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ETRUSCAN HYPOGEA IN 3D: A PROPOSAL FOR AN IMMERSIVE AND INTERACTIVE VISUALIZATION OF VOLTERRA'S FUNERARY CONTEXTS

1. Introduction

Within the framework of a workshop focused on the potential of pottery, and material culture in general, for the reconstruction of archaeological contexts, however, it does not seem out of place to present a contribution in which the topic is approached in the opposite direction, that is, starting from the context.

First of all, what do we mean by 'context' in archaeology? By transposing the definition of this term as given by linguistics, we can define it as the physical, spatial, and temporal situation in which an anthropic or natural action takes place. In archaeology, the object removed from its context has little scientific value, though it is intrinsically precious; in turn, the context without the object loses much of its informative potential. An empty or incomplete context is likely to give a partial or incorrect idea of how it was originally conceived or how it took shape.

In the case study herein, the context is represented by a selection of Etruscan hypogea located in Volterra, which are empty containers now, although the architectural complexity of some tombs may provide important information itself. In antiquity, however, these underground rooms must have looked quite different, densely populated with urns and other grave goods, as documented by ancient and recent finds from intact contexts, that is, contexts that have never been affected by grave robberies.

This research is part of a long-lasting and fruitful collaboration between the University of Pisa and the Scuola Normale Superiore, and more specifically between the Drawing and Restoration Laboratory (LaDiRe) of the Department of Civilization and Forms of Knowledge (UniPi) and the Virtual Reality Center of the SMART Lab (SNS) (Albertini *et al.* 2014; Olivito, Taccola, Albertini 2015; Albertini *et al.* 2016; Olivito, Taccola, Albertini 2016a; Olivito, Taccola, Albertini 2016b; Albertini *et al.* 2017; Albertini, Baldini, Taccola 2017; Taccola *et al.* forthcoming). The scientific project, titled *Ipogei etruschi di Volterra in 3D*, was made official by an agreement signed between the two institutes and the Municipality of Volterra in 2017, and it ended in September 2019. A first preliminary experiment resulting from such collaboration was presented at the KAINUA 2017 International Conference in Honor of Professor Giuseppe Sassatelli's 70th Birthday (Bologna 2017) and published in the conference proceedings (Taccola, Rosselli 2017).

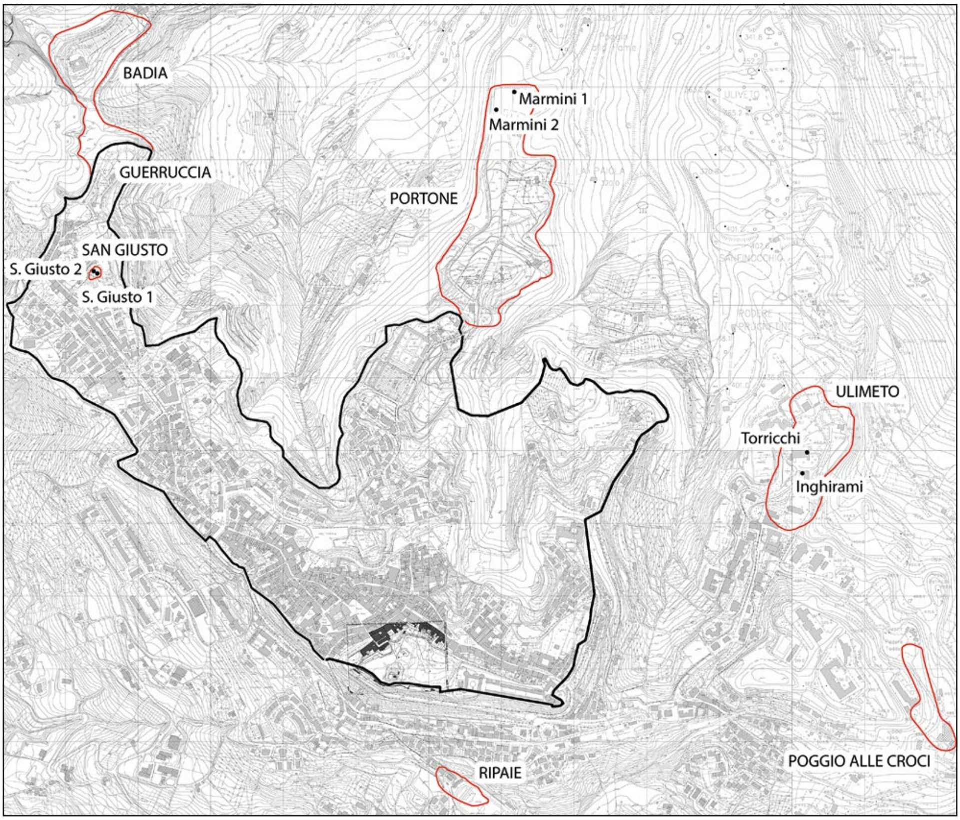

Fig. 1 – Map of Volterra. In black, the Hellenistic age walls; in red, the boundaries of the necropolises (capital letters). The black dots point to the location of the tombs selected for the VR application (lowercase).

As it will be better explained in the following pages, the main purpose of the research was to create an immersive and interactive visualization experience that could be easily learnt and enjoyed, using low-cost mobile devices, of six Etruscan hypogean tombs located in Volterra.

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2. The archaeological context

The 3D visualization of some well-preserved hypogea of Volterra is part of a wider ongoing research program carried out by the Archaeological Superintendence and the University of Pisa, which plans to accomplish a census of the Etruscan tombs of the ancient city, both those known from literary sources but no longer identifiable, and those that are still visible, with the aim of drawing up the archaeological map of the Municipality of Volterra and enhancing the still-visible funerary monuments.

As it is known, the Etruscan necropolises surrounded the plateau of Volterra by all sides (Fig. 1) and occupied the large limestone slopes on the northwest side, along the road to Pisa (necropolis of San Giusto-Guerruccia-Badia), the North side (necropolis of Portone), and the East side, beyond the valley of Pinzano (necropolis of Ulimeto-Poggio alle Croci). On the southern hillside, consisting of a steep slope of detrital material without calcareous surfacing, was located the necropolis of Ripaie (Rosselli 2018), which is no longer visible because it was covered when the municipal stadium was built. The necropolises of Volterra were generally used, some of them continuously, from the Iron Age to the Hellenistic period, and also utilized for Roman graves. Whereas there is no evidence of burials of the Villanovan and early-Orientalizing period, placed into simple pits or ditches, some chamber tombs carved into the limestone rock, called 'panchina', are still visible in the main necropolises. They were dug partly during the Archaic period and in large numbers in the Hellenistic age, when Volterra reached a considerable demographic development, as testified by hundreds of locally-manufactured urns and cinerary vases, dating from the late 4th to the 1st century BC.

Two hypogea situated in the neighborhood of San Giusto are currently the only remains of a large Etruscan necropolis risen in the Archaic and Classical age, originally extending on the northwest side of Volterra's plateau, not far from the deep landslide known as 'Le Balze'. Other hypogea of the same period have been discovered in the past decades both in the adjacent area of Santa Chiara and on the Guerruccia plain (Minto 1930), but nowadays most of those tombs are hidden under modern buildings and no longer visible. As all these graves were located within the Hellenistic town-walls, built between the end of the 4th and the beginning of the 3rd century BC, they were necessarily excavated before the fortification was built. Outside the walls, the large number of tombs discovered in the area of Badia and Montebradoni since the 18th century demonstrates the wide extension of the northwest Etruscan necropolis, used for a very long time up to the Roman Imperial age. Both hypogea are carved into the South side of the hill, where the church of San Giusto stands; the simpler one consists of a quadrangular room without benches around the walls, which probably have been completely removed at some indefinite time. When it was found, in 1985, it had already been looted, but a careful excavation unearthed some small ceramic fragments laying on the ground, dating to the late 4th century BC. The second hypogeum has a complex plan, consisting of a central rectangular atrium, with four small rooms with benches carved into the rock all around it. The tomb, totally empty, was discovered in the 19th century, and it was used as a shelter for the inhabitants of Volterra during the

Second World War, in 1944. Later, in the 1980s, the structure was restored and made accessible to visitors. The multi-chamber plan of such hypogeum recalls some similar specimens, dating between the 6th and 5th centuries BC, attested in Volterra on the nearby Guerruccia terrace and in the Valdelsa district.

The necropolis of the Portone is located outside the North portion of the Hellenistic walls and, as for the other necropolises of Volterra, it had been intensely explored since the 18th century by the owners of the local farmhouses. In fact, the first finding of a hypogeum full of cinerary urns dates back to 1731, when the discoverer transferred the artifacts to the Municipality of Volterra, thus starting the collection of the public museum. In that period, some Volaterran noblemen put together large collections of urns and grave goods extracted from the hypogea that had been discovered in their estates, most of which were acquired by the municipal museum and some sold to other museums, both in Tuscany and abroad. In the following century, the excavation of the necropolis was promoted by private collectors as well as by the Guarnacci Museum (Fiumi 1977); the latest explorations of the area, conducted by the Superintendency, date back to the 1970s (Cristofani 1973). The most common types of hypogea in the necropolis of the Portone have a circular plan with a central pillar or a quadrangular plan, but simple caves of a small size (called 'nicchiotti') have also been reported. All these structures, together with the cinerary urns and other grave goods, testify that the necropolis was mainly frequented in the Hellenistic period; however, the area was used as burial place even in earlier times, as proven by the discovery of some Iron Age pit tombs and grave goods related to the Archaic period.

Despite the large number of tombs known from literary sources, today only two remarkable hypogea are visible in the northern part of the area, the so-called 'Marmini', known since 1880 and currently open to visitors, in addition to a few small chambers along the modern road that crosses the necropolis, which have partly collapsed and are not accessible. One of the hypogea of Marmini has a complex plan, that consists of a central rectangular room with four small chambers in a radial arrangement; it is very similar to the late-Archaic and Classical hypogea of the necropolis of Guerruccia and San Giusto, but, because of the lack of any data about the burials in it, the period during which the tomb was actually used cannot be accurately known (Rosselli 2015). The second monument is located not far from the first one and consists of a circular chamber with two levels of benches running along the wall. In the middle of the room a rock pillar, bearing some noticeable traces of the grooves made by chisels, supports the ceiling. Despite the loss of all the original materials contained in the tomb, the circular plan with the pillar can reasonably suggest a timeline ranging between the 3rd and 1st centuries BC.

The necropolis of Ulimeto is placed on a long ridge in the eastern part of Volterra, joining the nearby low hill of Poggio alle Croci. Over time, a high number of Etruscan tombs have been unearthed from such areas, but, because of the considerable transformation of the landscape, due to the construction of the city hospital buildings, the original extension of the funeral area cannot be easily identified. However, the necropolis of Ulimeto also seems to have been mainly used in the Hellenistic period, with some evidence up to the Roman Imperial age. On the other hand, there are few burials relating to previous periods of Etruscan history. Also in this case, the most significant discoveries occurred in the 18th century and were made by the owners of the surrounding villas, in particular the noble Inghirami family, but also by the Municipality and the Guarnacci Museum. In recent times, the most remarkable findings occurred during the construction of the hospital buildings.

There are only two well-preserved and accessible tombs in the necropolis of Ulimeto. The first one is the well-known Inghirami tomb, discovered in 1861 near a country house belonging to the homonymous Volaterran family. The hypogeum was found intact, with over fifty cinerary urns inside related to several generations of the Etruscan *gens Ati* and laid over a long period, between the 2nd and 1st centuries BC. The urns remained inside the chamber until 1899, when they were acquired for the Archaeological Museum of Florence by Luigi Adriano Milani, who built a copy of the hypogeum in the garden of the Museum and filled it with the original artifacts. A steep dromos with steps carved into the limestone leads to a circular room with a large bench. At the center of the chamber stands a pillar, with a low platform in front of it, probably a stand for the urns. A short distance away from the Inghirami tomb is the hypogeum of Torricchi, located under a modern building and recently investigated by the University of Pisa (Rosselli 2020). The complex plan of the hypogeum, consisting of a large trapezoidal atrium which leads to three small grave chambers carved in the back wall, can be compared to other funerary monuments of the late-Archaic period of Volterra, although the ceramic sherds collected inside do not date earlier than the second half of the 4th century BC. The tomb hosted the ashes and burials of several generations of an aristocratic Etruscan family, as shown by the high quality of the remains of the grave goods placed next to the deceased.

L.R.

3. 3D data acquisition

The preliminary step to the accomplishment of the project was the choice of the tombs to be modeled in 3D and the survey itself.

Regarding the first point, we selected the most architecturally representative and safely accessible hypogea. Indeed, many of the underground tombs of Volterra, such as those of the necropolis of Badia and Guerruccia, Northwest of the city, were dug in a geologically very unstable ground, exposed to frequent

Fig. 2 – Examples of architectural structures of Etruscan hypogean tombs in Volterra. From left to right: Marmini 1 tomb, hypogeum of Torricchi and San Giusto 2 tomb (3D model top view).

landslides and currently inaccessible. Therefore, the choice fell on the two Marmini tombs (necropolis of the Portone), the Inghirami tomb and the hypogeum of Torricchi (necropolis of Ulimeto), and the two San Giusto tombs (Figs. 1-2).

Concerning the second point, the surveying procedure used for the 3D documentation was photogrammetry, the technique «which allows the derivation of accurate, metric and semantic information from photographs» (Remondino 2014). Although the subject has already been mentioned (Taccola, Rosselli 2017), it is appropriate to briefly review the workflow and the issues that emerged during the data acquisition process.

Agisoft Metashape is the software used to create the point cloud (Structure from Motion + Dense Image Matching algorithms) and the polygonal model of the tombs. The main issue is related to the lighting of the scene. Despite the use of calibrated lamps, positioned, whenever possible, at the same distance and angle from the SLR camera and the surface to be surveyed, the lighting was not always homogeneous. Such radiometric irregularity, as well as requiring the acquisition of a greater number of images, produced artifacts and noise in the point cloud to be cleaned manually with a further work step. Furthermore, dark zones and modern artifacts, such as cables, work tools, etc. had to be masked, i.e. virtually removed. Agisoft Metashape creates images with an alpha channel. It means that, when aligning images and creating the dense cloud, the software excludes portions of the photo masked with the black color of the alpha channel from the calculations, and therefore it does not display them in the point cloud.

For each tomb, Ground Control Points (GCPs), materialized as temporary and/or removable targets distributed on the floor, walls, and ceilings of the underground chambers, were measured with a total station. The GCPs were

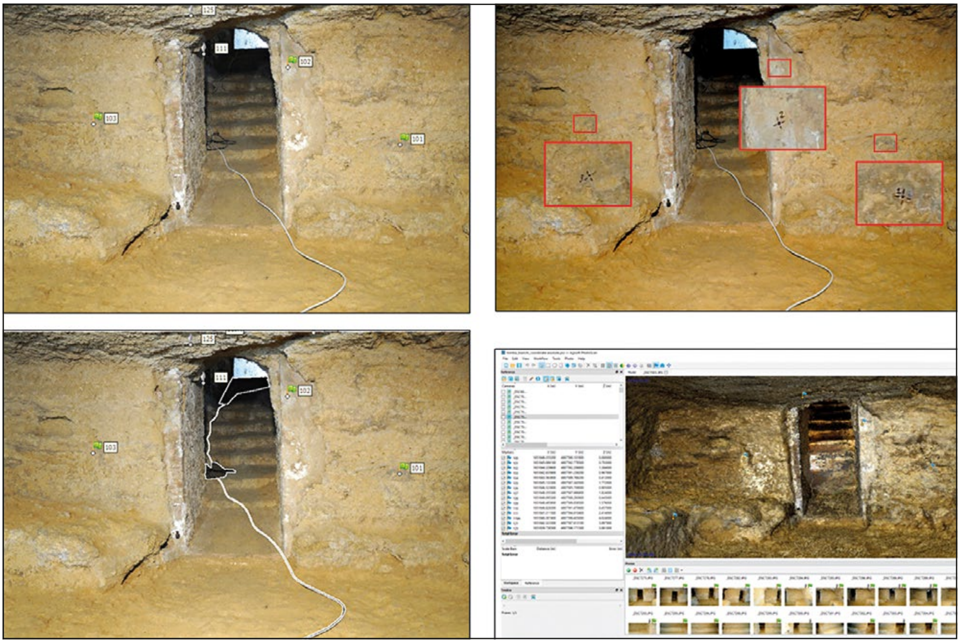

Fig. 3 – From top left, clockwise: detail of the removable GCPs; the original image; the image overlaid with the alpha channel mask; the corresponding point cloud: modern artifacts have been left out of the calculation.

uploaded in the software to scale and orient the point cloud: this procedure can also be used to estimate the accuracy/error of the point cloud itself. On average, the error generated in the survey of the six tombs is widely compatible with the aims of the project (Fig. 3).

As will be briefly discussed in paragraph 6.1, the acquisition and processing of the 3D data were followed by the post-processing and optimization of the 3D models, in order to make models that could be perfectly adaptable to the expected application and devices.

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4. Immersive and interactive VR in archaeology: a brief introduction

Archaeology derives undisputed advantages from the use of virtual reality, and particularly from 3D reconstruction, above all to present the researcher with an overall and understandable vision of the data represented.

The first examples of research that united these apparently so distant worlds date back to when technology was not yet ripe to deal with the technical complexities that this discipline requires both for the representation of data and for the interaction with them. The representation of three-dimensional space through two-dimensional techniques, tools and technologies, intrinsically encompasses problems and limitations that can only be overcome through new approaches that exploit our way of perceiving the real world (Reilly 1991).

Modern virtual technologies (virtual reality headset, augmented reality glasses, immersive projections, etc.) have opened new opportunities in the field of research, enhancing the visual approach of archaeological data (Bruno *et al*. 2010).

It is easy to understand how it is increasingly important not to consider digital technologies as simple tools to create highly impressive and photo-realistic reconstructions. In reverse, they are an extremely effective tool for those who aim to set up, visualize and interrogate a complex set of scientific data in visual form. At the same time, they are configured as extraordinary information vehicles that allow faster and more open dissemination of knowledge.

In this sense, the development of new techniques for the natural interaction of gestures in virtual environments is a topic of particular interest, allowing to reproduce and simulate, not only mentally but also physically, the operations and activities to which we are accustomed during our daily life and consequently during 'standard' research activities (Barceló 2001).

In addition, the increasingly high quantitative and qualitative level of data available to scholars represents a heterogeneous database, which can be more appropriately and effectively examined through the visual, virtual, and immersive representations of the data itself.

In this regard, digital technologies allow us to pursue a collection, visualization, and management of data in a much more accurate, detailed, rapid, and economic way than a few years ago.

If the use for scientific and research purposes can be certainly counted among the main ones, the possible impact that such a tool may have on the public of non-experts is not to be overlooked.

On the one hand, therefore, the main purpose of the discipline is to allow our scientific knowledge of the past to be more accurate, dynamic, not limited to static and definitive reconstructions, but rather open to continuous investigations on a set of multifaceted data. On the other hand, the need to share knowledge in a broader, easier, faster, and more accessible way for both experts and non-experts is no less stringent.

The variety of data that we can acquire and collect today undoubtedly requires innovative approaches to managing them, which can be more appropriately used and studied through visual representations of the data. In this sense, immersive and interactive virtual environments, together with the entire set of digital tools available, are the best way to analyze such data and try to answer in a more articulated way the many questions still open, formulating new questions to be investigated in the near future.

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5. Concept and evolution of the application

As previously mentioned, the research focused on the implementation of an interactive and immersive virtual reality application, which can be easily used on ordinary, low-maintenance and low-cost devices.

A beta version of the application, dedicated to the Hypogeum of Torricchi, was released in 2017 (Taccola, Rosselli 2017). The interaction mode (gaze-based only), the user interface and the type of VR headset (cardboard VR headset) are very basic and rudimentary.

This version was submitted to users of different ages, levels of education and IT skills, on the occasion of the FAI Heritage Days (March 2017). This step was functional to designing a new version that would take account of any feedback received. First of all, it was found that gaze-based interaction was not immediately intuitive and was not always correctly performed. In

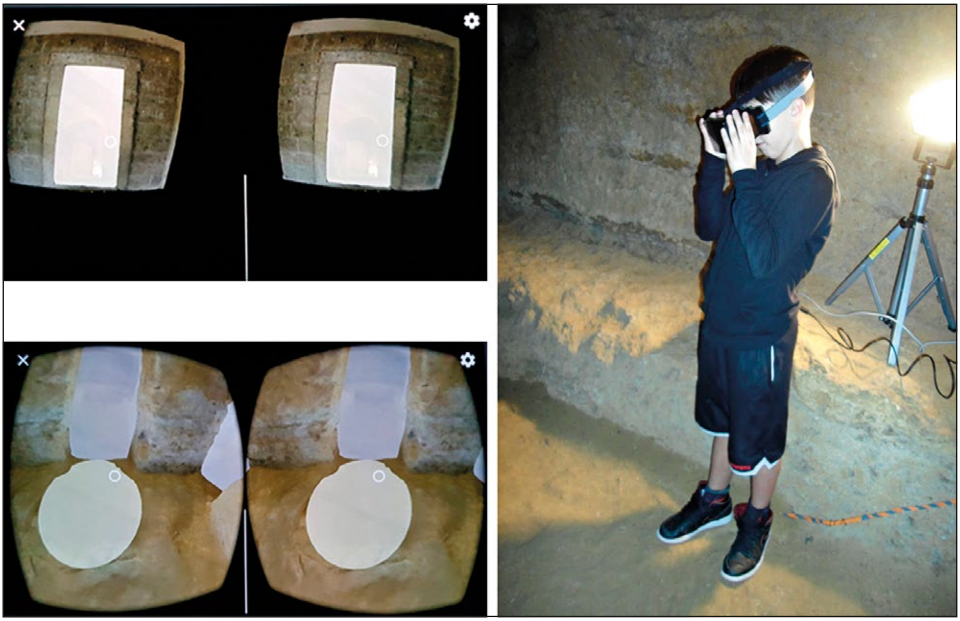

Fig. 4 – Details from the VR headset of the beta version of the application: the excessive size of the UI elements is clearly noticeable. On the right, the presentation of the application in the hypogeum of Torricchi.

Fig. 5 – The home page of the VR and the touch screen applications, with the logo and credits.

addition, the teleporting from the dromos to the underground chamber was too fast and, in some cases, it caused dizziness. The lack of textual information and the excessive size of the UI (User Interface) icons to interact with were issues that needed to be solved as well (Fig. 4).

Following the first release of the application, which was theoretically very user-friendly, even for non-expert users (apart from the aforesaid issues), the need arose to redesign the virtual experience in the underground tombs of Volterra in the light of the new hardware available.

The research went in two directions: creating a touch version of the application, downloadable for free from all mobile devices, such as smartphones and tablets; and a VR version available at the Guarnacci Museum in Volterra.

At an early stage, the use of a more complex VR headset was envisaged, equipped with motion sensors to perform, together with the controllers, free movement within the 3D model, the possibility of obtaining metric data, displaying annotations and metadata at various levels of complexity and detail: in other words, to interact naturally with the objects around the place, by reproducing complex gestures. Such a kind of approach can be defined as Active VR, with a medium to high level of interaction.

However, considering the users' target (museum visitors), we chose a less complex approach, which could be defined as Passive VR, that is, with a lower level of interaction. In short, a VR application that closely resembles the above-mentioned beta version. This involved using a lower-performing device and a simple, easy-to-learn interaction mode. Therefore, an easy-to-manage tool for both users and Museum staff, who would have otherwise had to be trained in the use of the application and the maintenance of the device. Not to mention the cost, which would have been much more substantial in the case of a wired VR headset like Oculus Rift or HTC Vive used with a high-performance laptop computer.

We worked on the UI, to make the interactive icons more appealing and diversified according to the metadata they stand for (for example, textual information, stratigraphic units, archaeological finds). The textual contents were written in a simple language, which combined the completeness of the information with the brevity of the text, so that it could be read without straining one's eyes, both on a mobile device and on the VR viewer. Because of this, the texts had to be divided and distributed across different points of the application: in the general introduction to the necropolises, at the entrance and inside the tombs. In the latter case, the panel with the text is also accompanied by multimedia contents (specifically, images and archival drawings). As part of the coordinated image of the project, we developed a logo that reproduced the idealized plan of a tomb (Fig. 5).

The more technical aspects, related to the structure of the application, the type of device used, the methods of interaction and the UI solutions, are illustrated in the following paragraphs.

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6. Implementation of VR and touch screen applications

Both VR and touch screen applications were developed with Unity, a game engine widely used in the creation of real-time 3D experiences. Unity can be used to create multiplatform solutions with minimal effort, such as VR experiences that can be easily adapted to the different headsets supported by the game engine.

We chose the Samsung Gear VR wireless headset – developed by Samsung and maintained by Oculus – as our target device to be used during the tour of the museum. The device is compatible with many Samsung smartphone models, and it ensures a fully immersive and interactive experience in the virtual scenario. Also, Oculus offers a Unity integration package, which includes several ready-to-use scripts and samples. This kind of experience provides the unprecedented opportunity to enjoy a virtual visit of all the archaeological sites at once. The headset is provided with a small controller, through which the user can interact with the virtual environment. Moreover, the Samsung Gear VR is lighter than a wired headset, and the wireless technology offers easy portability. All these features can contribute to reducing the users' discomfort.

The touch screen application is usable with all the devices running at least Android 7.0 Nougat, and it will be released on the Play Store soon. The touch input is handled natively by Unity; however, the Touchscript plugin has been integrated into this project, as it offers high-level support for gesture recognition.

6.1 *Setup of the virtual scenario and considerations about performance*

Since the performance of a wireless smartphone-based device is lower than that of a PC-based headset, some precautionary measures have to be taken to provide a proper frame rate (which is about 60 frames per second (FPS) for the real-time experience. The acquisition process with Agisoft Metashape generated 3D meshes, composed on average of almost 1.2 million triangles and 4.7 million vertices. Such geometries are excessively big for a smartphone to render – twice as much, for VR applications – in real-time. For this reason, the 3D models had to be optimized, retopologized and decimated. Such operations were performed within the Geomagic Studio software. The purpose of the procedure is to reduce mesh complexity, while keeping the geometry as unchanged as possible. Such optimization processes produced meshes of ca. 200k vertices and less than 100k triangles. After this process, polygonal models were once again imported into Agisoft Metashape to generate photorealistic textures.

After that, the 3D hypogea were imported into Unity, where virtual lights were positioned in every room for good visibility in the virtual environments. Due to the lack of natural sources of lights, virtual lights were set up for even lighting. Considering that the environment is static and that real-time lights weigh on performance, Unity can be used to create lightmaps, which are textures containing information about how the light behaves on 3D static surfaces. In this way, the rendering engine does not need to compute the light at runtime, thus relieving the workload and increasing the number of FPS.

6.2 *Structure of the application*

The application is organized in different virtual scenarios. Each scenario contains the results of the photogrammetry and the relevant metadata.

After the experience is started, a 3D virtual map of Volterra is shown in front of the user. The areas of interest (necropolises) are highlighted with a blue fade-in-fade-out effect, which is triggered as soon as the user's gaze crosses the perimeters. Once the area is selected with the controller, the user's view is brought closer to it, and an informative panel with a short but exhaustive historical description of the tombs is shown. From this panel, the user can pick a specific hypogeum to be virtually visited among the available ones.

A soft fade screen leads to a change of scenery, and the user's view is placed in front of the 3D virtual model of the tomb. Additional informative panels are visible at the entrance and inside the environment, to give historical information, pictures and curiosities. The environment is enriched with virtual indicators in the shape of rounded pointers planted in the ground. The purpose of such markers is to point at metadata and/or at objects found within the context of the tomb. Each indicator has a different icon, representing the type

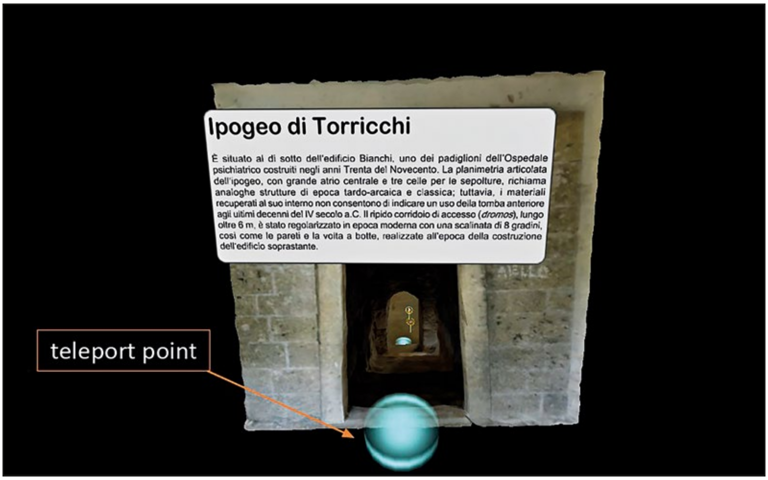

Fig. 6 – The entrance to the hypogeum of Torricchi, with the relevant introductory textual metadata. The teleport point is a virtual button to be pushed to get into the virtual environment.

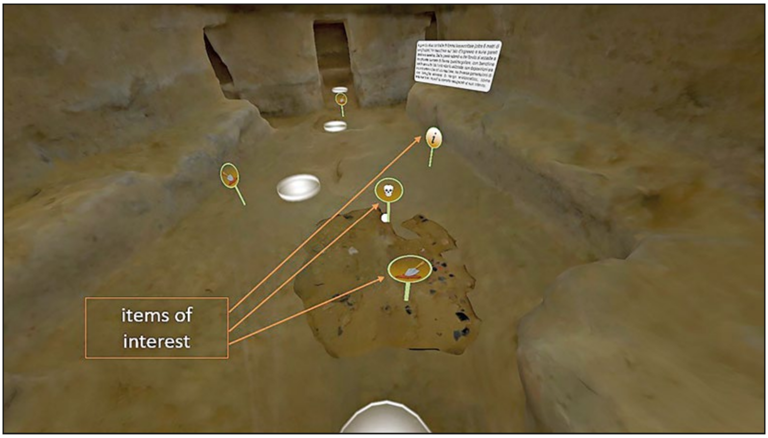

Fig. 7 – The central atrium of the hypogeum of Torricchi, enriched by the icons indicating the items of interest.

of metadata it is associated with. Furthermore, in order to avoid obstructing any part of the tomb walls, metadata information is hidden by default and can be retrieved by selecting the corresponding indicator.

The chosen VR headset does not offer positional tracking. Hence, in order to let the user move in the virtual environment, we developed a solution based on teleport points. Teleport points were implemented in the shape of flat, glowing cylinders (Fig. 6). A teleport point is a specific location where the user can move by selecting it with the controller. This provides a complete overview of the location, and the user can also thoroughly focus on the details.

The virtual hypogeum of Torricchi is worth mentioning, as its scenario has been enriched with some items of interest. In particular, several archaeological layers and, within one of them, a partially intact human jaw, were identified during the excavation process. In these cases, the presence of the items is announced by specific icons (Fig. 7). By selecting the jaw indicator, the virtual object gets close to the user and starts rotating. The archaeological layers can be shown or hidden at will.

6.3 *Interaction*

VR. As anticipated in the previous section, gaze-based interaction with the support of a controller was implemented for the VR application. A white circular pointer at the center of the screen indicates what the user is looking at. When the pointer crosses an area or an object of interest, it grows larger, showing that the area is selectable. The selection occurs by clicking on the round button of the controller. Moreover, the 'Back' button on the controller can be used to go back to the main scenario.

Touch screen. Regarding the touch screen application, the interaction is obviously based on touch. The features that in VR are available by pressing buttons on the controller, such as Select or Go Back, have been integrated through gestures or specific UI buttons.

The *Drag gesture* shifts the view of the camera, so that the user can look around the virtual environment.

The *Tap gesture* is used to select teleport points, excavations indicators, and UI buttons.

In the current version, the Pinch-Zoom gesture is not provided, for the sake of consistency with the VR version, where the possibility 'to get close' is denied because of the lack of a positional tracking feature.

M.M.

7. Conclusions: results and outlook

Creating immersive VR experiences of archaeological contexts, in the sense of a structure/container, within which one can move and interact comparatively easily, is now mainstream.

Research centers and museum institutions take such a type of approach as a tool for knowledge, for the users it is addressed to. Often, however, the design of a VR application is more focused on the technical aspects and the

Fig. 8 – Hypogeum of Torricchi. Virtual repositioning of the grave goods reconstructed from the sherds found during the excavation (3D models of the urn on the left and red-figured *kelebe* downloaded from Sketchfab.com).

exploitation of the hardware/software potential rather than on the user target and the information it conveys.

On our part, the choice of a simple and intuitive method of interaction, through commonly used or low-cost devices, and the use of easy-to-read (texts) and easily understandable metadata (archival images), have been deliberately adapted to the end-user, that is, to the standard museum visitor. Even making the application downloadable for mobile devices is part of the intention to share scientific information, albeit simplified.

Not to mention the social, as well as educational, role that this tool can play towards individuals with motor disabilities: an immersive VR experience of inaccessible places would be a viable approach to virtually break down otherwise impassable architectural barriers.

The project presented herein is not only the culmination of a research work based on interdisciplinary collaboration, but it is also a springboard for new developments and implementations, involving better-performing hardware and a more complex range of gestures, as originally planned. For example, the virtual experience can be further enriched, especially for those tombs, such as the hypogeum of Torricchi or the Inghirami tomb, of whose composition and grave goods we have reliable information (Fig. 8).

Hence, in cases like these, a 'complete' context, recomposed from the movable and immovable elements characterizing it at a given moment in its history, can be faithfully recreated. Even the integration of ambient sounds and dynamic lights (simulating torches or oil lamps), or a collaborative approach by several users at the same time, could be a further element enhancing the feeling of embodiment and engagement (Forte 2014) within the virtual environment.

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https://www.cfs.unipi.it/dipartimento/laboratori/ladire-laboratorio-di-disegno-e-restauro/
LaDiRe Youtube channel:
https://www.youtube.com/watch?v=SJoF6ZjUpSM&t=37s (Hypogeum of Torricchi).
LaDiRe Sketchfab collections:
https://sketchfab.com/leletaccola/collections/necropoli-di-volterra
SMART official site:
https://smart.sns.it/
SMART Virtual Reality Center Youtube channel:
https://www.youtube.com/channel/UCH9LDHlZU6_cXvygb1yWUbA
Touch screen application download (mobile devices)
http://smart.sns.it/volterra/VolterraTouch.apk

ABSTRACT

This article describes an interdisciplinary study carried out by a team of archaeologists, 3D surveyors and experts of new technologies applied to cultural heritage. The research was aimed at developing a virtual reality experience dedicated to Etruscan hypogean tombs in the city of Volterra. The application, intended for non-expert users, has been implemented in a touch screen version (mobile devices) as well as in VR mode (Samsung Gear Headset). In both versions, the user can easily interact with the immersive virtual context, browsing through the necropolises and/or underground tombs, and acquire textual and multimedia information.