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NEW VISUALIZATION TOOLS FOR SCIENCES AND HUMANITIES: DATABASES AND VIRTUAL REALITY

Thesis for the Degree of Doctor of Philosophy
in Chemistry

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Abstract

Within the scientific view, one of the major problems related to simulations developed for Virtual Reality, more specifically in research, is mainly related to the poor development of interaction between the data being displayed in the database in which they are contained, combined with the difficulty of making everything directly accessible in virtual environment.

In Digital Humanities, it becomes increasingly necessary to have an instrument capable of combining scientific visualization in Virtual Reality with the access and consultation of an open repository.

The work done for this thesis is based on the creation of a heterogeneous relational database called ArcheoDB, run by an open web platform, on which researchers can upload 3D content and share them with their own collaborators. The web platform and the database are alongside an application called "ArcheoDB VR Toolkit" developed with Unity Engine, which dynamically loads contents within the ArcheoDB database and visualizes them in a complex scene. This application also provide a detailed reconstruction of the various objects, the background of the discovery and the chemical analyzes made in a highly immersive way, thanks to the use of immersive visualization.

Likewise, in order for the application to be 3truly innovative, it must allow not only to display 3D data, but also to interact in real time with the displayed models, enabling to enrich and

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modify them, based on data consultation and metadata drawn from the database.

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Aim of the thesis

The work described in this thesis concerns the development of a heterogeneous platform consisting of a web database and a multi-device application for displaying scientific data that can be used by different devices in order to facilitate management of knowledge and collaboration among researchers. The first part of the work consists of the creation of an open source online platform connected to a database that can store 3D content, metadata and related information. Researchers will be able to create their own profile and workgroups and upload their 3D models.

The second part of the work consists in creating a multi-device application that can visualize via Virtual Reality, 3D objects with its metadata, allowing researchers to work directly on datas and upload them from the database in real-time. This type of tool will be able to display not only objects but also complex scenes, such as reconstructions of archaeological contexts and excavations. One of the main focuses of the application is to provide not just a simple 2D desktop display, but an application specifically designed for Virtual Reality and its use through HMD (Head Mounted Displays) (Figure 1.1) and C.A.V.E (Cave Automatic Virtual Environment) devices. In this way, it is possible to view a 3D model or an entire reconstruction by choosing the visualization method (HMD, CAVE, Desktop) and interacting with the virtual world using innovative and new immersive interaction systems and methods such as the Natural User Interface (NUI).

Chapter 1 - Virtual Reality

"Virtual reality is the use of computer technology to create the effect of an interactive 3D world in which the objects have a sense of spatial presence. The primary difference between conventional 3D computer graphics and VR is that in Virtual Reality we are working with things instead of pictures of things [Bryson, 1994a]".

Virtual Reality (VR) can thus be defined as a highly immersive simulation in a three-dimensional space, with which it is possible to interact dynamically. The most important features for a virtual reality system are different:

- Visualization: visual experience is the main component of any Virtual Reality system, it is possible to see the world around itself and the elements that make it up.
- Rendering System: To make the vision stereoscopic and not to run into Motion Sickness, the visualization system must generate at least 30 frames per second for each eye (minimum frame rate) with a performance that normally attesting around 60 frames per second for each eye (optimal frame rate) to eliminate almost completely the malaise from Motion Sickness.
- Tracking system: One of the main aspects of virtual worlds is spatialization, or rather the ability of the virtual world to adapt in real time to the user who is visiting it, and giving it the opportunity to be explored physically.

- Interaction: A virtual environment cannot be defined as such without an interaction metaphor, that is, a way of interacting between the user and the environment.

The interaction methods are many and range from the simplest use of external devices, to the use of natural user interfaces.

The following items are the essential elements for the definition and creation of a virtual world, which may be more or less immersive on the basis of several factors:

- Sound: Sound plays a very important component in a virtual environment, both in terms of sensation of immersion and immediacy in use, and from the point of view of action feedback.
- Sensations involved: Any sense involved increases the immersion of the user, it is possible to make olfactory perceptions through essences or taste through appropriate tools.

Figure 1.1: Virtual Reality

Chapter 2 - Devices for Virtual Reality

Devices for the use of virtual reality in science are mainly two3:

- Fully Immersive Virtual Wall and Panoramic Projection VR Systems
- Head Mounted Displays

One of the most complex systems of projection by immersion systems is CAVE (Cave Automatic Virtual Environment), developed at the University of Illinois in Chicago, a virtual reality system with up to 6 viewing plans (right, left, front, back, ceiling and floor) fixed orthogonal. 3D images are projected onto the walls and ceiling of the room to wrap the user in the virtual world. Sound spatialization combined with VR input or Gesture Recognition combines a significant degree of immersion. Throughout the years and with the advance of technology, CAVE systems (Figure 2.1) have gone from being formed by several multi-processor and multi-gpu machines coupled in parallel with single computers capable of handling all screens (new GPUs).

Figure 2.1: Cave Automatic Virtual Environmet (CAVE) at
Dreamslab

There are also other simpler projection devices such as
Panoramic Displays or Virtual Walls, which consist of a large
flat or curved projection wall that can project in high definition;
this kind of system is useful when the user is stationary and
does not need to have a complete view but only a part of the
field of view (eg. driving simulator or flight). One of the benefits
of projection based immersion systems is the ability to use
multi-user, one or more people can enter a quarry in and enjoy
the experience without any limitations.

A Head Mounted Display is a visualization system that uses a
screen pad with two screens that provide stereoscopic vision
(one per eye or a single screen divided into two) with integrated
head tracking, gyroscope and accelerometer systems that can
totally immerse the user in the virtual world, completely
extinguishing it entirely from the real context.

When talking about a Head Mounted Display (Figure 2.2), this falls into "personal" display systems, which can be used by one user at a time. In fact, this type of system differs from the projection systems listed above which are single-user devices, but they have the ability to dial within applications through network systems (multi-user experience shared in the same virtual space).

Figure 2.2: Head Mounted Display (HMD) HTC Vive

Chapter 3 - Virtual Reality and Augmented Reality for Scientific Visualization

Virtual Reality is an essential tool for the interpretation of scientific data. Visual representation makes it easier to understand and study the context. This type of representation can be "enhanced" through metadata and complex analysis systems within the various RV applications.

Simulation and 3D visualization of a given context allows the researcher to create hypotheses and directly test the results in the virtual world, whether by applying the hypothesis to an already existing concept or system or by creating a visualization system -ad hoc on its own hypothesis.

One of the greatest potentialities of the graphics computer coupled with Virtual Reality is the ability to change simulation parameters in real time, so you can see the different results in a clear and fast way.

The display process can be described as a sequence of processes [Haber & McNabb, 1990], the visualization pipeline (Figure 3.1):

- Data Analysis: Data is prepared for visualization (eg, by applying a smoothing filter, interpolating missing values or correcting erroneous measurements) - usually computer-centered, little or no user interaction.
- Filtering: Selection of data portions to be visualized - usually user-centered.
- Mapping: focus data are mapped to geometric primitives (e.g., points, lines) and their attributes (e.g., color,

position, size); most critical step for achieving
Expressiveness and Effectiveness.

-   Rendering: geometric data are transformed to image
    data.
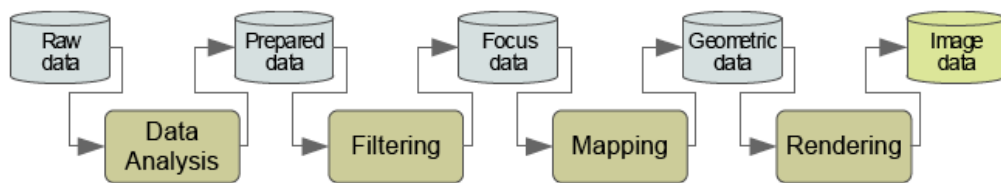
Figure 3.1: The visualization pipeline describes the (step-wise)
process of creating visual representations from memory stored data.

Chapter 4 - Virtual Reality in Archeology

Virtual environments and 3D visualization introduced a new element in the analysis of archaeological data, allowing the researcher to observe and perceive the information more naturally. The reconstructive hypothesis of an archaeological site, of an object in particular, or even the 3D representation of a physical magnitude, are examples of how a graphic representation can help in understanding the data itself (Figure 4.1). The use of archaeological data is not just a visual act, but the fundamental element is to allow the researcher to understand and manipulate, to test hypotheses and to seek meaningful results, and it is at this point that the method of interaction becomes fundamental; with the current human-computer interface systems it becomes intuitive, functional and simple, allowing a more natural approach .

Figure 4.1: The agora of Segesta in Immerive Environment

Virtual Reality offers advanced visualization and manipulation of datas applicable to archeology.

While up to now the approach has been much more oriented towards digital archiving of archaeological data, then on non-interactive 3d reconstruction, we are now getting closer to the goals that can be achieved with VR in archeology.

Especially in the last few years, there has been a clear improvement in Virtual Reality technologies, including the mass advent of these, such as 3D tv, 3D cinema, HMD, etc ..

For this reason, the worlds of Cultural Heritage and VR have often been in contact with highly advanced research projects. These new tools allow the user to view and manipulate interactive graphic data, providing a valuable help to understanding and using the data itself.

We currently have several technologies for realizing reconstructions and more or less immersive applications such as C.A.V.E (Cave Automatic Virtual Environment), Head Mounted Display (HMD) and Natural User Interfaces (NUI) systems.

The applications of the new technologies are varied, but the difficulty is to find the most suitable tool for the type of task we want to accomplish; this difficulty leads to various types of studies on the interfaces to make the best use of the tools available.

When you create a virtual environment it's essential to provide the most complete and immersive experience; to do this, it's

necessary to match the NUI (Natural User Interface) to devices like HMD and CAVE.

These interfaces, constantly evolving (some examples may be: Leap Motion, Kinect, visual tracking, MYO etc ...) are a valuable tool for using VR applications, by replacing standard and intuitive interfaces for those who are not a regular user like Joypad, Joystick, Wand etc ..

Virtual Reality is widely used for divulging applications within museums or exhibitions (Figure 4.2).

By increasing the computational capacity of new and cheaper personal computers, more realistic reconstructions can be achieved by using highly immersive systems such as HMDs (perfect for the outreach because even if mono-user these devices allow more portability that other VR systems do not have), which are designed to be applied to Videogames Engines such as Unreal Engine and Unity, enabling easy integration between 3D representations created with these Software and HMDs.

Figure 4.2: Colosseum Virtual Reality Exhibit at the Canadian War Museum

RV applications can be fundamentally of two types; the first one is a kind of virtual tour, the user is not free to move within the virtual environment but is driven inside it automatically or semi-automatically along pre-set binaries, a unique time for each user is set in the automated system, while in the semi-automatic one the user can take the time he or she wants to take advantage of (e.g. going back and forth in the presentation).

The second type of fruition of the virtual environment is instead the free visit, that gives the user the opportunity to move within the reconstruction in a totally autonomous way.

Both methods are effective, and the choice is strictly related to the type of application and to reference target. An automated or semi-automatic application is easily accessed by less experienced users and leads the user to focus more on the

content that they want to convey, while a free application instead brings more freedom to the user and provides more interactive elements, but is not easy to use for inexperienced users and results in less concentration on content.

Another interesting tool in this field is the use of the Augmented Reality, which allows to re-build artworks on-site using smartphones or tablets, thus integrating excavation visits, museums and study sites with explanatory multimedia elements (Figure 4.3). Some examples may be a visit to a museum where, as an additional content, framing a statue can provide additional contextual information such as note points, material info, and sculptor, or on a broken vessel, providing a careful virtual reconstruction of the workpiece missing.

Figure 4.3: Augmented Reality Application at Smithsonian National Museum of Natural History

The main advantage of Augmented Reality over VR is the portability of the application and the possibility of use through a tablet or smartphone in situ (let's think of a reconstruction of a city like Pompeii, which can be visited with a tablet allowing us to see how it was at its time).

Chapter 5 - Chemistry in cultural heritage

"Atoms and molecules do not seem to have much to do with art and humanistic cultural expressions. Actually, even during the primeval period of pictorial art, the choice of pigments for Etruscan and Roman mural paintings, for example, was made based on the properties of raw materials coming from natural deposits. This selection, often unconsciously of a chemical nature, was refined during the Renaissance: Raffaello, Leonardo, Piero della Francesca, Masaccio are among the main creators of new pictorial techniques obtained by mixing natural pigments with organic binders - such as egg , glue and casein. Nowdays, chemistry can go even further, offering sophisticated techniques to study the basic properties of materials that constitute a work of art and its state of degradation. At the same timechemistry can contribute to syntethize innovative products for restoration. It is a fascinating as indispensable role to preserving the historical and artistic heritage of cultural heritage. Yet, despite the fact that atoms and molecules are the primary constituents of art and the mechanisms that regulate their activities support their conservation, even in this case the contribution of chemistry goes into the background" (Campanella 2011).

The topics of interest in the chemistry applied to cultural heritage are different, as for istance:
- the nature and composition of the materials used

- the chemical-physical processes given by time and deterioration, which affect affect the artwork (eg oxidation processes, humidity, acid or base agents, etc.), providing a great deal of historical / artistic value information that can be used for restoration and conservation.

Starting from the importance of chemical analysis on materials, the need to have one tool for displaying and comparing chemical data within cultural heritage and archeology fields is growing (Fantacci 2010).

Chapter 6 - State of the art

The limits of the applications so far developed by the team of the SMART/DreamsLab in the field of Digital Humanities, and in particular in the field of archaeological research, are mainly due to the lack of the interaction modalities between the data visualisation phase within the virtual environment and the query and interrogation of the database were the excavation data are collected.

In fact, this is a critical issue for many of the projects of Virtual- and Cyber-Archaeology. It basically originates from the unavoidable difficulties in the creation of an articulated system allowing for the rapid and real-time consultation of different kinds of data during the Virtual and Cyber experience.

This is the case of Segesta and the reconstruction of the late-hellenistic agora (public square) of the Sicilian city (Fig. 6.1). The project of reconstruction and virtual interaction within a virtual environment has been developed since 2012, due to a synergic collaboration between the DreamsLab and the LSA (now SAET) of the Scuola Normale Superiore, together with the LaDiRe of Pisa University. Without doubt, it represents an extraordinarily important and successful project regarding the visualisation of data and 3D models derived from the archaeological practice within a virtual interactive environment (Olivito, Taccola, Albetini 2014 e Olivito, Taccola, Albertini 2015).

Nevertheless, due to problems mainly originating from the lack of an 'archaeological' database to examine while operating in the virtual environment, the Segesta project has not been able to fully overcome the concept of 'reconstruction' (Clark 2010). A major obstacle was in fact represented by the use of a database software (Filemaker) during the archaeological data collection phase. Indeed, this specific software does not allow for an easy and complete interaction within the virtual environment, so that the archaeological database (*Mnemosys*) was substantially not available for a completely immersive interaction.
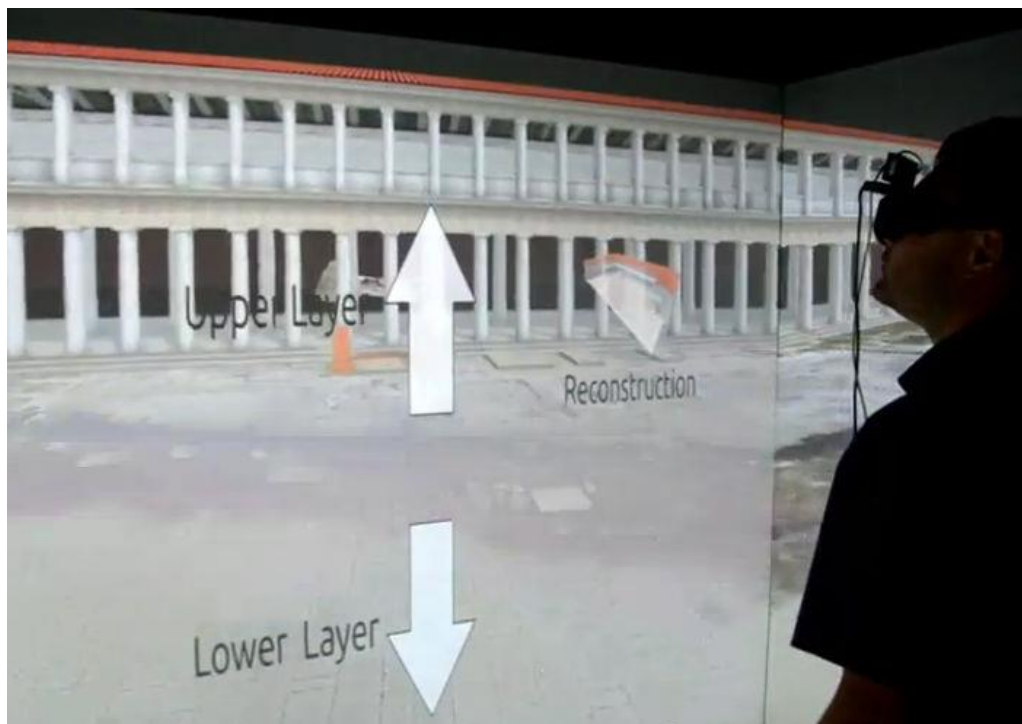

Figure 6.1: Agora of Segesta Reconstruction, layers of excavation

In order to avoid the complete recreation of a new database, allowing for the immersive interaction, a quite brilliant

solution to this problem has been developed and still represent a very meaningful step forward in the archaeological practice, especially due to the importance of the case study, that is the *agora* of Segesta.

Indeed, since May 2014 photogrammetric acquisitions of all the stratigraphic layers investigated in a crucial area of the archaeological site (the central area of the ancient public square) have been pursued. This made it possible to achieve the creation of several 3D models, not only of the different investigated layers, but also of single objects and important finds (e.g. a lion's head protome dripstone discovered during the excavation of one of the layers testifying the collapse of the huge portico (*stoa*) surrounding the *agora*; a Swabian oven). These models were visualisable the virtual environment as isolated items composing the final reconstruction of this area of the agora. Furthermore, while interacting with the models within the virtual environment, it was possible to look up the corresponding paper recording sheets using a tablet in order to access the database stored on a dedicated server.

It is easy to understand how the distance between the visualisation of the models and the interrogation of the corresponding data and metadata constitutes a problematic issue for the correct formulation of new hypothesis or the correction of older ones: i.e. for the whole interpretative process.

Thus, from a theoretical point of view the most urgent and important element is to pursue the realization of a new

investigation tool allowing for the real-time visualisation of 3D models and the access to an oped-data repository. The using of adjective implies the necessity to create a database always available for updates, corrections, enhancements deriving from the archaeological research, both on field or in archives and museums.

Such an application will certainly allow archaeologists to pursue the actual passage from the concept of static reconstruction to that of dynamic simulation (Clark 2010).

Last but not least, the application considered the necessity to have different levels of visualisation for the models, in which the present state of conservation of the archaeological datum could always be verified.

In this regard, the research has to focus mainly on the creation of different layers, easy to be prompted and making it possible to suddenly switch from the actual state of conservation to the corresponding 3D model resulting from the archaeological interpretation, the final aim being the achievement of a so-called simulation slice of that very specific context/object, which means the actual aspect of that context/object in a given period of time (Clark 2010).

The archaeological practice, especially the fieldwork activity, is in itself a destructive and non-replicable operation. As a consequence, the only possibility to retrieve the original aspect of an archaeological site as it was before the excavation is to access and use as many raw data as possible among those

derived from the fieldwork investigation (Hodder 2000, Gattiglia 2009).

With the birth of the so-called Processual Archaeology (or New Archaeology) and the criticism of the cultural-historical approach, L.R. Binford and other processual archaeologists started to consider each cultural phenomenon as unique and unrepeatable. From this point of view, the widespread use of scientific methods and technological tools (quantitative, taxonomic, computational, and laboratory analysis) seemed to be the only way to bring Archaeology nearer to the so-called Exact Sciences. Within this theoretical frame, in the 60s and early 70s the use of computer technologies seemed to perfectly answer the need for tools allowing for the storage of the increasing amount of archaeological data acquired during the fieldwork activity.

Yet, in the following decade this trend received critiques and objections, especially due to a new generation of archaeologists advocating a new socio-hystorical approach to the study of the archaeological datum.

As a consequence, only in the very last two decades a more mature and elaborated discussion on the use of database and computational tools emerged. The main point being the need for an open access to the archaeological record, which seems in fact to be the only possible way ensuring a wider dissemination of knowledge, also beyond the borders of the academic environment.

As a matter of fact, the transformations in the theoretical archaeological agenda affected the use and development of tools allowing for the acquisition and management of the data.

Needless to say, it is impossible to sum up here the huge amount of experiments, attempts, and projects, which contributed to the definition of the most up-to-date best-practices.

What we would try to do, then, is to highlight the two key elements in the evolution of the concept of archaeological database.

A real turning point in this sense has been the widespread use of computer technologies in the 90s, especially in terms of applications and GIS, easy-to-use also for those scholars with few or no-experience with computer technologies.

One of the best example in this sense is that of Çatalhöyük, where I. Hodder, actually one of the leading scholars supporting the Post-Processual revolution, has indeed extensively used all the possible computational, digital and virtual technologies, contributing to end the distinction between Archaeology and Informatics (Hodder 2000, D'Andrea 2009). Unfortunately, the problem with many of the databases developed during the 90s, and also with the first issue of the Çatalhöyük one, was their closed character, that is the impossibility, for those who were not involved in the project, to access and query the data.

In fact, more recently a further step in the new dialogue between Archaeology and Informatics has been stimulated by the increasing request for open data systems, allowing for a

wider and more public use of the information. In this sense, a very important element is represented by the diffusion and development of WEB-GIS (2D and 3D) where all the data, both from the archives and the new fieldwork activities are available for the audience of both experts and non-experts. Indeed, nowadays the focus is more on the open character of the database than on its ontology. In this sense, the evolution in the Çatalhöyük Project, with its website (http://www.catalhoyuk.com/research), is once again of great importance and constitutes one of the most valuable examples of best practices in this field.

These and other examples are mainly based on a WEB interaction, in which there cannot be space for an immersive experience.

In fact, the ultimate challenge for such an important and meaningful attempt, is to deal with a huge amounts of data (i.e. Big Data) and to think of the possible interaction metaphors and applications allowing for the easiest and also most fruitful use of the stored data, while operating within an immersive environment.

At present, Virtual and Cybernetic applications and technologies seem to represent very promising tools in the research of suitable and productive methods of interaction with the archived data. For this reason, and on the basis of the above-mentioned considerations on the evolution of the concept of database in the archaeological practice, the present work aims at further developing and stimulate the discussion and

the interaction between Archaeology and Informatics, with a particular focus on Digital-, Virtual-, and Cyber-Technologies.

Chapter 7 - Case studies

7.1 Kaulonia Virtual Reconstruction

Abstract

One of the biggest challenges that the analysis of archaeological data in virtual reality presents is the interaction.

Within the project of 3D reconstruction of Kaulonia archaeological site in Monasterace (Italy), developers had to deal with the need to implement an interface system inside the application without using external devices, in order to facilitate archaeologists in the data consultation.

A study about a system of movement and interaction with objects in the environment was conducted to create an interface for interaction based on look.

Subsequently, a method of interaction was developed by eliminating the problem of performing gestures and removing the entire "Learning Step" by users, so that it is possible to select and deselect elements, to move around in and rotate the view directly with the movement of the head.

As for the selection of the various elements within the application, a "cursor" specially implemented allows users to interact with the interactive elements: whenever the user sets a hotspot (point of interest) a pull switch is activated.

Within the application, it is possible to visualize a general overview of the excavation seen from above and to view the 3D models in the same spot where they were originally found: together with them, a brief historical description that contextualizes the object can be displayed.

A continuous progress of the study is allowing to explore new frontiers of digital data analysis in archaeology.

Introduction

In the last years, Cultural Heritage and Virtual Reality worlds have been in contact many times creating positive collaboration both for academic and dissemination purposes.

With the spread of new technology to the public and not only to the researchers involved in high tech field and thanks to a more affordable cost of the new hardware, a new kind of synergy has developed between Cultural Heritage and Virtual Simulations. This synergy can improve the understanding of the data for researchers and students who will study the excavations, the findings and their context.

This paper describes the entire workflow and the approach used to experiment new kinds of interaction in virtual reality simulations for Cultural Heritage, an advanced system where experts and specialists can discuss, visualize and manage heterogeneous data in the same immersive virtual environment.

The Sanctuary of Punta Stilo at Kaulonia: a brief historical-archaeological framework

The area covered by 3D survey and modeling dedicated to development of the application described in the following paragraphs is the Sanctuary of Punta Stilo at Kaulonia (Monasterace), an ancient Greek colony founded by Achaeans people at the end of the 8th century BC in the extreme south of the Italian peninsula.

The site, on the edge of a cliff overlooking the Ionian Sea (Figure 7.1), was identified by Paolo Orsi (1915), who in 1911 brought to light the foundations of a large Doric style temple built around the years 470-460 BC and restored in the last quarter of the 5th century BC.

Figure 7.1: The Sanctuary of Punta Stilo

After years of casual excavations, a systematic resumption of archeological investigation was undertaken between 1999 and 2014 by the University of Pisa and the Scuola Normale

Superiore under the direction of Professor M.C. Parra, to whom (2011; 2013; 2014; 2015; 2016) the publication about new researches is due.

The investigation has allowed the sacred area to be explored in an in-depth and extensive way, in order to reach an integral view of the context, enabling firstly to define the topographical and chronological boundaries of the sacred area, which was frequented without continuity solutions from the end of the 8th to the late 4th century BC, when the temple probably collapsed due to an earthquake and the sacred area went out of use and was destined to accommodate facilities related to the storage of goods traded through the nearby harbor.

In particular, for the previous stages to the temple edification, sealed by a thick layer of waste related to its factory, the research has brought to light the remains of monumental buildings, altars, votive installations, portion of urban walls (from which an opening it was accessed to the southern Sanctuary area), areas destined for crafts related to metalworking, as well as has allowed to determine the gods worshiped within the Sanctuary, Zeus and Aphrodite.

Among the most notable discoveries, an area dedicated to the late-archaic votive offerings, characterized by the presence of several cippus fixed in the ground (the largest of them with a dedicatory inscription) and a deposition of bronze weapons, composed of two anatomical schisters and a chalcedon helmet dedicated to Zeus. An outstanding discovery is represented by a small bronze table found not far away, known as Tabula

Cauloniensis, which has returned the longest Greek-Achaean inscription of Western colonies (Ampolo, Parra, & Rosamilia, 2013).

The area on which the Sanctuary is situated, as well as a large part of the adjacent coast occupied by the ancient city, suffered severe damage between 2013 and 2014 due to a series of violent storms which caused the collapse of the cliff and the permanent loss of large portions of wall structures, especially in the southern sector of the sacred area.

3D modelling: Computer graphics

Regarding the virtual simulation of the Doric temple, computer graphics techniques have been applied, using as a basis the data and the hypothetical reconstructions known in literature, and so far, available only in hard copy (Barello, 1995).

On the one hand, the method has provided for the acquisition and the vectorization of 2D data in 1:1 scale, while on the other hand, for the direct survey of architectural elements found in the most recent excavations. From these data, it was possible to realize the virtual simulation of the sacred building thanks to simple extrusion, revolution, lofting and Boolean operations and integrate it within the 3D model of the entire Sanctuary made by UAV photogrammetric survey (Figure 7.2).

Figure 7.2: 3D model of the Doric temple.

3D data acqusition: Photogrammetry as a measurement and analysis tool

Photogrammetry is the science that, using passive optical sensors, allows for three- dimensional metric information of objects by interpreting and measuring photographic images (Remondino, 2014). In the cases subject of study, the photogrammetric method know as Structure from Motion was used.

With regard to the acquisition procedure, in the terrestrial photogrammetry a series of converging photos are taken by moving around the object to be detected, in order to cover all its geometry, while in the aerial photogrammetry several vertical images are acquired according to a grid pattern, which can be reinforced by a series of oblique and

convergent shots. In both methods, it is essential to ensure an overlap between photographs of 60-80% (Figure 7.3).

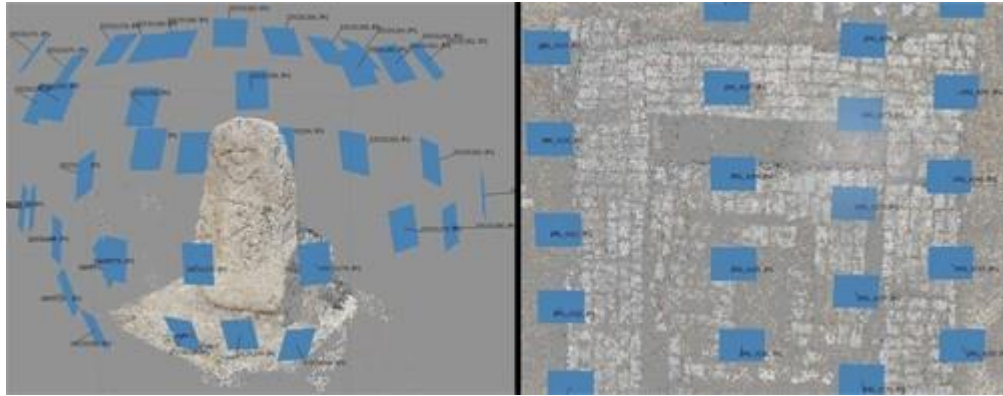Figure 7.3: Terrestrial (left) and aerial acquisition procedure.

The software used, Agisoft PhotoScan Professional, foresees as a workflow the orientation of the images, the creation of the sparse and dense point cloud, the transformation into structured geometric model (mesh), and the generation of the photorealistic texture (Figure 7.4).

Figure 7.4: from the dense cloud to the textured polygon model.

Finally, the 3D object is scaled and oriented by setting a known distance or by entering known coordinates (absolute or relative to a local reference system).

For the aerial survey at the sanctuary of Punta Stilo, a hexacopter UAV equipped with an SLR camera was used. Among the steps imposed by the workflow, the first and most important is the design of the flight plan. The software manages georeferenced images imported from Google Maps, on which the operator has to position the flight plan.

The flight plan can be configured in two customizable patterns, grid and circular, for a maximum of 32 waypoints per mission. In addition, it is necessary to set the speed of the drone, the flying altitude (calculated from the take-off position), the distance between the waypoints, the holding time on the waypoint, the angle of sight of the camera and the shooting mode (eg. each waypoint, or every few waypoints, or - as in our case - every few seconds).

During the flight, telemetry, position and path of the drone are displayed on the laptop in real time (Figure 7.5).
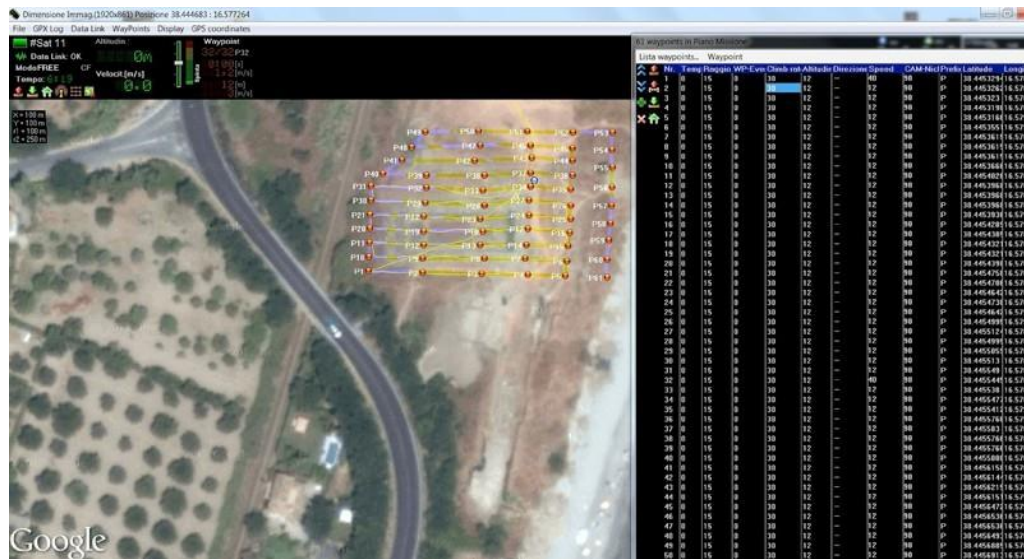
Figure 7.5: The position of the UAV along the waypoints, displayed in real time.

A second operation involves the positioning of GCPs (Ground Control Points), which allow the correct orientation of the model and, in case of GNSS data use, its georeferencing.

Regarding the area surveyed, approximately 5500 m2, the flight plan provided for a grid pattern, with waypoints spaced 4 m on the x axis and 16 m on the y axis and the speed of the UAV fixed at 1.2 m/s at an altitude of 12 m, while the camera was set for a shoot every 2 seconds.

So, a picture every 2.4 m, ideal for a 70% overlap between the photos according to the flight altitude (Taccola, Parra, & Ampolo 2014).

Other monuments in situ, including the archaic cippus inscribed, were acquired with SfM terrestrial surveying procedures.

It is appropriate to mention the acquisition procedure of bronze artifacts found in the Sanctuary. The photogrammetric survey of the bronze weapons deposit and the Tabula Cauloniensis was carried out in two phases, before and after restoration (Figure 7.6).

Figure 7.6: 3D model of the bronze weapons deposit, before (left) and after restoration.

Virtual Reality Visualization

The large amount of data resulting from the excavation study must be handled wisely, interpreted and understood. In this regard, a virtual view helps to understand the data and their context of finding, providing a valuable support for study and teaching. It's not just making 3D models, but also integrating

into the whole working process the possibility to use new interactive technologies. In fact, one of the great benefits of virtual reality, is the ability to enable more natural forms of interaction, that will support archaeologists in the understanding their digital artefacts.

A very important issue will be to understand what is the best interaction. This paper indeed describes the whole design process leading to the prototype application, used by the archaeologist to access the excavation data and findings, visualized in a Head Mounted Display.

An essential element for the use of data that is provided, is how to handle them: a natural interaction means interacting without any learning step, providing a functional and invisible interface to the user that provides the various commands useful for interaction. It is important therefore that the application enables the user to fully manage real-time features such as metadata viewing, the ability to parse the objects in detail, and highlight the most important parts of the study so to improve and facilitate the learning process

The application is born with a polyvalent purpose, primarily as an aid to scholars and students to study, analyze and learn the excavation and its findings, in order to make the learning process active, a real collaborative space where the user can freely visit the area and understand the morphology and the conformation of buildings.

Another purpose of the reconstruction is the dissemination, that allow the finds to be available to the public and to provide

information on the objects and the historical context of the findings, providing the relative metadata.

A further important aspect not to underestimate is the conservation, since various storms destroyed a huge portion of the excavation, which can only be visualized through the 3d photogrammetric model. This digital resource is very precious and will allow for the study of the lost elements even by the new scholars who will approach them in the future (Stanish 2013).

Development of a new approach to the consultation and analysis: Oculus Rift

One of the main focus of this application is to develop a new approach for the consultation of the archaeological data, with a complex set of tools integrated in the applicaton. In the design phase, it was decided to use a head mounted display to make the excavation visualization more immersive and engaging as possible.

The first experiment was in fact based on an Oculus Rift (Head Mounted Display), without any input device. In this case, the interaction was limited because it was based only on the movement of the head.

In the new phase, thanks to a new Head Mounted Display (HTC ViVe), with dedicated virtual reality controller, it has been possible to develop a new interaction.

The concept of the application has been to satisfy two specific requests by the archaeologists:

- the ability to navigate in the 3D model of the excavation and to see the acquired findings
- the ability to interact with the findings, analyzing them closely.

When the project started in 2015, we have evaluated many interaction solutions: we tried to use a OptiTrack system that does the tracking of movements, but used in combination with the helmet limited its practicality and portability; so, at first, we decided to just use a helmet for virtual reality, without any type of input device. As said before, when we started developing on Oculus, it was impossible to interact with the application without using external tools; an integrated controller for the movements came out later, so there was a need to develop a system of movement and interaction that use only the HMD sensors, without the need for additional hardware like joypad or any other similar device.

At that point, the question was: how to interact without external system?

We made an interaction study to understand, as well as how to interact, how to give feedback to the user on his actions within the virtual environment.

We thought that the interaction with eyes were the most natural thing: the user can directly observe what interests him; if his look is still for more than a specified time, the resulting action is triggered.

At that stage and with this type of interaction the user had a general overview of the excavation site, and once he got in the area of interest the view was locked at that point so he had the possibility to watch around his position at 360°, to select an object, to see the 3D model and the metadata. The 3d models rotated on themselves, without the possibility of interacting with them, same thing for the text, which was static.

Development of a new approach to the consultation and analysis: HTC Vive.

The next step was to evaluate the best solution to overcome the limitations of the previous system. The choice fell on "VIVE" head mounted display, which integrated the controls already tracked within the virtual environment, and a motion system that makes possible the use of the whole body (Figure 7.7). With these new opportunities, interaction was applied to archaeological data, with interesting developments.

Figure 7.7: HTC Vive head Mounted Display with tracking system and controllers.

Firstly, it was integrated a free exploration of the excavation: now, there is much more freedom in the movement both in sight and in the management of the 3D objects and text associated with them.

It has also been integrated to the 3D simulation of the temple, to have a direct comparison between the evidence of what is there now and what was there originally. Then an additional feature has been inserted: the ability to change the direction of light, this feature allows users to better observe the finds, and in the case of the inscriptions this is very useful.

At the start of the application, the user can view the area of the excavation from the top, then he will be teleported into the most interesting area of the site where the artifacts were found. When in place, he can look around and select the various

objects by pointing on each tag and clicking on the pad. Once the tag is activated, the user can observe in the left hand the finding, with the possibility of observing and manipulating it, watching the object details and shape. In the right hand, instead the text that explain the finding history will appear. In the case of objects with specific features, like the helmet, the object is automatically moved over the controller.

After seeing the discovery area and analyzing the individual finds, the user can find a menu where is possible to select the free movement mode.

In this mode, with the left hand, the user can select any point of the excavation where to be teleported, so to have a movement in the virtual space that is not too large in the real space.

The user can also reach the Doric Temple excavation site, where he can see the 3D simulation of the temple simply by activating the tags as for the previous objects (Figure 7.8).

With the light feature it is possible to perceive the real dimensions and understand the importance of this structure. By changing the angle and brightness it is also possible to understand how lighting in the temple was thought.

Figure 7.8: Findings Metadata and model.

Conclusions

The project has reached a good point, but we are already thinking possible developing for the near future. Some interesting ideas are born by those who worked within the excavation: for example, it could be useful to expand the reconstruction, adding some other secondary findings and their metadata or to contextualize the site in its original environment.

Even more interesting would be the ability to integrate a mean to connect different helmets for collaborative visualization, making a real collaborative space for studying and teaching.

The application design process forced a reflection on the interaction modalities that archaeologists could use in virtual environments. This has made possible not only to visualize the 3D models, but also to interact with them, in order to better

understand and use the data. For archaeologists, it is very important to have the possibility to explore excavation scenarios in addition to displaying reconstructions of buildings or important findings.

7.2 Aghia Triada in Virtual Reality

Introduction

Virtual environments and 3D visualization have introduced a new element in the process of data analysis derived from cultural assets, allowing the researcher to observe and perceive the information more naturally. The composition of a building material or structure is an example of how a graphic representation can help in the integration of the data itself and in the subsequent and eventual communication with the work.
The use of scientific data is not only a visual act but it must allow the researcher to understand and manipulate information or hypothesize for meaningful results. The interaction method thus becomes fundamental: with the current human-computer interface systems it becomes intuitive, functional and simple, allowing a more natural approach. The advent of new mass technologies such as smartphones, tablets, or 3D cinemas has allowed to see and manipulate interactive graphic information even for those who practice research, providing a valuable help for understanding and using the data (Figure 7.9) .

Figure 7.9: Haghia Triada Virtual Reconstruction on Oculus Rift

Virtual Reality Technologies

Virtual Reality Technologies (RVs) are evolved over the last few years: methodologies are refined, computing capacity has increased, and price components have declined discreetly, allowing research centers to start developing applications or VR tools without particularly important funds.

Among these most significant tools are:

- Head mounted screens (HMD)
- CAVE
- Virtual virtual glasses
- Data gloves

· Suitable for data

· Workbenches

· Natural user interface

CAVE systems, in addition to increasing computing power and lowering costs for hardware, have seen a substantial increase in the quality of manufacturers and resolution, more accurate and functional monitoring systems and new graphical machines (en-gines) and development tools, also by the explosion of consumer-oriented software.

As far as "interaction" is concerned, until recently, Data Gloves was used, a set of gloves with sensors with a real time tracking position and gesture, made for interacting with the Virtual Environments. Some examples are the Peregrine and the "5DT Gloves Data" of LLC Realities, "Data Suits" (which work like data gloves but all over the body), Joystick and Wand. These technologies are still used in some areas but are leaving room for more natural interaction methods such as infrared and tracking optics; are an example of systems like Optitrack, Kinect and Leap (also developed in various versions, greatly improved over the years). These systems, called NUIs (Natural User Interface), make fruition more intuitive and natural, especially for users who approach the VR for the early days, making the experience even more subtle.

Head Mounted Display

A Head Mounted Display (HMD) is usually made up of one or two pairs of semi-transparent lenses housed inside a cradle. In front of the lenses is a miniaturized display that can be LCD, AMOLED or LCoS (CRT active liquid crystals). The old HMDs, in fact, were cathode-ray tubes and are now obsolete.

The old tools for Virtual Reality were big and bulky tools, uncomfortable and difficult to understand to the user. As with technology in general, tools for virtual reality have become smaller, lighter and more affordable; Large, heavy, wrap-around HMDs have been replaced with lighter models that fall right into the front of the face.

There are HMDs that show a fully-generated computer image (CGI) and others that show a world-mediated image and add virtual elements (Augmented Reality).

History of the head mounted display and technical specifications of the Oculus Rift

In 1960, Morton Heiling created what was considered the first virtual reality headset developed for the Sensorama application, equipped with a series of sensors including a binocular system that allowed visual experience. Recently, the great innovation in the HMDs was the Oculus Rift, which in addition to having a higher resolution than the older models,

mounts a gyroscope, an accelerometer, and a positional optic tracker outside, at a much lower price (Table 7.1).

The table below shows the specifications of the HMD used to develop the application:

Display	OLED
Resolution	960 x 1080p
Display Dimension	5,6"
Sensors	Accelerometer, Gyroscope, Magnetometer
External Sensors	Camera
Motion Tracking	1000 Hz
Field of view	110 degree
Connectivity	HDMI, DVI e USB

Table 7.1: specifications of the HMD used to develop the application

Implementation

The Haghia Triada site, the subject of this application with Head Mounted Display, was originally rebuilt by DreamsLab at the CHNT 18 conference (2013). The user could visit the

reconstruction of the archaeological site in various ways; starting from an outside view of the structure, including landscape, then entering the interior rooms. Originally, the application was designed for desktop use, which is also available on the web through a Web Player (Albertini 2014).

The application is developed with Unity Game Engine, a graphics engine particularly suitable for Virtual Reality and with great community support.

The interior rooms have been rebuilt virtually, both for the architectural part and for the objects found inside, trying to keep as close as possible to the "real" data; administrative documents (on which a 3D acquisition was made) were placed at the excavation points. In some points of interest it was possible to obtain textual and photographic metadata together with the 3D analysis of the acquired artefacts (Figure 7.10).

Interaction

Initially, interaction was implemented through mouse and keyboard. With the mouse movement you could rotate the line of view on the X and Y axis and the left click was used to select objects; through the keyboard, the directional arrows were used for the user's movement within the reconstruction.

Figure 7.10: Analysis of a Cretula with text alongside

With the implementation of Oculus Rift, it was necessary to rethink the interaction within virtual environment, as the approach to application changes radically. Thanks to HMD, the immersion and the sense of involvement increase, thus providing a stronger and more cognitive experience. As for the motion and interaction device, the mouse and keyboard have been replaced with a joypad, much more suitable for use with HMD than the previously used tools, which have a learning step for the user and the inability to see the keys that are pressed by wearing the HMD. Through the joypad the movement is now handled through the two analogs on the pad: the left adjusts the movement while the right is for navigational view.

In conclusion, it's now possible to look around 360 degrees by moving your head with integrated sensors in the HMD and the

interaction with objects is implemented by pressing a button that triggers the metadata (Figure 7.11).

The metadata that can be used within the application are shown on a sliding plane that stays alongside the object.

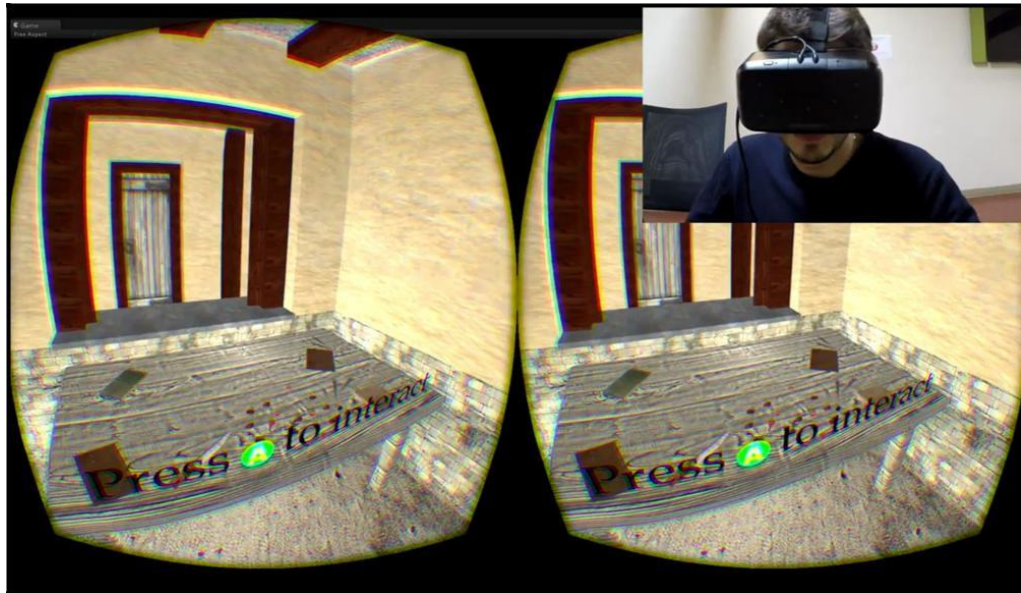Figure 7.11: Metadata displayed on the panels inside the reconstructed scene

Future developments

The application will be implemented with additional content and metadata, where the missing rooms will be contextualized; also it will be developed a more precise reconstruction of the environment in which it was Haghia Triada, recreating the surrounding fauna and inserting the native tree species in the reconstruction.

As a possible implementation we are also working on the catalogs so that they can be accessed directly within the application over the various templates (as for all those that can be inserted within the reconstruction) or in a special section where to browse the catalog of the finds.

It might also be possible to integrate an interaction made with the creation of a usable interface with the movement of the look. This would replace the joypad with head movement, moving by observing points of interest and related metadata.

Conclusions

We can conclude by analyzing the developments of this new immersive application that presents the reconstruction of Haghia Triada in an innovative way. First of all archaeological contents can be visualized in a more immediate and comprehensible way. With these new approaches, the various data can be explored not through a screen, but directly immersed in the reconstructed context, a factor that makes understanding closer to our perceptual sensitivity. Of course, all this is made possible by the ever-developing technologies that have allowed more and more to implement the full support of reconstruction and its ways of fruition. Currently Haghia Triada's site is visible directly within MUSINT.

7.3 Praedia of Iulia Felix

This new approach, obviously deriving from the previous experiences of the Segesta project, will has been tested on a very interesting case study, that is a room (the *atrium* 24) of a Pompeian building, the so-called *Praedia* of *Iulia Felix* (on the *Praedia* see Olivito 2013).

The Bourbon excavations in the area of the *Praedia* started in 1750, discovering a huge complex in which private areas and public sectors organised around a big central garden seem to be strictly connected with one another. The question of the main function of the *Praedia* is still open, as well as the personal background of the owner, *Iulia,* and her family. What seems to be clear is that in the final phase of the city (i.e. before 79 A.D) the *Praedia* was a very important building, furnished with an elegant and still functioning bath complex, and with several rooms and spaces to be rented to people who had quite a high social status.

As far as this project is concerned, it is fundamental to state that it aims at creating a system also exportable in other contexts, and in particular in the other rooms and spaces composing this Pompeian building which in the near future will be the object of a more accurate archaeological and historical research. Besides, the specifici case of study has been selected for the very multifaceted nature of data available for its study, together with the several interesting problems concerning the history of the research, the conservation state of the site, the reconstruction of wall-paintings and sculptures and,

eventually, the likely future acquisitions in the archives of the Museo Archeologico Nazionale di Napoli and the Parco Archeologico di Pompei.

Furthermore, it is of great importance to stress how the project originated and was developed in a very synergic scientific environment, in which experts in different field operated: on the one hand, archaeologists (Riccardo Olivito, SMART of the Scuola Normale Superiore) who contributed to the acquisition of data and metadata to be filed in the repository and contributed to the creation of the application, expressing requests and noticing doubts and weaknesses so as to achieve a final product responding to the the very needs of an archaeological and art-historical research; on the other hand, experts of Digital- and Virtual-Technologies who discussed, investigated, and actually developed the application, not only following the requests by the archaeologist, but also actively contributing to open new possible paths for future developments, originally not taken into consideration by the archaeologists.

This is a very meaningful issue. The interaction and synergic collaboration between scientists with a different cultural backgrounds is crucial to the successful outcome of research projects in which more traditional approaches of the archaeological practice and technological innovations aim at enhancing the historical knowledge. Indeed, too often in recent years some archaeologists thought of avoiding the dialogue or even the technical expertise of Digital-Technologies experts in the attempt to pursue the reconstruction of archaeological

contexts, monuments and objects. This is the case for several examples of Virtual Archaeology projects developed between the end of the 90s and the first decade of the new millennium. Although highly impressive for what concerns the visual aspects, this trend showed all its weakness from a scientific point of view. As noticed by Forte (Forte 2014), Virtual Archaeology mainly focused on graphic and visual issues. As a result, it was substantially unable to develop an articulated cybernetic system within actual tridimensional environments (Forte 2010).

Thus, as far as the present project is concerned, the goal of the first phase of development and test is to create a tool allowing for the query, interaction and modification of the traditional reconstruction of the *atrium* 24 (Figure 7.12) while interacting in an immersive virtual environment.

Figure 7.12: Atrium Photo

In this sense, a good example of the aims of the project is represented by the so-called '*forum* frieze' (Olivito 2013).

As already mentioned, the Bourbon excavations in the area of the *Praedia* started in 1750. Together with the reports on the field activities and the main discoveries - often simple lists of findings - the field director K. Weber drew up some plans (in which every room was associated to a progressive number and to the list of findings discovered inside the room) clearly demonstrating that the remains of the '*forum* frieze' were brought to light in the *atrium* 24. Besides, this provenance is definitively confirmed by two fragments still *in situ,* showing also the actual position of the frieze in the vertical development of the wall decoration (Figure 7.13).

Figure 7.13: Portion of the wall with freize

Soon after their discovery, the paintings were listed and detached, unfortunately not in a totally safe manner due to the superficial techniques used in the detachment operations.
Thus, as often is the case of Pompeian paintings, at present the main problem in studying this extraordinary document is the reconstruction of the original unitarity of the fragments and the connection between the frieze and the room where it was arranged. Furthermore, it is still difficult to even try to reconstruct the original sequence with which the fragments were displayed on the walls of the *atrium* (Figure 7.14)*.*

Figure 7.14: Fragment

Obviously, such a consideration has deeply affected the correct visualisation of the frieze and eventually its historical reading.
In order to try to solve this problem, a new tools has been developed allowing archaeologists to suggest a new reconstruction of the *atrium* (and its painted decoration) while operating within the virtual environment.

In this sense, a very meaningful help was represented by the almost complete collection of all the available data on the frieze and the *atrium* (Olivito 2013): drawings and plans of the *Praedia* during the Bourbon investigations, excavations diaries, drawings of the fragments realised shortly after their discovery, modern photographs of the paintings in the Museo Archeologico Nazionale di Napoli.

In addition to this, the 3D model of the *atrium* was created using the Maya 3D software (a preliminary model had already been presented in Olivito 2013 and has been now improved). It obviously represented the starting point for the development of the whole applications (Figure 7.15).

Figure 7.15: Reconstruction Atrium 24 (Current State)

On the basis of these elements, an open-database has been created, in which to store all the existing data concerning the *atrium* and its decoration.

Then, within the virtual environment all the models of the fragments could be visualized within the virtual environment, together with all the data and metadata relating to them (e.g. measurements, number of the inventory in the depository of the Museo Archeologico Nazionale di Napoli, etc). The metadata would be accessible through specific icons and gestures.

Summing up, the new application will represent a tool allowing for to creation, modification, and especially visualisation of different hypotheses of the original sequence of the fragments and, more generally speaking, of the whole display of the wall decoration of this Pompeian room, allowing archaeologists to operate within a virtual environment reproducing quite faithfully the walls of the *atrium* 24 of the *Praedia* of *Iulia Felix* (Figure 7.16).

Figure 7.15: Reconstruction Atrium 24

One of the main interactions within the virtual environment will be the possibility of making the virtual fragments slide along the walls of the room. This task will be easily achievable due to two considerations:

- we know with certainty the position of the frieze in the vertical development of the painted wall decoration of the *atrium*, as the two preserved fragments still *in situ* are at a height of 2,47 m from the floor level;

- the total height of the '*forum* frieze' was 1 m ca., as shown by the fragment on the South wall of the *atrium*,of which only the upper and lower borders are preserved.

Given these considerations, an interaction metaphor will be created so as to allow for moving the models of the paintings on a 'track' with a height of 1 m, running on the four walls of the virtual *atrium*.

A second interaction metaphor will allow for the zooming in and out on the fragments so that make it possible a careful observation of the single details will be possible while operating in the virtual *atrium*.

Finally, it will be possible to query all the existing metadata and continuously compare the new 'simulation' with past reconstructions and hypotheses.

It is then easy to imagine how the new application could plug the gap intrinsically existing in the traditional methodological approach to the study of such a document. Indeed, it will make it possible, although only in a virtual manner, to visualise in real time, and within the virtual environment, all the data available for that specific context. Besides, it will allow the user

to interact with the data and enhance and enrich an open-database, expressly created in order not to prevent from the acquisition of new useful elements.

Chapter 8 - ArcheoDB Project - Archaeological Database for Virtual Reality

ArcheoDB project (Figure 8.1) born from the need to have a database for 3D objects and related metadata, through which archeologists can access and work. The project revolves around building a platform that includes all the elements suitable for collecting heterogeneous archaeological data and its interfacing with virtual and augmented reality applications. ArcheoDB is a complex platform consisting of a database relay that can contain 3D archaeological finds with all the attached metadata, from which you can extract the data and upload it to the Toolkit ArcheoDB Vr Toolkit, which allows you to view data in virtual reality. The main objectives of this research plan can thus be summarized in:

1. Creating a web platform dynamically adaptable to different types of device

2. Creating the 3D Model Database

3. Total transparency of the interface and data so that it can be used by different professionalism

4. Creating a virtually virtual space for archeological finds and contexts

Figure 8.1: Archeo DB logo

8.1 Create dynamic and multi-platform web platform:

ArcheoDB is a dynamic web platform that can be adapted to all types of devices (desktops, smartphones, tablets, etc.). The multi-device web interface has a number of advantages: it gives users a better user experience based on the device used, allows different interpretations of the same data and proposes different content based on the access mode.

8.2 Creating the 3D Model Database

The platform will be able to handle different types of data and also become a valid classification and indexing element. With a single platform users will have all the material available for consultation, making it possible to share in search and application development. Each object type that is included in the database is cataloged together with the metadata and general information and its 3D models, Mesh, Texture, chemical and spectroscopic analysis.

8.3 Total transparency of the interface and data

One of the main elements of ArcheoDB is that it can be used and adapted as much as possible to various devices and different types of use. It will be designed and built to encourage the use of all kinds of professionalism (computer, chemist,

historian, archaeologist, etc.), trying to provide a totally "transparent" use of the data, without the user noticing the processes or having to worry about what type of data is used for your device / context of use. For example, an enhanced smartphone application will have different resolution models for desktop or tablet, in the same way the chemical analysis data will be organized differently depending on the type of access, all this automatically without any intervention by the user.

One of the major strengths of archeoDB is to be able to combine large amounts of heterogeneous data in the same platform: 3D models, chemical and spectroscopic analysis, state of degradation, historical details and context, all within a database that can be accessed in real time by a large variety of applications.

8.4 ArcheoDB VR Toolkit for Virtual Reality

Platform integration with advanced visualization and interaction tools such as CAVE (Cave Automatic Virtual Environment), Head Mounted Display (HMD), holographic displays is made possible through interaction with dedicated virtual reality and augmented reality tools.

By means of a specially created protocol, you will be able to create a constant data stream between the database and the 3D visualization devices. This way you can expand the platform dynamically, on any type of current device, and on any kind of tool that will become available in the future.

By using ArcheoDB (Figure 8.2) users will have access to a large database for the use and sharing and collaboration of 3D archaeological contents, sharing models with collaborators or with all platform users depending on the type of material. Archeologist just have to sign up to the ArcheoDB web platform and upload their own templates and information by providing the privacy permissions they feel appropriate. Archeodb Toolkit from the ability to visualize the various chemical analyzes on the artwork, making comparisons and validating validating the reconstructive hypotheses.

Figure 8.2: Archeo DB VR Toolkit logo

Chapter 9 - ArcheoDB Technical Implementation

The ArcheoDB platform is a MySql, PHP and Html-based web infrastructure, consisting primarily of a relational database that contains all the data and metadata of server-loaded data and metadata, and a Content Management System (CMS) that can provide a system user control, monitoring, exchange, and operation on uploaded data.

9.1 ArcheoDB Database

The software used to develop the ArcheoDB Relational Database is MySql, a Open Source software compliant with the ANSI SQL and ODBC SQL standard licensed GNU General Public License, which supports programming languages such as Java, PHP, Python and many more. The use of MySql is matched with the Xampp multiplatform software made up of Apache HTTP Server and all programming tools in PHP and Perl.

Given the nature of ArcheoDB, which is primarily based on the sharing of 3D material for viewing, each user can participate in one or more "WorkGroup".

Workgroups that can be created so that various users can join and exchange their material in a direct and simple way. It's also possible to upload content and share it with individual users or keep them private (accessible only from their profile).

It's possible to set a "Privacy & Sharing" field that allows users to determine whether the uploaded material is intended for use by members of the site, if it is only shared between some users (workgroup), individual users, or as a personal consultation material.

9.2 User Database

The user database section is created so that any uploaded information belongs to a specific user with the possibility of being shared with others.
The data that is required when joining the platform is:

- General Data [Name, Surname, Gender, Workplace]
- Login details [E-mail, Password]

The user database is the main element to which all other databases (workgroups, materials, and works) are attached. At any time through the user's control panel, users can change all the general information and access credentials initially provided.

9.3 Database Workgroup

Workgroups are a key component of ArcheoDB. Each user can create an unlimited number of workgroups, so they can collaborate without any restrictions with different user groups. Through the control panel of each user, you can create a Workgroup or join an existing one.

9.3.1 Creating a Workgroup

When creating a Workgroup, the user sets the main parameters for the workgroup functionality; each parameter can be modified following its creation in order to adapt to future needs quickly and easily. The main parameters of the workgroup are:

- Name and ID: Each workgroup is associated with a unique name and identifier that will allow users to join faster to an existing workgroup
- Group Privacy: Indicates the level of visibility within the platform. Depending on the degree of privacy used visibility will vary, the profiles are essentially two:
- Audience: Total visibility of the group within the platform, each user can search it through the integrated search function, see the members that belong to it, and public information related to it, you can also apply for admission to the group administrator.

– Private: The private visibility level allows you to create a workgroup that is not indexed in the search platform, so you can join it only by invitation or by the unique identifier of the group (ID) and always after approval of the admin.

● Description: The group description can be viewed by other users when you consult the group before you access it.

● User invitation function: at the time of creation and at any time after when the group was created it is possible to invite users to their workgroup by entering their e-mail. If they are not registered with ArcheoDB they will receive an email with the application form and a link from which people can subscribe to the portal.

9.3.2 Enter an existing Workgroup

If the user does not want to create a workgroup, but to become part of an existing one, there are several ways:

● Access request: The user may request access to an existing Workgroup via the group page (accessible from the search if it is public or by the id if private).

● Invitation of an Admin: The user can be invited by the admin of a workgroup, in this case the user can accept whether or not to be part of it.

- Email invitation: When the admin adds a member by entering his email, the system checks if he's subscribed to the ArcheoDB platform, unless he or she has sent an email to the recipient who specifies what ArcheoDB is, who invited him to enroll and the workgroup name and description he was asked to attend.

9.3.3 File Database

Each site user can upload their content within the 3D model platform, Mesh, Texture, Raw Data. Each file that is uploaded to the site will have attached metadata to include, some mandatory, and other optional:

- File Name *: The name that contextualizes the 3D file / object
- File format *: format of 3D model, mesh etc
- Description: Description of file content
- Images *: images related to the work, the first will be the preview and the others will be shown on the page related to the file as a slideshow
- Historical Period: the historical period is an important field, though not mandatory because it allows to search for historical time within the database
- Collection: Users can create a file album so that he can group common objects or relate to a particular context or digging together.

- Chemical analysis: it is possible to load the results of chemical and spectroscopic analysis   performed on the object.

  * Required fields

From the point of view of the database the fields that characterize each single work are:

- Mod_id: unique identifier of each file
- Mod_name: file name
- Mod_extension: file Format - 3D Templates, Mesh, Texture, Raw Data -
- Mod_description: description of the file
- Mod_images: 3D model images
- Mod_period: historical period
- Mod_collection: reference collection to which the file is associated
- Mod_chemistry: chemical and spectroscopic analysis

9.3.4 Collections Database

The collection database should contain all the archive system and the "folders" of the individual users. Each platform member has the possibility to create from the personal control panel, a variable number of collections in which to place their contents, so that they can organize and manage their work better. This type of system also allows you to quickly share data with your workgroup, since the user has the ability to

share all the contents of a given collection with one or more workgroups by accessing the individual collection settings.

9.3.5 Storage of uploaded files

When uploading a file, this is placed in a directory, cataloged according to its format and is renamed with a unique id to be retrieved from the database when requested.

9.4 User Control Panel

Once logged in, each user can access his / her control panel, from which they can access various features ranging from profile management to workgroup editing and uploaded files.

- Managing user profile: Through the panel users can access to the control panel where they can change the personal data, change the login data (email, password).
- File Management: By accessing the file management section users can view their uploaded files, subdivide them into folders, search in their catalogue, and share files privately or with other users.
- Workgroups Management: The general management section of workgroups related to the user account, from which people can view the Workgroups they are subscribed to, exit an existing one, or create a new one.

Clicking on a particular workgroup user can enter in the Workgroups management and editing panel.

- Contacts list: It's possible to add other users to the contact list, from which user can send and share files with single people, without necessarily creating a workgroup.

9.5 File Repository

The most important element of ArcheoDB platform is the repository of 3D files, allowing to manage one's own files and shared files in workgroups. Every 3D file uploaded to the platform goes to user's own collection, from which they can access from the control panel at any time. To view a content just enter the tab.

Once opened the 3D file card is open, people can download the 3D model so that they can upload and view it on the ArcheoDB VR Toolkit software, see the fields, and edit the metadata in the attachment.

Chapter 10 - ArcheoDB VR Toolkit

ArcheoVR Toolkit in its experimental version was created to meet the need for a research tool that can help archaeologists propose a new reconstruction of the original atrium aspect, working directly within the virtual environment.

Starting from this basis, an open-source database was created, in which all the existing documentation on the atrium and its existing decorative apparatus converge. The developed application for VR will have a fundamental purpose: create, modify and, above all, visualize different hypotheses about the original sequence of fragments, and more generally on the whole development of the parietal decoration of the environment, operating within a virtual environment that faithfully reproduces the atrium walls.

One of the basic interactions within the virtual environment is the ability to slice fragments along the walls of the room. This operation will be facilitated by two considerations:

- we are certain of the position of the figured figure in the vertical development of the decoration of the atrium since the two surviving fragments are placed at a height of 2.47 m from thefloor;

- the overall height of the frieze was approximately 1 m, as shown by the fragment kept on the South wall of the atrium, the only one that holds both the lower edge and the upper edge. Based on these considerations, a first metaphor of interaction with the fragments will be created: the paintings can be moved

along a 'binary' high m 1 and extended on all four walls of the virtual atrium.

A second interaction, also quite simple, will allow you to increase or decrease the zoom level on the individual fragments so as to favor the close observation of fragments within the virtual environment.

Lastly, you can recall your existing archive documents so you can continuously compare the stage of the 'simulation' came with the information extracted from the diaries and plants written at the time of the eighteenth-century excavation.

The ArcheoDB platform was created as a 3D file repository, alongside a visualization tool in Virtual Reality and Augmented Reality in real-time. ArcheoDB VR Toolkit is a multiplatform software available for Windows, Unix, and MacOS systems, created with Unity 3D and capable of displaying 3D models and complex environments. The methods for displaying VR Toolkit are essentially two:

- Tool for displaying 3D models and metadata
- Tool for viewing 3D scenarios and metadata

Using VR Toolkit users can connect directly to their file repository on the ArcheoDB platform by uploading content in real time. As described above, it's possible either to view a single 3D object or to build a complex scene composed of multiple objects and a background. After selecting the content you want to view, you can choose the type of display. ArcheoDB

VR Toolkit supports many types of Virtual Reality devices such as Head Mounted Displays, C.A.V.E and Classic Desktop Systems for Standard View.

10.1 Supported Head Mounted Displays

A Head Mounted Display is a worn-out display system. Thanks to a complete tracking of head movements, the user can immerse themselves in virtual reality. Supported HMDs include Oculus Rift, HTC Vive, Samsung Gear and Cardboard. When using the application from PC, the app automatically recognizes the type of device that is connected and displays it on the "Display Input" selection screen, when you open the application on Android devices, you are asked which type of device between Cardboard and Gear you want to use.

10.2 Unity Game Engine

Unity3D (or simply Unity) is a video game engine that has become increasingly popular since 2005 (first release), especially among mobile developers, to be able to define the most used video game engine in the world.
Over the years Unity has added the ability to export to many platforms including all desktop operating systems, almost all mobile devices (iOS, Android, Blackberry, shortly Windows 8),

for the web (with a special plugin such as Flash) and for the main consoles (Wii, PS3, Xbox, and shortly the next generation). This makes it a formidable choice for small groups of developers who intend to bring their software on multiple platforms.

10.3 Database Direct Connection

One of the main features of ArcheoDB VR Toolkit is to interface directly with the ArcheoDB relational database, giving users the ability to viewing 3D models or teir own Wokgroups. The intuitive interface of the application allows connection with its profile, providing different possibilities:

- View templates through one's own personal repository: By connecting directly to user profile on the ArcheoDB platform, viewing of all of files in real-time, sorted by folders and organized according to the criteria provided by the user. Using a scrolling menu, it's possible to select files from personal repository and upload them directly to the application
- View the templates of Workgroups: users can upload templates within workgroups mirrored to your platform profile
- Load 3D models from the local computer: VR Toolkit is created as an integrated platform directly with the ArcheoDB database. However, users can upload any type

of 3D model from a local one, making it the ambivalent tool for online or offline use, especially for field simulations or under study (eg. use for evaluation and study directly on the archaeological site)

Interaction with the ArcheoDB platform database is handled by using scripts in C # and PHP, which allow a real-time link to the database and all files available from your profile. As mentioned earlier, it is also possible to upload files from your local folder to such that the use is not limited and bound to an internet connection. Choosing to have two types of "access" to 3D files is linked to the need for on-site use. Imagine being on an archaeological excavation and having to contextualize different types of objects within an environment: in this you will be able to access your ArcheoDB Toolkit via your phone, upload your previously downloaded scene, wear the Virtual Reality Headset, and start studying the layout directly in the reconstruction, having the original context at hand. The potential of the system is diverse, from on-site use on smartphones and portable desktops, to home / work with desktop PCs, CAVE and HMD devices

10.4 Models and 3D Scenes

As mentioned above, the tools for viewing are two distinct ones, when you enter the application you will be able to choose which type of content you want to display (3D model or 3D Scenario)

so that interaction metaphors is appropriate to the display mode. The two types of display are: 3D Model and 3D Scenario.

10.4.1 Mode View: Single 3D model

3D model is the display mode that allows the user to view a 3D model and the metadata attached to it. With this type of display you can study and observe the model by zooming in the most important parts, moving it in the viewer, and adjusting the brightness and contrast. Metadata attached to the 3D model will be shown in a side window so that they can be viewed at any time during the display.

10.4.2 Mode View: Scenery 3D

ArcheoDB gives users the ability to create scenes to place 3D objects loaded onto the platform so that objects can be contextualized, studied and hypothesized about their finding or function they originally had.
Once the client is opened and the display mode is selected in "Scenary Mode", usercan set the scene according to the parameters:

- Background
- Lighting

- 3D models
- Type of display
- Type of interaction

10.4.2.1 Scenery Mode: Background

The background is the core element of the scene. Thanks to this parameter you can upload a 3D model of an environment (for example, an overview of an archaeological excavation or reconstruction of a room in Domus Romana) in order to set up a starting point and to have constant immersion.

Background is an important element in most reconstructions, as it serves both to contextualize objects (eg. placement and retrieval hypotheses), but also to help the user in his hypothesis, giving a more specific and accurate overview of what which was the context in which the object / discovery was used. In the absence of a background scenario, however, you can set a neutral space and its color to display, move, or modify 3D objects.

10.4.2.2 Scenery Mode - Illumination

After choosing the type of background to use, user can choose the type of lighting and the source from which light is obtained. The type of lighting identifies the type of light and color, so you can set either sunlight or artificial light and color tones. The

second parameter of the lighting is the location of the light source, which can be located at various cardinal points (N, NW, W, SW, S, SO, O, NO) to simulate the lighting according to the daylight. This kind of feature is crucial in contexts where scholars try to understand the technical choices made by artists or builders in terms of lighting.

10.4.2.3 Scenery Mode - 3D Models

The third mode of Scenery Mode is to set up and load 3D objects that will compose the scene. It is possible to insert several objects into the scene, with a limit imposed not by the number, but by the complexity of the models in the scene; this is to avoid a too heavily loaded scene and prevent possible application slowdowns. The Scenery Mode give the possibility of manipulating and moving objects in reconstruction, in order to advance hypotheses about the reconstructed context.

10.4.2.4 Scenery Mode - Display Type

When selecting the parameters, you need to set the scene display type, the devices that receive the video signal output:

- Head Mounted Display
- CAVE
- Desktop

Once the display type has been chosen, the rendering will change depending on the selected playback devices, so user can see the content with various devices and in various work modes (from desktop, to CAVE by exposure, or through HMD for desktop study or excavation).

10.4.2.5 Scenery Mode - Interaction Type

After selecting the display method user have to select which interaction method to use, to move and to interact with the environment of the scene. The interaction methods vary depending on the display mode user choose:

- Joypad
- Leap Motion (Natural User Interface)
- Mouse and keyboard

At the time of choosing, the application checks what the PC's connected devices are and proposes the various choices to the

user. If the application starts on Android, the display mode will be set to Default on the Head Mounted Display (usable with Gear and Cardboard).

Chapter 11 - Unity Workflow

ArcheoDB VR Toolkit uses unity as a graphical engine, thus allowing it to have a solid foundation and a community that can keep the project up to date as it an open source application. There are various tools for creating 3D models, Unity has native (built-in) support for many file formats for model files like **Autodesk FBX** (.FBX), **Collada** (.DAE), **Autodesk 3D Studio** (.3DS), **AutoCAD Drawing Exchange Format** (.DXF), and **Wavefront Geometry Object File** (.OBJ). and **Blender** (.blend).

11.1 Unity Project

The project is the home container for the application: the scene, assets, data, sound, script and animation that compose a Virtual Reality application. Assets are one of the core element of Unity 3Dand refer to all the independent file and data on which game depend [cit unity 4 f.]. Various files are generally created with external software and then integrated into unity; it is important, then, when creating a new project to have an efficient pipeline, using software for modeling such as blender, Maya or 3DS Max and phostohop for 3D models and above all a software that can optimize and optimize assets in a way to ensure the best performance for the integrated import tool in Unity.

11.2 Assets

As previously mentioned, assets are the main elements of each project and can be of various types and formats such as:

- Textures: Textures are standard 2D raster images, usually created by software such as Adobe Photoshop or Gimp, or obtained by color information from photogrammetry software. Unity supports a large number of formats (jpg, psd, png, gif, tiff etc). The main purpose of a texture is to be "mapped" over a 3D mesh, so it can cover it completely, making it more realistic and adding more visual information.

- Meshes: A mesh in Unity refers to any asset, whether animated or not, which represents a 3D geometry. Whether it is a 3D object, a building, walls, doors, frescoes, any visible entity in the game engine is a separate mesh. A mesh contains various types of information such as: Geometry, UV Mapping of the texture and can contain Rigging and animation. Geometrycontains all the information to define the geometric structure of the object. Geometry consists of vertices, sides and polygons that form the mesh form in the scene.

- UV mapping: is the information that represents the mathematical instructions given to the Texture so that it

perfectly wraps the mesh on which it is applied. Using uv mapping reduces the amount of materials/textures to be used within a scene.

- Rigging and Animation: define how mesh changes over time (present specialty enella organic modeling)

When creating a model for visualization it is necessary to think how it will be used within a 3d scene (as in our case) and it is important to define the number of polygons that dial the mesh. A too high number of polygons and too much complex geometric information can lead to slowdowns of the entire application. When creating a mesh it is therefore important that it is as simple as possible in polygonal termi, without compromising the quality of the model. This discourse applies to all Virtual Reality applications and applies even more when working with very heavy computational tools like Head Monted Displays and CAVE. Therefore, will be necessary to optimize geometries as part of the workflow of those who create 3D content for the ArcheoDB platform.

In addition, Unity can include audio and video formats of different formats. In fact, Unity allows users to import various audio formats such as MP3, WAV, OGG, etc. As for video formats, the main formats that can be used are AVI, MPG, MOV, MP4. When uploading an audio or video file within Unity, it's good to know that uncompressed formats are preferable since Uniy tends to compress it further internally.

11.3 Database Connection

Archeo DB's Virtual Tool allows you to load two models inside the scene, the first way is through local folder, uploading the model and selecting it from a folder locally, the second method instead lets the user upload his own files directly from the Database from ArcheoDB, by logging in real-time to the user's file repositories.

Chapter 12 - Conclusions and future work

Thanks to Virtual Reality, the process of study, analysis and learning within archeology and cultural heritage is changing. The Virtual Reality give to researchers the ability to have a tool that allows the visualization of immersive reconstruction, with fidelity to the original context, also having the opportunity to consult the metadata and the chemical-physical analisis inherent to the archaeological object reproduced.

The ArcheoDB platform is a virtual "Open Source" repository that can not only accommodate 3D content storage, but it also offers the ability to share them with other users inside or outside the workgroup and display content in various ways, along with metadata and contexts discovery and acquisition. Using ArcheoDB VR Tooltkit Archaeologist can use Virtual Reality to visualize content by having direct access to the database and downloading in real-time models and virtual reconstructions.

ArcheoDB VR Toolkit is also designed to be a multiplatform application that can be used for practical use on an archaeological excavation (using mobile virtual reality Head Mouned Displays such as Samsung Gear and Cardboards) or through PC usage. There are also several types of interaction that adapt to the various devices used, so that not only the display but also the interaction are customized.

Future work developments on my project will be designed to support creation and advancement of work on the ArcheoDB

platform, constantly updating and making it accessible through other types of graphical engines (e.g. Unreal Engine, Cry Engine and Source SDK) so that they can have access to the database from other types of graphics engines. Another interesting feature to be evaluated would be to include support for direct visualization of 3D models, or anyway from their preview, directly from the platform, taking advantage of the web plugin provided by Unity.

References

– Addison A. C. *Emerging trends in virtual heritage*. IEEE multimedia 7.2 (2000): 22-25.

– Albertini N., V. Barone, A. Brogni, S. Legnaioli, D. Licari, and E. Taccola. 2014. *The agora of Segesta in immersive virtual environments.* Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean Basin, Proceedings of the sixth international conference 4. Vol. I:299-304.

– Albertini, N., Jasink, A.M., Montecchi, B. 2014. *Digital acquisition and modeling of the Minoan seals and sealings kept in two Italian Museums*. In: Proceedings of the 18th International Conference on Cultural Heritage and New Technologies, Museen der Stadt Wien – Stadtarchäologie: 1-22.

– Ampolo C. (2014). *Zeus a Kaulonia: la Tabula Cauloniensis, un elmo con dedica e il loro significato storico*. In M.T. Iannelli & C. Sabbione (Eds.), Le spose e gli eroi: offerte in bronzo e in ferro dai santuari e dalle necropoli della Calabria greca, 123-124. Vibo Valentia, Italy: Adhoc. Retrieved from https://www.academia.edu/

References

– Ampolo C., Parra M.C., & Rosamilia E. (2014). *Kaulonia. La Tabula Cauloniensis: note preliminari.* Annali della Scuola Normale Superiore di Pisa, Classe di Lettere e Filosofia 5, 6/2 Supplemento, 72-80. Retrieved from https://www.academia.edu/

– Antinucci F. *The virtual museum.* established by: Mauro Cristofani and Riccardo Francovich (2007).

– Aukstakalnis S. and Blatner D. *Silicon Mirage; The Art and Science of Virtual Reality.* Peachpit Press, 1992.

– Barceló J. A., Forte M., and Sanders D.H., eds. *Virtual reality in archaeology.* Oxford: ArchaeoPress, 2000.

– Barceló J. A. *Visualizing what might be: an introduction to virtual reality techniques in archaeology.* (2000): 9-36.

– Barcelo, Juan A., Maurizio Forte, and Donald H. Sanders. "The diversity of archaeological virtual worlds." BAR INTERNATIONAL SERIES 843 (2000): 3-8.

– Barello F. (1995). *Architettura greca a Caulonia.* Edilizia monumentale e decorazione architettonica in una città della Magna Grecia. Florence, Italy: Le Lettere.

– Barrettara M. 2014. *New methods for sharing and exhibiting 3D archaeology.* The Post Hole 31: 8-13.

– Bates J. *irtual reality, art, and entertainment*. Presence: Teleoperators & Virtual Environments 1.1 (1992): 133-138.

– Bauer J. *Integration of Web-Based Information isualizations into a Scientific Visualization Environment*. Master's tesis at the Faculty of Informatics at the Vienna University of Technology. 2014

– Benko H., Ishak E. W., and Feiner S. *Collaborative mixed reality visualization of an archaeological excavation*. Proceedings of the 3rd IEEE/ACM international Symposium on Mixed and Augmented Reality. IEEE Computer Society, 2004.

– Bowman D. A., and McMahan R. P. *Virtual reality: how much immersion is enough?. Computer* 40.7 (2007).

– Bruno F et al. *From 3D reconstruction to virtual reality: A complete methodology for digital archaeological exhibition*. Journal of Cultural Heritage 11.1 (2010): 42-49.

– Bryson S. *Virtual reality in scientific visualization in "Computers & Graphics"*. Vol. 17, Issue 6, November–December 1993, P. 679-685.

– Campanella L. *Chimica e beni culturali: Intervista a Luigi Campanella.* 13 September, 2011. Web. October 2017.

http://www.scienzainrete.it/contenuto/partner/chimica-e-beni-culturali-intervista-luigi-campanella

– Card S. K., Mackinlay J. D., and Shneiderman B., editors. *Readings in Information Visualization: Using Vision to Think*. Morgan Kaufmann, San Francisco. 1999

– Carlsson C. and Hagsand O. *DIVE A multi-user virtual reality system.* Virtual Reality Annual International Symposium, 1993., 1993 IEEE. IEEE, 1993.

– Champion E. Bishop I., and Bharat D. *The Palenque project: evaluating interaction in an online virtual archaeology site.* Virtual reality 16.2 (2012): 121-139.

– Champion E. *Applying game design theory to virtual heritage environments*. Proceedings of the 1st international conference on Computer graphics and interactive techniques in Australasia and South East Asia. ACM, 2003.

– Chi E. H. *A Taxonomy of Visualization Techniques using the Data State Reference Model*. In Proceedings of IEEE Symposium on Information Visualization (InfoVis'00),

pages 69–75. IEEE Computer Society Press. 2000.

– Clark J.T. 2010. *The Fallacy of Reconstruction*. In Cyber-archaeology. ed. M. Forte, 63-73. Oxford, England: Archaeopress.

– Clark J. T., et al. *Digital archive network for anthropology*. Journal of Digital Information 2.4 (2006).

– Colombini M. P. and Modugno F. eds. *Organic mass spectrometry in art and archaeology*. John Wiley & Sons, 2009.

– Cruz-Neira C. *Virtual reality based on multiple projection screens: the cave and its applications to computational science and engineering.* (1995).

– Cruz-Neira C., Sandin D. J. and DeFanti T. A. *Surround-screen projection-based virtual reality: the design and implementation of the CAVE*. Proceedings of the 20th annual conference on Computer graphics and interactive techniques. ACM, 1993.

– D'Andrea A. *Documentazione archeologica, standard e trattamento informatico.* Budapest. 2006

– Dawson P., Levy R, and Lyons N. '*Breaking the fourth wall': 3D virtual worlds as tools for knowledge*

repatriation in archaeology. Journal of Social Archaeology 11.3 (2011): 387-402.

– Dell'Unto N. *The use of 3D models for intra-site investigation in archaeology*. BAR International Series 2598 (2014).

– Di Giacomo G. and Scardozzi G. *Un webGIS per la conoscenza delle antiche città della Mesopotamia*. Virtual Archaeology Review 2.3 (2011): 9-13.

– Doonan O. *Towards Reflexive Method in Archaeology: The Example at Catalhoyuk*. American Antiquity, vol. 67, no. 4, 2002, p. 787+. Academic OneFile, Accessed 10 Oct. 2017.

– Dos Santos S. and Brodlie K. *Gaining understanding of multivariate and multidimensional data through visualization*. Computers & Graphics. 28(3):311–325. 2004.

– Earnshaw R. A., ed. *Virtual reality systems*. Academic press, 2014.

– Evans T. M. and Daly P. T. eds. *Digital archaeology: bridging method and theory*. Psychology Press, 2006.

– Fantacci S., Amat S. A. and Sgamellotti A. *Computational chemistry meets cultural heritage: challenges and perspectives.* Accounts of chemical research 43.6 (2010): 802-813.

– Fernie K., et al. *Creating and using virtual reality: a guide for the arts and humanities.* Oxbow Books, 2003.

– Forte M. 2010. *Introduction to Cyber-Archaeology. In Cyber-archaeology.* ed. M. Forte, 9-13. Oxford, England: Archaeopress

– Forte M. *3D Archaeology: New Perspectives and Challenges— The Example of Çatalhöyük.* Journal of Eastern Mediterranean Archaeology and Heritage Studies. 2014. 2 (1):1-29.

– Gaitatzes A., Christopoulos D., and Papaioannou G. *The ancient olympic games: being part of the experience.* Proceedings of the 5th International conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage. Eurographics Association, 2004.

– Gaitatzes A., Christopoulos D., and Roussou M. *Reviving the past: cultural heritage meets virtual reality.* Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage. ACM, 2001.

References

– Gaitatzes A., et al. *Hellenic cultural heritage through immersive virtual archaeology*. Proc. 6th International Conference on Virtual Systems and Multimedia, Ogaki, Japan. 2000.

– Gaitatzes A., Christopoulos D. and Roussou M. *Reviving the past: cultural heritage meets virtual reality*. Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage. ACM, 2001.

– Gallo, G., et al. '*Coming back home'. Il modello virtuale della statua romana di Asclepio del Museo di Siracusa (Italia).* Virtual Archaeology Review 1.2 (2010): 107-111.

– Gattiglia G. *Open digital archives in archeologia. Good practice in "Archeologia e Calcolatori"*, suppl.2, 2009, pp. 49-63

– Giorgi R. et al. *New methodologies for the conservation of cultural heritage: micellar solutions, microemulsions, and hydroxide nanoparticles.* Accounts of Chemical Research 43.6 (2010): 695-704.

– Goodrick G., and Earl G. *A manufactured past: virtual reality in archaeology.* Internet Archaeology (2004): 15.

References

– Gruen A. *Virtual Archaeology–new methods of image-based 3D modeling*. New Technologies for Archaeology. Springer Berlin Heidelberg, 2009. 287-305.

– Guidazzoli A. et al. *Cross-media enhancement of Italian archaeological museum collections*. Virtual Archaeology Review 5.10 (2014): 93-106.

– Haber R. B. and McNabb, D. A. *Visualization idioms: A conceptual model for scientific visualization systems*. In Visualization in Scientific Computing, pages 74–93. IEEE Computer Society Press. 1990.

– Haber R. B. and McNabb D. A. *Visualization idioms: A conceptual model for scientific visualization systems*. Visualization in scientific computing 74 (1990): 93.

– Hodder I. ed. *Towards reflexive method in archaeology: the example at Çatalhöyük*. No. 28. McDonald Institute for Archaeological Research, 2000.

– Jablonka P., Kirchner P, and Serangeli J. *TroiaVR: A virtual reality model of troy and the troad*. CAA 2002 The Digital Heritage of Archaeology (2002).

References

– Kalawsky R. *The science of virtual reality and virtual environments*. Addison-Wesley Longman Publishing Co., Inc., 1993.

– Kansa E. C., Kansa S. V. and Watrall E. *Archaeology 2.0: new approaches to communication and collaboration*. Cotsen Digital Archaeology series (2011).

– Koutek M. *Scientific Visualization in Virtual Reality: Interaction Techniques and Application Development.* Tesis at the Faculty of Information Technology and Systems (ITS). Delft University of Technology (TU Delft). 2003

– Lévy P. and Bononno R. *Becoming virtual: Reality in the digital age*. Da Capo Press, Incorporated, 1998.

– Limoncelli M. *Il restauro virtuale in archeologia*. Carocci, 2012.

– Limoncelli M. *Virtual Archaeology a Herapolis di Frigia: restauro virtuale e restituzione 3d degli edifici di ordine dorico.* Herapolis 3 (2009): 493-503.

– Lock, Gary R. *Using computers in archaeology: towards virtual pasts*. Psychology Press, 2003.

References

– McCormick, Bruce H. *Visualization in scientific computing*" ACM SIGBIO Newsletter 10.1 (1988): 15-21.

– Moreno R. and Mayer R.E. *Learning science in virtual reality multimedia environments: Role of methods and media.* Journal of educational psychology 94.3 (2002): 598.

– Niccolucci, F. *Virtual museums and Archaeology: an international perspective.* established by: Mauro Cristofani and Riccardo Francovich (2007).

– Olivito R., Taccola E., Albertini N. 2015. *A Hand-Free Solution for the Interaction in an Immersive Virtual Environment : the Case of the Agora of Segesta.* ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL-5/W4:31-36

– Olivito R., Taccola E., Albertini N. A *Hand-Free Solution for the Interaction in an Immersive Virtual Environment: the Case of the Agora of Segesta.* In «ISPRS-International Archives of the Photogrammetry. Remote Sensing and Spatial Information Sciences», XL-5/W4, 2015, 31-36

– Olivito R., Taccola E., Albertini N., *Hand-free Interaction in the Virtual Simulation of the Agora of Segesta, in Campana.* S. et al. (eds.), CAA2015. Keep the revolution

going.Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology (March 31st to April 2nd 2015), pp. 321-328.

– Orsi P. (1916). Caulonia. *Campagne archeologiche del 1912,1913 e 1915.* Monumenti Antichi dei Lincei 23, 685-944.

– Parra M.C. (2011). *Dal Santuario di Afrodite a Punta Stilo, guardando alla città e al territorio, dopo oltre un decennio di ricerche.* In M.C. Parra & N. Facella (Eds.), Kaulonía, Caulonia, Stilida (e oltre), III. Indagini topografiche nel territorio, 3-44. Pisa, Italy: Edizioni della Normale. Retrieved from: https://www.academia.edu/

– Parra M.C. (2013). Kaulonia. *Scavi nel santuario di Punta Stilo (2011-13): verso una lettura d'insieme del complesso.* Annali della Scuola Normale Superiore di Pisa, Classe di Lettere e Filosofia 5, 5/2 Supplemento, 81-95. Retrieved from https://www.academia.edu/

References

– Parra M.C. (2014). *Da Clete a Pitocrito: bronzi votivi dal santuario di Punta Stilo a Kaulonia*. In M.T. Iannelli & C. Sabbione (Eds.), Le spose e gli eroi: offerte in bronzo e in ferro dai santuari e dalle necropoli della Calabria greca, 110-115. Vibo Valentia, Italy: Adhoc. Retrieved from https://www.academia.edu/

– Parra M.C. (2015). *Il santuario del Capo Cocinto: "nuovo" osservatorio occidentale di presenze multiculturali*. In E. Kistler, B. Öhlinger, M. Mohr & M. Hoernes (Eds.), Sanctuaries and the Power of Consumption. Networking and the Formation of Elites in the Archaic Western Mediterranean World, 275-286. Harrassowitz Verlag: Wiesbaden. Retrieved from https://www.academia.edu/

– Parra M.C. (2016). Kaulonia. *Scavi nel santuario di Punta Stilo (2014): risultati e progetti di ricerca*. Annali della Scuola Normale Superiore di Pisa, Classe di Lettere e Filosofia 5, 8/2 Supplemento, 81-85. Retrieved from https://www.academia.edu/

– Pescarin S. *Archaeopress, Virtual reality and cyberarchaeology virtual museums*, in F.REMONDINO, S. CAMPANA BAR International Series 2598, 3D Recording and Modelling in Archaeology and Cultural Heritage. Theory and best practices, Oxford 2014, 129-133.

References

– Pletinckx D. et al. *Virtual-reality heritage presentation at Ename*. IEEE MultiMedia 7.2 (2000): 45-48.

– Pletinckx D. *Virtual archaeology as an integrated preservation method*. Virtual Archaeology Review 2.4 (2011): 33-37.

– Pujol L. *Archaeology, museums and virtual reality*. Digithum 6 (2004): 1-9.

– Reilly P. *Putting the materials back into Virtual Archaeology*. (2015).

– Reilly P. *Towards a virtual archaeology*. Computer Applications in Archaeology. Oxford: British Archaeological Reports, 1990.

– Remondino F. (2014). *Photogrammetry - Basic Theory*. In F. REMONDINO & S. CAMPANA (Eds.), 3D Recording and Modelling in Archaeology and Cultural Heritage - Theory and Best Practices, 63-72. Oxford, England: Archaeopress.

– Ryan ML. *Narrative as virtual reality: Immersion and interactivity in literature and electronic media*. Johns Hopkins University Press, 2001.

References

–   Salvadó N. et al. *Advantages of the use of SR-FT-IR microspectroscopy: applications to cultural heritage.* Analytical chemistry 77.11 (2005): 3444-3451.

–   Sanchez-Vives M. V., and Slater M. *From presence to consciousness through virtual reality. Nat Rev Neurosci* 6.4 (2005): 332-339.

–   Scagliarini D. et al. *Exciting understanding in Pompeii through on-site parallel interaction with dual time virtual models.* Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage. ACM, 2001.

–   Scheiblauer C., Zimmermann N., and Wimmer M. *Interactive domitilla catacomb exploration.* Proceedings of the 10th International conference on Virtual Reality, Archaeology and Cultural Heritage. Eurographics Association, 2009.

–   Stanco, F., and Tanasi D. *La computergrafica nella ricerca archeologica. Dal 3D Modeling alla Digital Archaeology.* AIAr 2008, quinto congresso nazionale di Archeometria, Scienza e Beni Culturali. AIA, 2009.

– Stanish C. S. *Cyber-archaeology and world cultural heritage: insights from the holy land.* " Bulletin of the American Academy of Arts & Sciences (2013): 27.

– Stuart R. *Design of virtual environments.* Barricade Books, Incorporated, 2001.

– Sylaiou S. and Patias P. *Virtual reconstructions in Archaeology and some issues for consideration.* IMEROS: An Annual Journal for Culture and Technology 4.1 (2004).

– Taccola E., Parra M.C., & Ampolo C. (2014). *The sanctuary of Punta Stilo at Kaulonia- Monasterace (Rc, Italy): preliminary results of the close range photogrammetric surveys 2012-2013.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 40-5, 559-563. doi:10.5194/isprsarchives-XL- 5-559- 2014.

– Tarr M. J. and Warren W. H. *Virtual reality in behavioral neuroscience and beyond.* Nature neuroscience 5.11s (2002): 1089.

–   Terras M. *A Virtual Tomb for Kelvingrove: Virtual reality, archaeology and education.* Internet archaeology 7 (1999).

–   Thorn A. *Unity 4 fundamentals. Get started at making games with unity.* Burlington, MA. Taylor & Francis, 2014.

–   Thorn A. *Unity 4 Fundamentals: Get Started at Making Games with Unity.* CRC Press, 2013.

–   Tominski C. *Event-Based Visualization for User-Centered Visual Analysis.* PhD Thesis, Institute for Computer Science, Department of Computer Science and Electrical Engineering, University of Rostock, forthcoming 2006.

–   Tost L. P., and Economou M. *Evaluating the social context of ICT applications in museum exhibitions.* Proceedings of the 7th International conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage. Eurographics Association, 2006.

–   Tost L. P., Economou M. *Worth a thousand words? The usefulness of immersive virtual reality for learning in cultural heritage settings.* International Journal of Architectural Computing 7.1 (2009): 157-176.

References

– Tost L. P. *Does virtual archaeology exist?.* in Posluschny Lambert & Herzog 2008 (2008): 101-7.

– Upson C. et al. *The application visualization system: A computational environment for scientific visualization.* IEEE Computer Graphics and Applications 9.4 (1989): 30-42.

– Van Grieken R. Delalieux F. Gysels K. *Cultural heritage and the environment.* Pure and Applied Chemistry 70.12 (1998): 2327-2331.

– Vandenabeele P. et al. *Raman spectroscopic database of azo pigments and application to modern art studies.* Journal of Raman Spectroscopy 31.6 (2000): 509-517.

– Wickens C. D. *Virtual reality and education.* Systems, Man and Cybernetics, 1992., IEEE International Conference on. IEEE, 1992.

– Wilbur S. P. *An archaeology of cyberspaces: Virtuality, community, identity.* The cybercultures reader (2000): 45-55.

– Wilbur S. P. *An archaeology of cyberspaces: Virtuality, community, identity.* The cybercultures reader (2000): 45-55.

References

– Winn W. *A conceptual basis for educational applications of virtual reality*. Technical Publication R-93-9, Human Interface Technology Laboratory of the Washington Technology Center, Seattle: University of Washington (1993).

– Zubrow E.B.W. *Archaeopress, From Archaeology to I-archaeology : Cyberarchaeology, paradigms, and the end of twentieth century*. in Forte M. Cyber-archaeology, Oxford, England 2010, 1-7.

– Zubrow, E. B. W. *Digital archaeology*. Digital Archaeology. Bridging method and theory, London (2006): 10-31.

– Zyda M. *From visual simulation to virtual reality to games. Computer* 38.9 (2005): 25-32.

Publications

– Albertini, N., Baldini, J., Taccola, E., Barone, V. (2017). New Methods of Interaction in Virtual Reality for the Study of Archaeological Data, The Asian Conference on Arts & Humanities 2017 Official Conference Proceedings, 101-111.

– Albertini, N., Baldini, J. (2016) L'applicazione dell' oculus rift nelle ricostruzioni archeologiche: l'esempio di Haghia Triada, MUSINT 2 Nuove esperienze di ricerca e didattica nella museologia interattiva (pp. 47-53).

– Albertini, N., Baldini, J. (2016) Il laboratorio dreamslab e le sue applicazioni alle scienze dell'antichità, MUSINT 2 Nuove esperienze di ricerca e didattica nella museologia interattiva (pp. 121-129).