions. The use of VR in the CH needs an intense interdisciplinary collaboration among IT (Information and Technology) and cultural experts for providing attractive environments that are also accurate from a scientific point of view. Each detail of the interactive VR simulations must be validated by the cultural experts, in order to avoid the diffusion of inaccurate and superficial information. On the other side, VR scientists can suggest new possible solutions to CH experts, on the basis of recent technological advances [1].

Archiving, reconstruction, restoration, interpretation, simulation, dissemination are the most used keywords related to the use of VR in the CH field. For

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example, VR has been effectively used for digital reconstruction of existing monuments [2], and for digital restoration of paintings [3]. By means of 3D modeling and animation, different interpretations and theories about the vestiges of the original places or monuments have been investigated [4–6].

By means of VR, it is often possible to offer students, scholars and tourists, an organic presentation of a CH site placed in in locations difficult to reach and hard to visit [7]. From this point of view, VR introduces new interaction patterns in the cultural context increasing its role in conservation, interpretation and dissemination of ancient cultures; however sometimes interaction patterns such as virtual devices are simply meant to assess historic or naturalistic objectives rather than introduce visitors to experience ancient cultures. To develop an environment where to share and exchange knowledge about a specific context of interest, it is crucial to enrich the VR visualization with additional information concerning the context in which the heritage was originally set. VR technologies are particularly useful to fulfil such goals because they make the integration of multifaceted information easy in an interactive and appealing way [8, 9]. Some researches have been already presented [1, 10–14] to investigate efficient integration of database technology for accessing contents from multiple digital archives of CH information.

In this paper, we present a preliminary version of a VR reconstruction of the Etruscan Necropolis of Tarquinia (UNESCO site since 2004), where a relevant number of painted tombs are present; however, not all of them are open to the public at the same time. Using VR, we have designed a modular and flexible application, in order to give an overview of the area with the location of the tombs, and to perform virtual visits enriched by the integration of additional materials currently stored in different cultural institutions.

Section 2 is meant to give some information about the Necropolis, and section 3 to present the details of the VR reconstruction and of the VR installation used to develop and test the application.

## 2 The Etruscan Necropolis in Tarquinia

The Necropolis of Tarquinia, together with that of Cerveteri, are UNESCO sites since 2004. In particular, Tarquinia is an outstanding testimonial of the Etruscan culture, with its 6.000 unearthed tombs cut in the rock among of which 140 are extraordinary painted. The earliest graves date from the $7^{th}$ century BC. Most of them are made of a single room, while others are more articulated. Currently, 64 graves are accessible and some of them are protected by glass whereas others are open in rotation for visits.

The perception of the existence of the Necropolis goes back to the Renaissance, but the first findings were documented only in 1699. The most part of the painted tombs were discovered in the second half of $18^{th}$ century. Across the centuries, many paintings were detached from the walls and were then lost or destroyed, others are currently not visible due to the fading of the original colors. In these cases our knowledge of these paintings is mainly based on descriptions and paintings made by artists and scholars in $17^{th}$ and $18^{th}$ centuries

[15]. It must be noticed that these copies present several differences when compared to the original ones: some elements and details were not considered, the overall style was often changed. Some of the differences have been caused by the insufficient knowledge among the artists of the Etruscan culture, some surely are due to the difficulty of painting at the light of fire torches. However, often these changes were introduced with precise reasons, for example to make the copies uniform with the stylistic canons of the current age, more familiar to the public. In fact, it must be considered that often these copies were made to be sold by art merchants.

In the proposed reconstruction of the Necropolis, we have implemented virtual navigations for the Tomb of Pygmies and the Tomb of Shields. 3D models and textures of these two tombs have been created by the archaelogists having access to the graves for research reasons. The 3D modeling of other tombs is currently in progress. The use of 3D models makes it possibile to appreciate and investigate the morphology of the architecture in its completeness, providing an opportunity to see every detail in relation to the rest of the architecture, allowing a full view of the monument in each of its components: walls, ceilings, floors, niches, furniture, dromos. Moreover, it allows to better understand the relationship between different paintings and their spatial context: 3D models give the opportunity to virtually travel within the hypogeum and to perceive visual pathways depending on the use of space in Etruscan times.

The Tomb of the Pygmies was discovered in 1961, and it is dated from 350-325 BC. It is made of only one room, and most of its paintings are currently lost. It is named after one of the few scenes still visible: a battle betweenpygmies and cranes.

The Tomb of the Shields, belonging to the Velcha family, was discovered in 1870, and it is dated from 350-300 BC. It is painted with scenes representing the members of the family and decorated shields that give the tomb its name. Their copies were drawn in 1871 by the painter Gregorio Mariani. Since 1900, watercolor paintings based on these drawings were commissioned to painters working for the Danish art collector and philanthropist Carl Jacobsen [15]. The drawings are currently conserved in Rome, while the paintings are now in the Museum of Art in Boston.

Subsection 3.2 describes the layout of drawings and paintings in the virtual navigation inside the Tomb of the Shields.

## 3 Virtual Reality Reconstruction of the Necropolis

The VR reconstruction of the Necropolis here implemented is based on a modular and flexible approach using separate modules, in order to handle a site composed by a large number of independent tombs. A main application is dedicated to the choice among currently reconstructed tombs, and independent applications are dedicated to virtual navigation inside selected tombs. Such an environment is

already active even with a very limited number of reconstructed tombs. New completed modules can be easily linked at any time to the main application. Moreover, due to the complete independency of the applications, different developers can work to the reconstruction of different tombs at the same time, just relying on a template of the application.

Different choices are less effective, such as a full 3D reconstruction and integration of all the locations inside a unique application, because the necessary stage of measurement and acquisition of textures is not an easy and fast process: it must be performed accurately by personnel having access to the tombs, in accordance with maintenance works and visit hours. Therefore, it may take several months before having a 3D modeling and texturing of all the tombs, even limiting the process to the most relevant ones.

The applications have been developed using the open-source Processing environment [16]. Processing is an environment for the development of Computer Graphics and Multimedia applications, whose programming language is based on Java, extended with higher-level functions and libraries. For the development of the applications, we have used external open-source libraries for the loading of *Bing*™ satellite maps of the Necropolis area, and of the OBJ 3D models of the tombs.

We have decided to include stereoscopic visualization inside the VR reconstruction. Stereoscopic visualization simulates human binocular vision, allowing a more accurate simulation and perception of depth and distances of a virtual environment. If the visualization device used during the navigation has adequate sizes, it is possible to achieve a realistic depiction of measures between the real environment and its visualized simulation. We have developed and tested the applications inside a VR installation available at the University of Milan, characterized by a large projection screen. Therefore, we have implemented a Processing library for stereoscopic visualization using anaglyphic visualization or quad-buffer technology. In subsection 3.3 we will describe the VR installation and we will give some details about the hardware requirements of the applications.

In the following subsection we will give also further details on the applications.

### 3.1 Main Application

The main application is based on a menu enabling to choose among available reconstructed tombs: it loads a satellite map of the Necropolis area, and shows the reconstructed tombs that are available in blue circles on the map. Moving the mouse cursor over the circles, the names of the tombs appear on the screen. Clicking over a circle, the main application is closed, and the chosen virtual navigation of the tomb is triggered. All of the functionalities of the satellite map website are still available inside the application: it is thus possible to zoom and move around the area. This is important, because the tombs in the Necropolis are very near to each other, and when they will be all reconstructed, the map will be quite crowded of blue circles.


**Fig. 1.** The interactive map of the Necropolis (left) and loading screen after the selection of a tomb (right)

Besides the above mentioned reasons related to modularity, we decided to use this approach also because it helps in studying the geographical location of painted tombs: by using an interactive map, it is possible to understand the actual spatial location of the tombs over the whole area of the hill used as a necropolis. This helps in assessing the use of space in relation to its history and in investigating the dissemination of tombs according to style of paintings and type of architecture. A screenshot of the main application with the indication of the available tombs is shown on the left in Fig. 1.

Adding a new reconstruction of a tomb to the main application is very easy, and it does not need to change the code of the application. In fact, the main application reads the information about the available tombs from an external configuration file. To add a new tomb, it is only needed to add some lines of text: the name of the tomb, the coordinates of the tomb in the map, and the relative path to the executable file of the new application.

### 3.2 Virtual Navigation of the Tombs

In a 3D reconstruction of an environment, the first and most important stage is the acquisition of data to be used inside a 3D modeling and texturing tool. The data can be obtained both with laser scanner technology or with traditional measuring systems.

While the laser scanner technology is excellent to retrieve measures and distances, the philological interpretation of the relationship between architectural features of the tombs and paintings can only be assessed through traditional measuring systems that can be better controlled and implemented by the archaeologist's eye [15], in order to enhance the cultural value which is the aim of the present project, as will be explained afterwards. This is the reason why we take advantage of the models and textures of the Etruscan tombs created by the archaeologists having access to the site.

Accurate sessions of photographic acquisition were carried out for the creation of textures used for the reproduction of the paintings. Many samples were

acquired of each area that compose the inside of the tombs, to give evidence of the state of conservation not only of the painted walls, but also of the floors and ceilings. The accuracy of this process enriches the virtual navigation, allowing to appreciate the various details of the Etruscan frescoes: brush marks, graffiti, use of cord soaked in color to create the meshes of regular geometric figures, the deterioration of paints, etc... As a consequence, the final result depends mainly on the accuracy of this process, that could be more difficult because of the characteristics of the site, e.g. limited accessibility, presence of maintenance works or rubble, lack of light, etc. Even if experience leads to a more efficient and faster process, this stage is surely time-consuming [17].

In this paper we are focusing on an organized presentation of the tombs inside the Necropolis area, and a fruition of the reconstructed environments. As stated in section 2, currently the 3D models and textures of the Tomb of the Shields and of the Tomb of the Pygmies are available. Other sessions for the acquisition of measures and images of other tombs are currently in progress.

After the selection of a tomb from the main application, the models and textures are loaded. This process may take some time according to the quality of the selected textures. During the loading stage, some information and pictures about the tomb are shown (an example is shown on the right in Fig. 1).

The virtual navigation, based on a first-person point of view approach, starts at the entrance of the tomb. The virtual camera is placed at a height of 1.7 meters from the floor, but this parameter could be changed by editing the external configuration file.

The user can virtually walk inside the environment by using mouse and keyboards (more advanced interaction devices can be supported in the future).

It is possible to enhance the visitors experience and education suggesting a walk-through of the monument including the perception of the architectural structure and of any detail giving information about the ritual use of space in the Etruscan age. This could also help in avoiding the risk of misleading anachronistic and spectacular modern approaches.

In case of visualization in a multi-user environment (like e.g. a theater room), a single user will be in charge of controlling the virtual navigation. It must be considered that her/his personal choice can affect the other users experience. However, in some cases (for example, if this person is an expert or an archaeologist) this situation may be useful for a better presentation of the virtual experience.

In the virtual navigation, to avoid trespassing walls, a map of the floor of the tomb (obtained during the measurement sessions on the site) is used to determine the walkable areas inside the virtual environment. With this technique, the user can move from room to room only through really doors and passages. At the bottom-left corner of the VR visualization, a map is placed to show the user's position in the VR scene.

One problem we had to solve was how to illuminate the virtual tombs. In the real environments there is no natural light: some artificial lights are placed inside the tombs, controlled by a switch timer, during tourists visits. Inside the

tombs there are signs of smoke on the walls, and therefore it was suggested that probably fire torches were used when needed to illuminate the environments. Some studies are currently ongoing about the placement of these torches, and whether their use and position might have had some importance during ritual activities.

In our simulation, considering the main purpose of the application, i.e. cultural dissemination, we have decided not to place light sources on the walls of the tombs, leaving this question open for future works and virtual simulations. We have then decided to link the virtual illumination source inside the simulation to the virtual camera. Therefore, while moving inside the tomb, the light changes, following the virtual observer, like if she/he was wearing a hard hat with a light. To have a realistic effect, we have introduced an attenuation parameter in order to decrease the intensity of light when the distance from the virtual camera increases. In Fig. 2 we show two views of the virtual navigations inside the Tomb of the Shields and the Tomb of the Pygmies.

In section 2, we have already mentioned drawings and paintings of the original scenes on the walls of the Tomb of the Shields made by artists during 18th century [15] and nowadays stored in different cultural institutions. In the virtual navigation of this tomb, we have introduced the possibility, by pressing a key, to visualize these additional materials, superimposed on the original walls of the tomb. In Fig. 3 we show some views of the drawings and paintings placed over the original frescos of the Tomb of the Shields.

Therefore the 3D model allows a visual comparison between the ongoing situation of the paintings of the tomb and its copies placed in their right position, produced since the date of the discovery. It is also possible to spatially place objects or documents stored in museums or institutions elsewhere in the world.

These examples show the potentiality of VR as a cultural dissemination tool, allowing a synergy between different sources of information not available in reality. Textual or audio description of the origin of these paintings may be added to enhance the level of the virtual experience. Additional material to be included in the visualization is retrievable from networks of digital archives of information developed in the previous project T.Arc.H.N.A. [1, 10, 11, 14].

Finally, by exiting the virtual navigation, the application will close and the main application will be launched again, making possible to start a tour in another available reconstruction.

Implementing applications for the visit inside other tombs necessarily needs some development and testing, therefore the process will not be as easy and fast as the above mentioned integration of new tombs in the main application menu. However, the implementation process will surely have benefits by using the two currently available simulations as application templates. In fact, the implementation of a virtual navigation of a tomb similar to the Tomb of the Pygmies (characterized by simple geometry, and without additional material to integrate in the visualization) would be very fast: the code used for the Tomb of the Pygmies can simply be adapted by loading the new model and textures, and tuning some visualization parameters. For more complex environments, in which

**Fig. 2.** A view of the Tomb of the Pygmies (top) and of the Tomb of the Shields (bottom)

it is necessary the integration and visualization of other cultural information, more time will be needed. However, many implementation choices and details from the Tomb of the Shields can be reused in the new applications.

### 3.3 Hardware Requirements and Flexibility

The application was tested inside the Virtual Theater of the University of Milan [18], a multi-user VR installation, characterized by a semi-cylindrical screen with height 2.70 m, radius 3 m, and arc length 8 m. The projection system of the Virtual Theater is composed by four high resolution Barco Sim 5Plus projectors with built-in *INFITEC*$^{TM}$ filters for passive stereoscopic visualization. The resolution of the projected images is 2416 x 1050 pixels. From an observation distance of 3.5 m, the field of view involved by the visualization is 120° horizontally and 90° vertically. An image of the Virtual Theater is shown on the left in Fig. 4. Real-time rendering in the Virtual Theater is computed on a quad-core HP XW9300 workstation with a *NVIDIA Quadro*$^{TM}$ FX5500 graphic board, equipped with quad-buffer technology.

The characteristics of the Virtual Theater allow a realistic depiction of measures and distances of the original environments, giving as result a very immersive experience in the visualization and navigation inside the virtual reconstruction. An image of the visualization of the Tomb of the Shields reconstruction inside the Virtual Theater is shown on the right in Fig. 4.

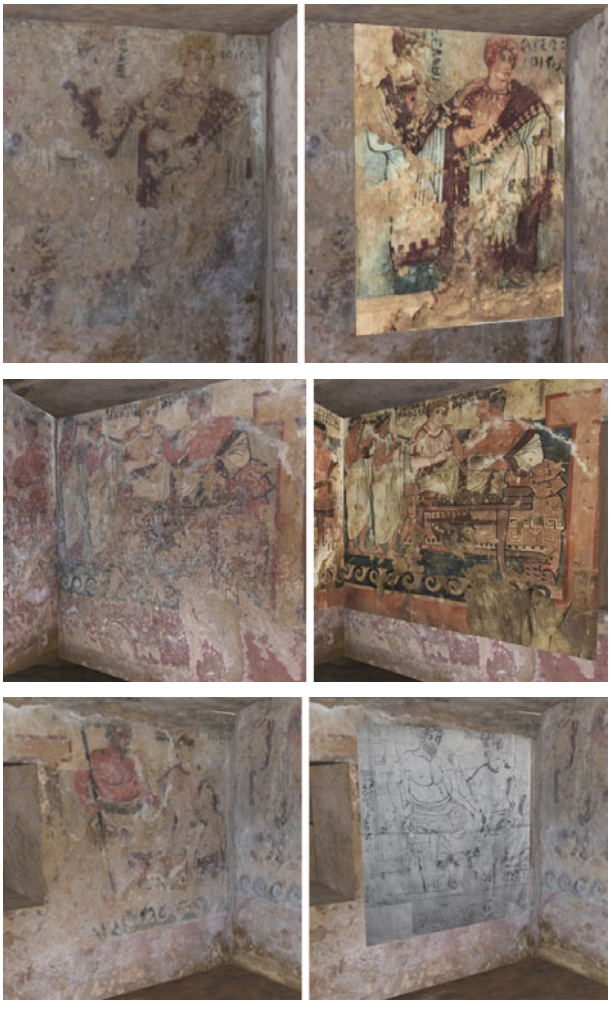

**Fig. 3.** Watercolor paintings and drawings visualized over the original frescos in the Tomb of the Shields

A VR installation with the same characteristics of the Virtual Theater is probably not compatible with a normal museum budget. However, the VR application was designed in order to be as flexible as possible, in order to allow visualization and navigation on different hardware settings. Therefore, it is possible to arrange a visualization and navigation setup on the basis of different available budgets, ranging from a multi-user room to a single-user workstation.

First of all, the application is cross-platform, being the Processing programming language based on Java. As a consequence, it could run on different operating systems (proprietary or non-proprietary).

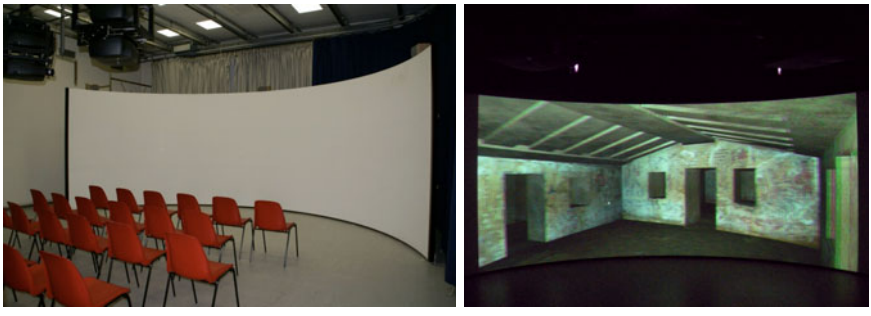

**Fig. 4.** The Virtual Theater of the University of Milan (left) and the application projected on the semi-cylindrical screen (right). The user controlling the navigation is not shown in the picture.

Moreover, different versions of the textures were prepared, and it is possible to choose their quality by changing a parameter in the external configuration file. Therefore, by choosing a lower resolution of the final rendering, and an adequate quality of the textures, the application can be adapted to run on machines with different computational power.

From the visualization point of view, the implemented library supports two stereoscopic visualization options: quad-buffer technology, and anaglyphic technique.

The first option needs a high-level, expensive, graphic board, and it is usually adopted in large VR installation like the Virtual Theater. It gives the best visualization quality and resolution, and it is easy to use from the development point of view. The second technique is instead based on the application of color filters to the right and left views of a stereoscopic image, and it does not need any particular technology, but just a standard display and cheap anaglyphic glasses. The visual quality is quite low, with an evident colors distortion. The anaglyphic effect is not difficult to create: it needs some elaborations on the original color signals of the frames. However, other different technologies for stereoscopic visualization are currently available, with different costs and characteristics; thus, it is possible to choose the best solution on the base of the available budget.

In any case, the library allows also to adopt a classic monocular visualization, and it can be extended with other stereoscopic visualization techniques.

## 4 Conclusions and Future Works

In this paper, we have presented a Virtual Reality reconstruction of the Etruscan Tombs in Tarquinia. The application allows to choose between available reconstructed tombs, whose location is visualized in a satellite map of the Necropolis area. The navigation inside the virtual tombs is based on a first-person point of view approach, using stereoscopic visualization for an immersive perception of the distances and measures. By means of VR technologies, it is possible to

integrate in the simulation additional materials such as drawings and paintings made in the $18^{th}$ century, currently conserved in different places around the world. The application was tested inside the Virtual Theater, a Virtual Reality installation available at the University of Milan.

The VR application presents virtual navigations inside two tombs (Tomb of the Pygmies and Tomb of the Shields), using 3D models of the environments created by the archaeologists having access to the site. The overall design of the VR reconstruction of the Necropolis has been created in order to be modular and flexible, allowing a fast development of new modules.

Currently, 3D modeling of other tombs is in progress, and as soon as this stage will be completed, new virtual navigations will be developed and integrated in the main application.

Moreover, we will also integrate new stereoscopic visualization techniques in the implemented Processing library, in order to allow more flexibility in the possible choices of the visualization setup.

Finally, we will perform an user evaluation of the presented application considering both experts and non-expert users.

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