SCUOLA NORMALE SUPERIORE

Classe di Scienze

PhD Thesis

New approaches to scientific visualization in virtual immersive environments for science and humanities

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Abstract

Virtual environments and 3D visualization have introduced a new element in the process of data analysis, allowing the researcher to observe and perceive information in a more natural way.

The structure of a molecule or even only the 3D representation of a physical quantity are examples of how a graphical representation can help understanding the data itself and the subsequent and eventual communication to the public.

The use of scientific data is not only a visual act.

The fundamental element is to allow the researcher to understand and manipulate information, testing hypotheses and looking for significant results, and that's the point where the method of interaction becomes critical; with the use of existing human-computer interface systems it all becomes intuitive, functional and simple, allowing a more natural approach.

Virtual Reality provides advanced visualization and data manipulation solutions applicable to multiple disciplines related to each other as chemistry and cultural heritage studies.

The advent of new mass technologies from smartphones to the Head Mounted Display has allowed to see and manipulate interactive graphic information even for those who practice field research, providing a valuable help to understand and use the data.

This thesis will show the fields in which visualization techniques can be applied, particularly in the field of chemistry and cultural goods, referring to case studies developed in recent years.

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Introduction

Immersive visualization for the study of sciences

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Figure 1.1 One of the first Head Mounted Display

Chapter 1

1.1 Technologies for Virtual Reality

Virtual Reality Technologies (VR) have evolved over the last few years, techniques have refined, computing capacity has increased, and most of all, device prices have dropped discreetly, allowing research centers to begin developing VR applications or tools without particularly important funding

Among these, the most important tools are:

- Head mounted displays (HMD)
- CAVE
- Augmented reality glasses
- Natural User Interface
- Tracking Device

Old tools for Virtual Reality were big and bulky, uncomfortable and difficult to understand for the user.

As for the technology in general the tools for virtual reality have become smaller, lighter and cheaper; the large, heavy and enveloping HMD, have been replaced with lighter and more comfortable models (fig. 1.2).

Figure 1.2 Evolution of HMD in recent years

The new HMDs allow you to enjoy a better immersive experience, completely involving the user.

The industry has expanded a few years ago due to Oculus Rift, which in addition to having higher resolution than older models, also mounts a gyroscope, an accelerometer and an external optical positioning tracking system.

CAVE systems, in addition to increased computing power and reduced hardware costs, have significantly increased the quality and resolution of projectors, new more accurate and functional tracking systems, and also new engine graphics and development tools, also due to the commercial explosion of consumer-oriented software.

Regarding the interaction, up to a few years ago, many invasive tools were used, such as sensory gloves that let you trace the user's position and gestures used to interact with the Virtual Environment.

These technologies are still used in some areas but are being replaced for more natural interaction methods such as optical tracking; some examples are systems such as Optitrack, Kinect and Leap (also developed in various versions, significantly improved over the years).

These systems, called NUIs (Natural User Interface), make fruition more intuitive and natural, especially for users who approach VR for the first time, making the experience even more immersive (fig. 1.3).

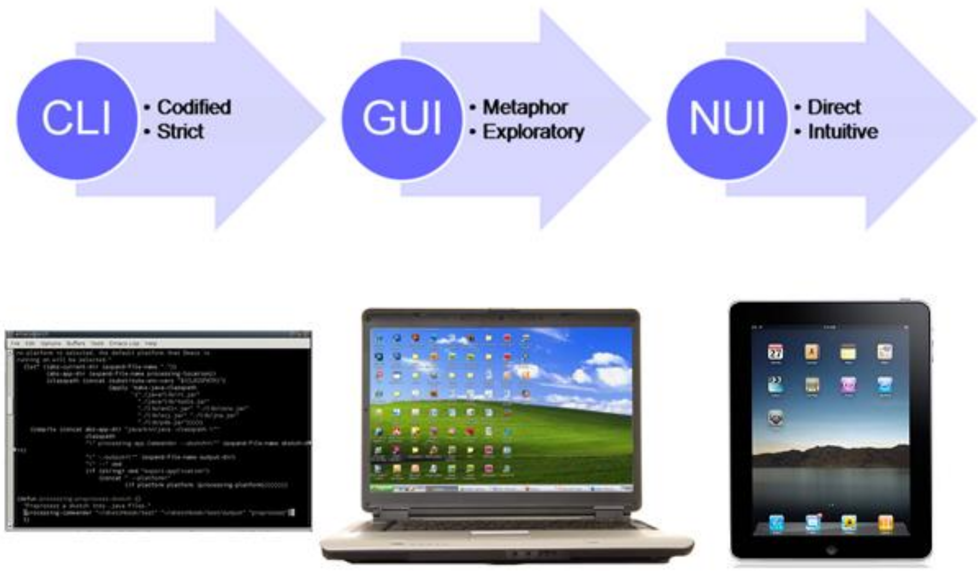

Figure 1.3 Evolution of user interface

1.2 Virtual Reality for graphical visualization

When we talk about VR, or rather a virtual environment, we mean a set of resources and tools that can simulate not all reality, but only the part that interests us: this goal is achieved thanks to the help of realistic 3D graphics, audio feedback and aptic feedback.

Depending on the type of device used to stimulate vision, hearing or feel, we can get a more or less immersive environment, which gives us a greater impression of being present within the environment itself.

The three basic components of VR are: IMMERSION, which represents a measure of the perception that the user has of the surrounding environment, typically achieved by focusing mainly on the sense of sight and hearing; PRESENCE is a measure of the involvement of the user, or rather how much he feels involved with the experience he is living; INTERACTION, represents the user's ability to communicate with the environment through more or less natural inputs.

Virtual environments are able to recreate a rich, interactive, passionate and educational context that supports the cognitive experience.

Consider for example the opportunity to recreate a virtual chemistry laboratory, where scientists can experience situations that would be difficult or impossible to replicate.

Users interact with an environment that can make them aware of their mistakes in a conscious manner without fear of causing real damage. In addition, errors are repeatable and replicable, in case you want a better understanding of where the problem is.

Pointing to the feature of immersion, it is possible to build virtual environments in which to simulate the reality of interest and to give the illusion of not having a real mediation, ie not having to interfere with a computer tool as a means to communicate with the virtual world .

The virtual environments features such as presentation fidelity and natural user interaction are two crucial elements when analyzing scientific data in VR, especially when you need to focus on realism.

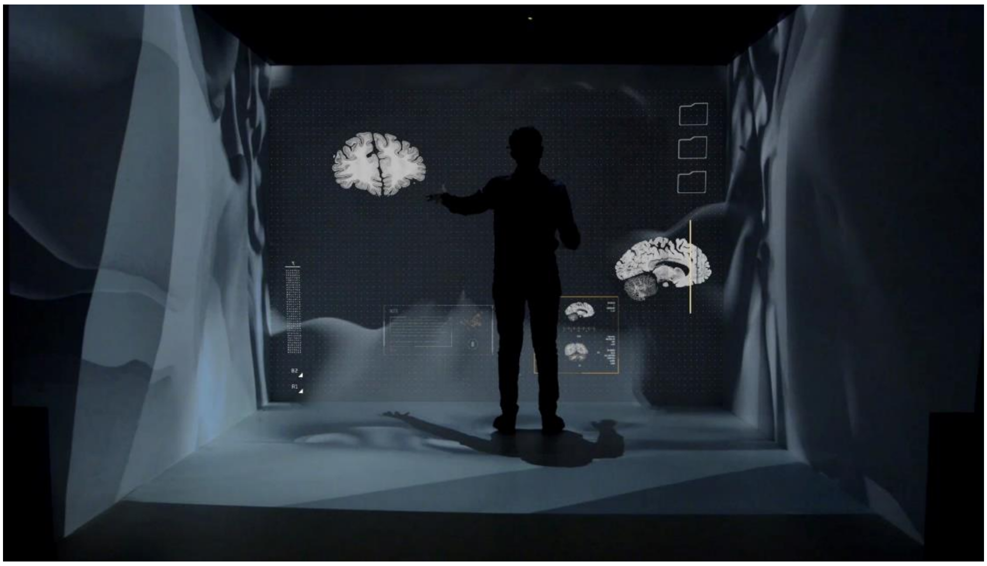

Figure 1.5 Concept of a natural interface designed for virtual reality

Many studies have shown that the realism of the object displayed (obtained thanks to accurate graphics, high framing, realistic environmental responses) promotes the sense of presence of the user, which is therefore focused on what he sees and favors the " Suspension of disbelief ".

Interaction, as already explained, represents the user's ability to influence events within the environment itself; this encourages the user's predisposition to the application, as he feels able to "cause reactions" consistently with what he expects.

This goal is achieved by giving you the ability to manipulate, rotate and observe, from different perspectives, the object of interest (a molecule, a galaxy, an archaeological find) in order to increase the perception of it and the understanding of the related data (fig. 1.5).

Usability is an essential concept for any good interactive application, as it represents the ability of a user to perform a task as effectively and efficiently as possible.

Usability can be divided into two subcomponents: the so-called "perceived meaningfulness", which is the feeling that what is being done has a definite meaning and purpose, and the "perceived ease of use", ie simplicity of use perceived by the user.

These two components favor the good predisposition of the user towards the application; in a usable environment, the user has the ability to handle the objects in an easy and intuitive way, and therefore the perceptual variable of orientation in space is inserted within this scheme for obvious reasons related to the ability to manipulate, rotate and so on.

Usability is also closely related to self-efficacy, that is, the user's perception of having the ability to successfully achieve a goal, such as interacting with the environment by observing the reaction you expect to see.

Finally, presence is a psychological factor, as already mentioned, fundamental for virtual environments, and in general to promote the transmission of knowledge.

1.3 Virtual Reality for research and learning

Graphic interfaces as we know it today, were born in the 1980s, and have become commonplace for most of the world's population. Once standardized, they have become part of everyday life, enabling users to interface with different types of machines, from personal computers to video game consoles.

In addition, the evolution of computer graphics has now enabled us to display "convincing" 3D models on our screens, representing any kind of information of interest.

Virtual reality can provide a rich, interactive and highly engaging context, thus acting as a valuable support to the understanding process. Thanks to the VR you can have a "learning by doing" approach, which thanks to the direct interfaces, increases the perceived immersion and the learning procedure.

The first-person experiences play a crucial role in the interaction with the virtual world.

The user builds its own reality through his perception and his prior knowledge, having perceptual illusion between the real and virtual worlds. VR gives the user the opportunity to think and to have a deeper vision of the process through which an individual draws knowledge from the world.

All VR technologies are strongly multidisciplinary (fig. 1.4).

Both in science and humanities, these visualization approaches enhance the visual component of the proposed data.

Below we can analyze some approaches used in the most successful field of study in this sense, where virtual reality has expressed greater interaction.

First, we will analyze the visualization of molecular structures in the chemical field, and then the application of these visualization techniques to the historical-archaeological context.

Finally, we will see how these two approaches are linked to each other through research work carried out in recent years.

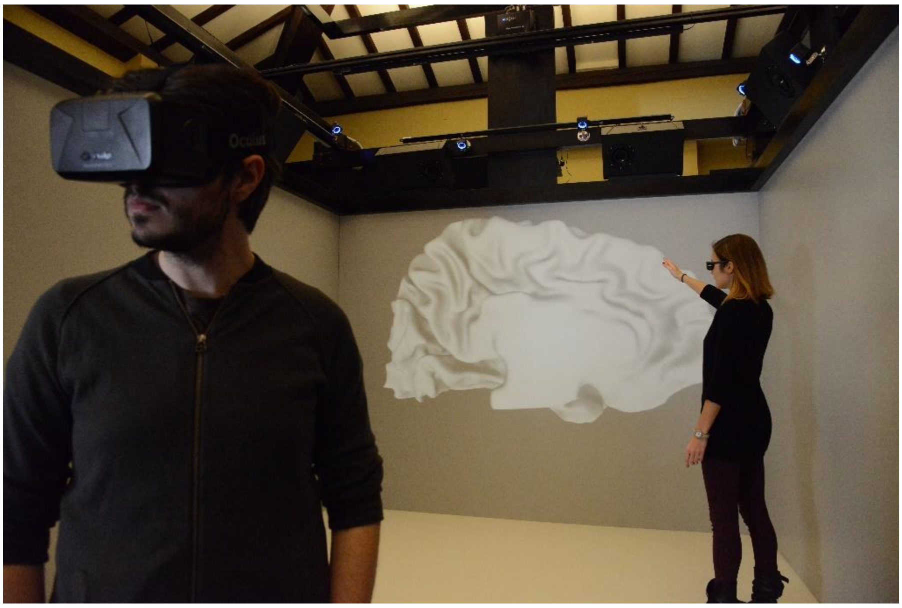

Figure 1.4 Example of multiscale application on collaborative VR devices

Chapter 2

2.1 Data Visualization in Chemistry

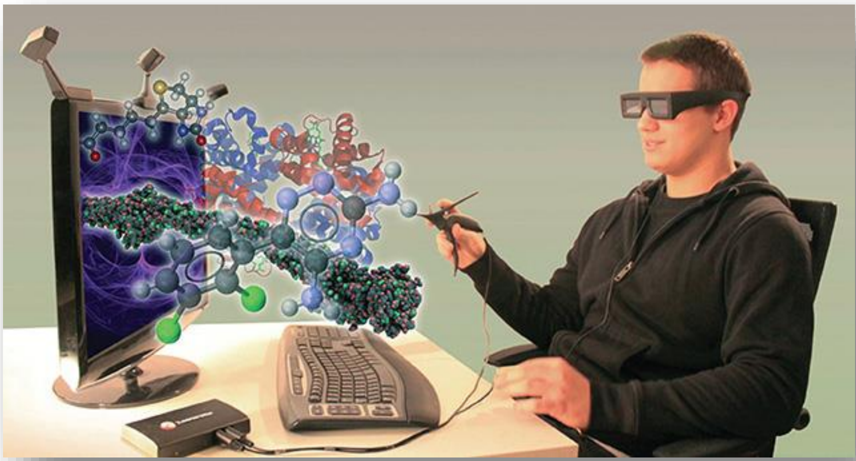

Figure 2.1 3D visualization of a molecule in 3D

We can interpret chemistry as composed of three forms:

- macro and tangible: things that can be seen and heard
- submicro: atoms, molecules, ions and structures
- representational: symbols, formulas, equations, graphs

Many of the elements that we find in the world and we know are in macroscopic form.

In the chemical field, however, to have a total understanding of the object, you have to move in the microscopic field, where the behavior of substances is interpreted at a molecular level.

Various techniques for representing molecules and associated structures are used in the field of computer graphics; these techniques are by themselves complex and constantly evolving (fig. 2.1).

2.2 Conventional Molecular Representations

Among the simplified representations of a molecule we can find “ball and stick”, the representation of Van der Waals (also identified as “space-filling” or CPK) and Licorice visualization; these are some of the most classic and frequently used.

The structure was initially obtained using lines between the atoms (simplified licorice model), subsequently it was based on a more sophisticated model with cylinders and spheres (ball and stick, space-filling and licorice).

Until recently the visualizations were implemented through triangulation of the spherical and cylindrical surfaces, but the main limitation of this approach is that it creates models with a large number of triangles; this is not an optimal solution, especially when you need a high quality rendering, in fact, such a large amount of triangles is very greedy in computational terms, even using modern hardware.

With the development of programmable graphics cards, a new technique has been introduced to address this problem, the Ray Casting.

With this approach, it’s possible to represent a huge number of spheres and cylinders with careful precision at any zoom level.

2.3 Visualization of the secondary structure

The secondary structure (or Cartoon) is a metaphor particularly useful for describing complex molecular structures and highlight specific points of interest.

This abstract representation simplifies macromolecular structures by removing some intricate details and providing a hierarchical view. The metaphor focuses on the organization known as secondary molecular backbone.

The display of these metaphors with a classic triangulation technique requires a compromise between image quality and rendering efficiency.

During the last years several methods have been tried to exploit the parallelism of the GPU compared to the CPU.

These enhancements allow interactive manipulation of the secondary structures of proteins and the real-time observation of changes of the backbone, even in very large systems.

2.4 Molecular Surface visualization

One of the most common definitions used to represent molecular surfaces is that of Connolly also known as Molecular Surface or MS. As in the conventional representations described above, the surfaces are traditionally represented by a large number of triangles.

Recently, the Ray casting technique on GPU has been successfully applied to achieve alternative surface representations, significantly reducing the number of triangles, so that the dynamic evolution of the surface can be followed in real time.

The evolution of the surface can be currently displayed for medium-sized protein systems; for the first time, a pixel-precise visualization of a surface may be carried out at any zoom level.

The Ray Casting on GPU technique was used to represent the Molecular Skin Surface (MSS); this surface is slightly different from the MS and offers several advantages:

- Its mathematical definition confers properties such as the absence of self intersection and the increase of the smoothness, both missing in the MS.
- The MSS is composed exclusively of equations of second degree, while the MS requires the integration of equations of second and fourth degree which slow down the surface calculation.

By contrast it is necessary to delimit each part of the surface and the MSS is necessary to calculate a particular structure named Mixed complex for each configuration.

This calculation must be performed on the CPU and is computationally hexose.

The changes on the surface in real time are limited to molecules ranging from a few hundred atoms to molecules up to a thousand atoms, such as small molecules and peptides.

Recently, the methods of Ray casting MS and MSS have been extended through the implementation of multi-core CPUs in addition to GPUs.

2.5 Visual effects to improve the representation of molecular structures and facilitate their perception

Lighting effects have become an essential tool for the visualization of molecules (fig. 2.2).

The complexity of macromolecular structures requires special effects to properly appreciate and understand their complex forms.

One of the basic visual effects is adding specular lighting in the visualization scene, even if this is not enough to describe complex shapes; for this reason, sophisticated effects such as depth cueing or cel-shading are increasingly used.

In addition, sometimes it's desirable to combine various representations, such as ribbons and surface representation.

There are also additional visual effects, which can be applied in real time, that can greatly enhance the perception of the molecular form.

Using these new visualization methods, you can add shading to a global scene and place a molecule in a 3D environment to improve its perception.

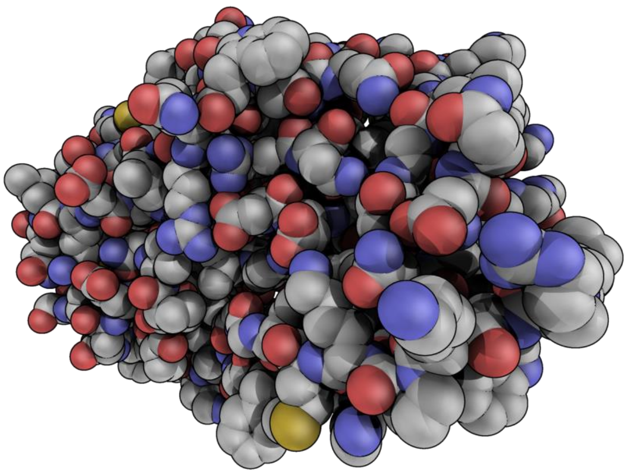

Figure 2.2 Molecule with light effects

Ambient occlusion is an increasingly popular technique in this regard. This method takes into account the overall dark, improving depth perception.

The perception of the form can be improved by emphasizing the outlines of a structure where two overlapping parts of a molecule are separated by a distance greater than a certain threshold.

Similar representations are increasingly integrated in the famous molecular visualization programs such as PMV or Chimera.

In the same spirit, the program BALLView provides an effect of cel-shading with contouring silhouette to represent the secondary structure.

The contouring silhouette method is designed to create a halo effect that helps to identify depth discontinuities.

Finally, you can add more realistic lighting effects such as High Dynamic Range (HDR), in wich the rendering affects how the light is preserved in the optical phenomena of reflection and refraction.

This feature is particularly important for transparent materials such as glass, for this can be used to create artistic effects (crystal effect etc ..) with the molecules.

An interesting way to represent the uncertainty of the position of the atoms, without leading to the overcrowding of the scene is to use blur effects.

The Lee and Varshney method (Lee, 2006), for example, relies on the use of transparent multi-layer surfaces to create the blur effect while the

Schmidt-Ehrenberg method (Schmidt-Ehrenberg, 2002) is based on the volume rendering.

The blur effects can also highlight the depth of field.

2.6 Texture mapping for molecular graphics

The common aim of texture mapping is to reduce the geometric complexity while increasing the realism of the display, allowing it to show large amounts of molecular data while being less greedy in computational terms.

Texture mapping can be used to:

- View and filter multi-channel information of the structural properties of the molecular surfaces
- Improving the quality and accuracy of the contours in high isodensity
- Increase the rendering speed of the space-filler in atomic representations
- Apply rendering techniques to large distributions in real time

The implementation of these new techniques require only moderate changes to existing molecular modeling applications.

The texture mapping is a technique widely used for advanced visualization applications, in wich the major concern is maintaining a constant and adequate frame rate when moving to real-time 3D object.

2.6.1 Concept of Texture Mapping

The texture mapping is a technique that consists in applying an image on the surface of an object by wrapping it (fig. 2.3).

The image exists in a spatial coordinate space called texture.

The individual elements of a texture are called texels.

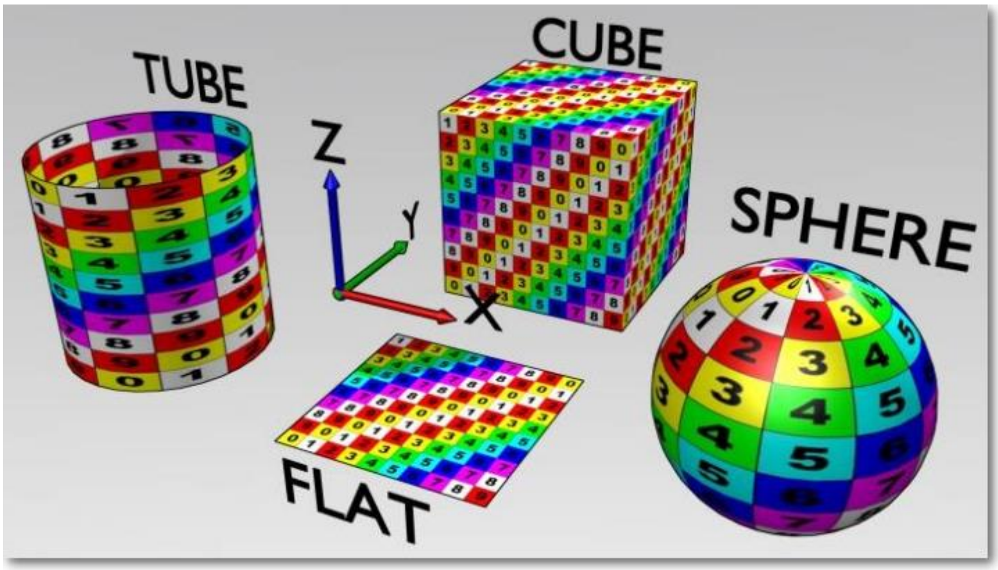

Figure 2.3 Example of texture mapping on various object

At present, the purpose of the texturization is to add realism to a rendering and at the same time reduce the geometric complexity.

The texture mapping can be used in various ways to improve the visualization of the data; the two essential components for the texture mapping process are the texture (texture space) and 3D geometry.

The assignment of the texture coordinates is often explicit (eg. Specific texture values are attached to each vertex of the object). Alternatively, the texture coordinates can be automatically generated by two methods:

- The first based on the distance from a reference plane in the world or in the object space

- The second based on the normal of the object to determine the coordinates of the texture depending on the direction in which the user is watching

The texture space can be one-dimensional (1D), two-dimensional (2D) or three-dimensional (3D). Like pixels in the viewing space, each element of the texture is called texel (texture element). Current technology offers a lot of flexibility on how to implement the information of each texel.

Multi colors are also supported , transparencies and look-up indices corresponding to value tables. As a basic definition, the texture space can be considered as a special memory, where a variety of information can be stored and then connected to the representation of an object in 3D space.

2.6.2 Fields of application for texture mapping techniques

Molecular Surfaces

The detailed study of the molecular surfaces has become an important tool for the interpretation of the properties beyond the molecular structure, in terms of atoms coordinates.

The combination of these two forms of molecular representation with texture mapping capabilities offer a variety of new ways to view the properties of a molecule.

Both approaches use algorithms capable of generating 3D objects with surfaces composed of triangles.

The combination of these molecular representations with texture mapping possibilities, offers a new way to visualize the molecular properties.

Display large amounts of 3D data has always been a challenge for graphical applications in real-time, not only in molecular visualization, but also for other scientific areas with high demand for interactivity and visual simplification.

Color Coding

In interactive molecular graphics, high contrast and color variation have always been difficult to solve.

While the standard hardware implementation allows to give a specific RGB to the surface, the color interpolation on the pixel is operated in a linear manner.

With many dotted surfaces the problem is reduced, for example, aligning the surface vertices with the expected color code or a multipass render can completely remove the artifacts.

These methods still require a large number of polygons or high algorithmic complexity, thus being unsuitable for interactive real-time applications.

One of the solutions to this problem can be achieved by representing the color map as a texture 1D.

Mapping property to the texture space instead of the color space allows the color to be achieved through information taken from the average of the two nearest relevant vertices.

Similarly to the 1D texture used as a color code on the molecular surface, the texture space can be extended to two or three dimensions, by incorporating additional information for each new dimension. Particular attention should be paid in try not to load too much the surface information.

An additional and important feature is the use of transparency, which allows to filter and distinguish the important information from those superfluous and further give qualitative properties in a quantitative context.

The implementation of the so-called filtering can be inserted in the color-coding techniques discussed above if is used a texture map 2D or 3D.

Applying this technique gives good results for filtering properties, such as electrostatic potential and electric field.

Real-time Phong shading

The electron density map is often rather complicated, because there can be high levels of local curvature; this is one of the biggest problems of an accurate visualization. The correct perception of the curves can be obtained with a much higher computational effort compared to a shading technique (Phong Algorithms). Contrary to the linear interpolation of the color of vertex colors, the Phong shading approach interpolates the normal for each pixel of a geometric primitive by computing the light equation in a subsequent step.

One possible solution is the use of normal mapping in which, contrary to the Phong shading, the interpolation is not performed directly on normal. The normals are still automatically used to generate the texture coordinates based on the orientation of the surface vertices in the world coordinate system. The image below shows the surface area calculated with Phong approach (fig. 2.5).

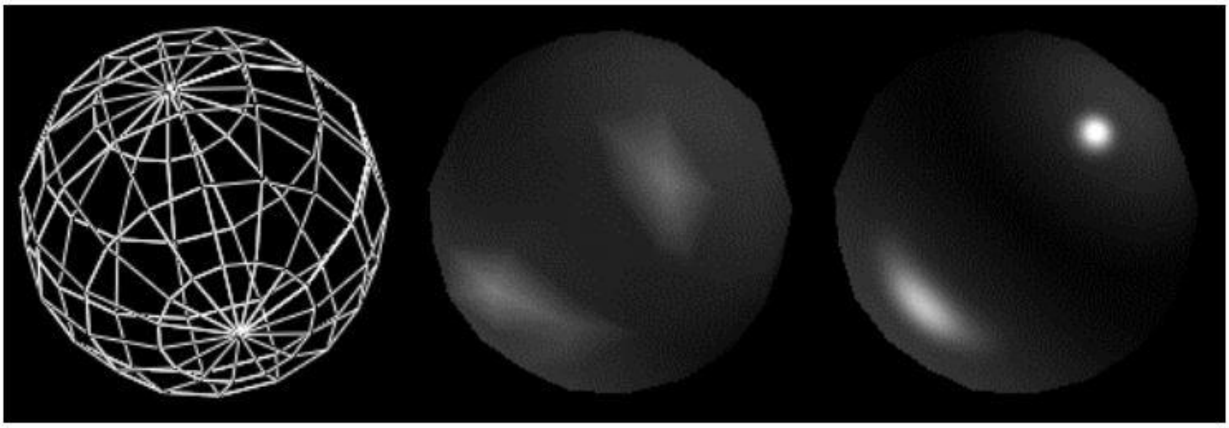

Figure 2.5 Surface area calculated with Phong approach

Real-time space-filling models

The use of high-definition CPK models is restricted to small molecules.

The spheres that are used to represent the individual atoms must be tessellated, which increases the complexity of the geometric model.

The rendering of large molecules without degrading the visual quality is not possible without a reasonable computational effort, but the problem can be solved with a special form of texture mapping.

Each atom is represented by a square on which is attached an image of a sphere and the areas of the square that are not covered by the ball are drawn transparent.

The only flaw is that every single ball can intersect with the object.

To handle this problem in an appropriate way, you can use a special function that allows proper removal of hidden lines on a per-pixel detail.

2.6.3 Texture mapping and future development

The potential of the hardware to support texture mapping have been demonstrated in various molecular graphics applications .

The technique is primarily used when:

- Geometric complexity needs to be reduced to have real-time performance in interactive applications
- Information needs to be increased to adequately represent the properties of the molecule
- It is necessary to filter irrelevant information from a more complex context
- Increase rendering quality to improve the correct perception of complex surfaces

Undoubtedly the texture mapping technique has yet to be improved and refined, however, we can expect a future in this direction, with an increasing use of technology in the field of molecular visualization.

2.7 Future development and application in other fields

Analyzing the tools, technologies and software for 3d visualization currently present and their evolution over time can make us understand how this theme on the field of Molecular Graphics is expanding; increasing the immersion and understanding of the data it is assumed that these resources will gain more and more attention in the field of chemical research and molecular sciences in general.

This overview of the molecular visualization has been useful to identify those techniques and technologies which make us able to graphically portray any kind of 3D model; we will further explore how those techniques can be applied to any 3D visualization field of study, ranging from sciences to cultural heritage.

Chapter 3

3.1 Data Visualization in Historical and Archaeological Areas

The first step in the creation of a strong relation between Archaeology and technology dates back to the 60s, when Archaeology was involved in a deep theoretical debate concerning all the aspects of the research activity, data interpretation and dissemination methods.

With the birth of the so-called Processual Archaeology (or New Archaeology) archaeologists started using use scientific methods and technological tools (quantitative, taxonomic, computational and laboratory analysis), that seemed to be the only way to bring Archaeology nearer to the so-called Hard Sciences.

Still, this trend led many archaeolgists to overestimate the role played by scientific analysis tools to the detriment of the interpretative process.

For this reason, during the 80s, the so-called Post-Processual archaeologists questioned the theoretical approach of the New Archaeology, correctly pointing out the variety and unpredictability of factors (of human, social, cultural, and environmental nature) which affect the historical process and cannot be considered as invariable and independent from the context in which they take place.

According to this view, an historical reconstruction is not merely a sum of calculable elements.

It is indeed a combination of factors and phenomena wich, once investigated with the methods and scientific instruments introduced by

Processual Archaeology, have to be interpreted devoting special attention to the context and the individual and psychological factors.

It's in this articulated theoretical context that new techniques of computer-graphics and Virtual Reality have been recently integrated, stimulating a transition from two-dimensional to three-dimensional visualization methods.

This allowed for the birth and development of the so-called Virtual Archaeology and for a strong advancement in the production of archaeological reconstructions which, since the end of 90s and the beginning of the 21st century have been increasingly characterized by a high-photorealism.

Unfortunately until a few years ago, Virtual Archaeology did not pay too much attention to perception and behaviours and, consequently, to the capability of understanding the past and its different articulations.

This was mainly due to the fact that the reconstructive process was quite independent from the interpretative one.

For this reason, scholars have become increasingly interested in the necessity to emphasize the dynamic and continuously changing nature of the historical and archaeological data, which are inevitably influenced by an endless transformation both in its formation and in the interpretation processes.

A new trend has been developed on the basis of the 'Cybernetic approach', for which an important element is represented by the transition from the concept of 'reconstruction' to that of 'simulation'.

Indeed, 'reconstructions', in the way they have been used so far, involve the idea that a certain object, structure, or even context could be reconstructed as it used to be.

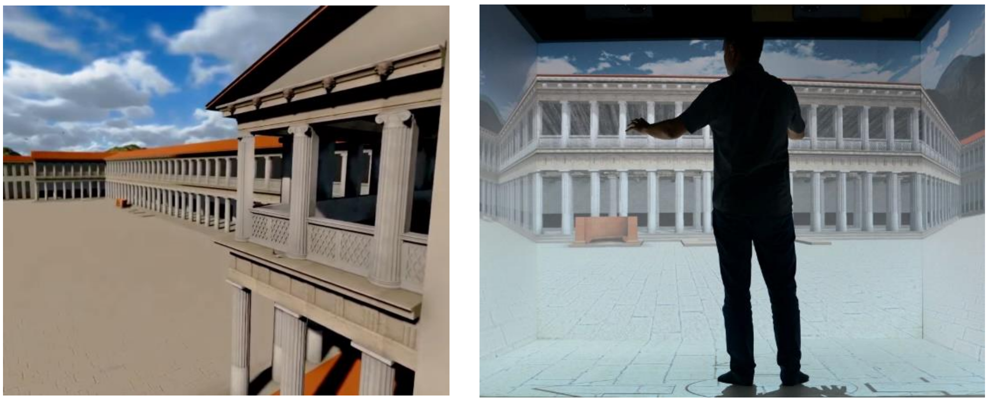

Figure 3.1 From simple 3d reconstruction to accurate virtual environment

Such a supposed truth is obviously fallacious, since it is simply impossible to have all the data and information one would need in order to re-create a certain item in a certain historical moment.

On the contrary, 'virtual simulations' are based on the idea that the virtual environment within which they are created is not a closed and unalterable space.

From a theoretical point of view the open character of simulations, either traditional or virtual, enables the possibility to take into consideration different variables, so that it could be possible to create an infinite number of 'models'.

At the same time, and on behalf of the concrete presentation of the research results, cyber-archaeologists are aware of the importance to use a 'simulation slice', that is "a representation that reflects reasoned interpretation of how a particular place may have looked, and the kinds of things that may have happened there, at some slice in time" (Clark 2010).

A 'simulation slice' is not a 'reconstruction', but rather only one of the possible interpretations of a certain context.

Nowadays, Cyber-Archaeology seems to be the best approach to ensure a more thorough and dynamic investigation of the Past and, at the same time, a more detailed and effective dissemination of scientific results, even to non-experts.

3.2 Digital technologies and Virtual-Cyber Archaeological approaches

It is crucial not to consider Digital Technologies as mere tools to achieve highly impressive and photorealistic reconstructions, but as data repositories and informative vehicles allowing for a more rapid and open dissemination of knowledge.

The key to understanding the transition from Virtual- to Cyber-Archaeology lies in fact in the centrality of the 'interaction' with the environment.

It is not surprising, thus, that the cyber-archaeological approach recognizes a key role to the concept of 'embodiment' (Thompson and Varela 2001; Lesure 2005), to be intended as the way by which we experience the world and, due to the interaction with it, we perceive and know it.

For this reason, in the cyber-archaeological practice it's critical to take into account the immersive and interactive nature of virtual environments together with the visual dimension, with the unavoidable passage from the idea of 'reconstruction' to that of 'simulation' (Clark 2010).

In this regard, the development of new techniques of natural gesture interaction in virtual environments is of great value, allowing us to mentally and physically reproduce and simulate operations and activities we are used to during our daily life.

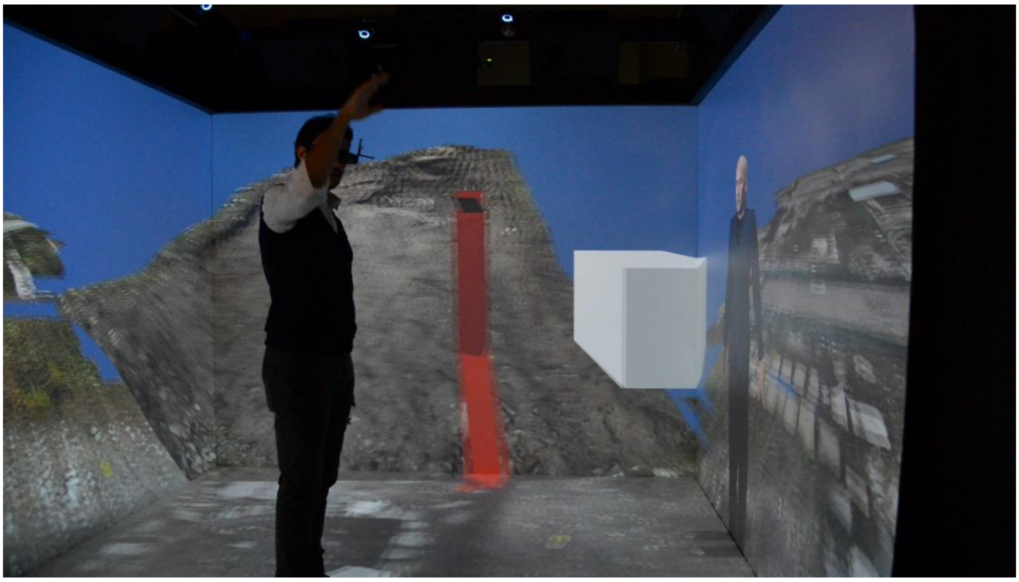

Figure 3.2 Interaction study on archaeological field

The huge amount of data represents a heterogeneous database, strictly and strongly interconnected, which can be more suitably interrogated through its visual representations to take advantage of our brain skills, which activate one-third of the neurons when processing visual information.

In this regard, Digital Technologies do allow us to pursue a collection and management of data in a much more accurate, detailed, rapid, and inexpensive way even compared to just a few years ago.

For this reason archaeologists have to evaluate, select, and filter data and information looking at the final purposes and users they want to reach.

On one hand, the goal is to allow our scientific knowledge of the Past to be more accurate, dynamic, not limited to static and definitive reconstructions but rather open to continuous investigations of a multifaceted set of data.

On the other hand, the objective is to share knowledge in a wider, easier, and more rapid and accessible way to both the experts and non-experts.

3.3 Interactive database

Together with the creation of a virtual environment based on the acquisitions and 3D models of a certain building or space, it is fundamental to create databases not only devoted to record textual data, but also available for the storage of digital acquisitions and elaborations acquired during all the investigation phases.

Not only this represents a very meaningful and powerful support for the Scientific Community and a big improvement in terms of cost-effectiveness. Indeed, this is actually necessary in order to pursue a 'simulation', which is mainly based on the possibility to modify the already existing model on the basis of new elements deriving from new research.

Besides, it is essential that the virtual environment has to allows scholars and even non-experts to interact with several different kinds of data, enriching or simplifying the simulation depending on the level of accuracy needed.

In this sense, the simulation has to be 'open' which means available for further addiction or, on the contrary, subtractions: by doing so, it would be possible to pursue a real-time change of the model, following the mental and cognitive process active during the data elaboration phase.

3.4 Dissemination, Museums and Virtual Reality

The impact of these technological innovations has also involved the field of dissemination and communication to non-expert, both on-site and in the museums.

Since the 70s of the last century museums were progressively computerized, with the creation of virtual inventories and stock photos.

The widespread diffusion of Virtual Museums is therefore a well-known phenomenon.

Still, it has to be noticed that, in order to have a correct approach to this topic, we should always conceive and refer to the virtual museum as a communication product made accessible by an institution to the public that is focused on tangible or intangible heritage.

It typically uses interactivity and immersion for the purpose of education, research, enjoyment, and enhancement of visitor experience.

Virtual museums are usually, but not exclusively, delivered electronically when they are denoted as online museums, hyper-museum, digital museum, cyber-museums or web museums"

Indeed, a virtual museum is not the real museum transposed to the web.

It is not an archive of, database of, or electronic complement to the real museum.

And last, but not least, a virtual museum is not what is missing from the real museum.

On the contrary, a virtual museum, and more generally speaking a virtual apparatus for the dissemination of knowledge especially in the field of Archaeology and Art History, should allow to expand the visual communication and enrich the textual apparatus to which it is traditionally given the task of explaining the contents of an actual museum.

Figure 3.3 Examples of virtual analyzes made on museum artworks

Chapter 4
Case Studies

We have seen how Virtual Environments and 3d representation can be useful for the displaying of data in apparently very different fields, like chemistry and cultural heritage.

Below there will be illustrated various case studies that have been developed over the last few years to show how visualization of data in the scientific field is really a valid new tool as traditional ones.

In the area of scientific analysis in archeology and cultural heritage, particularly innovative studies have been carried out, based on the use of natural interfaces within reconstructions, excavation layers, support materials and every type of metadata; it was interesting to observe the approach of researchers, who try immersive study environments for the first time.

4.1 The Agora of Segesta in immersive virtual environments

4.1.1 Interactive database

Virtual Reality (VR) and Cultural Heritage (CH) are two worlds that have been in contact many times in the last years, sometimes creating very interesting projects but often not fully taking advantage from the possibilities of this collaboration.

New technologies are now widely spread to the public and not only to the people working in high-tech fields: most of the people now can use a smartphone with cameras and sensors, can go in a cinema watching a 3D movie and is used to see graphical informations in museums and exhibitions.

This situations helps the researchers to increase the level of collaborations between VR and CH, aiming to what is a paramount for high quality results: a complete synergy.

Nowadays, the ideas are coming from a strong interaction between the two areas, and this multidisciplinary dialog allows to very innovative and effective applications.

Expert in the CH fields indicate real needs for the research they are running, clearing out limits and essential requirements for a better understanding of the data.

On the other side, VR researchers can offer solutions and enlarge the possibilities, introducing technologies and software that are maybe coming from other fields but they may fit to these requirements.

This strong synergy not only is the right solution for solving effectively the problems in the research, but, now more than ever, can lead to new challenges,offering systems and applications that may change the public audience and experts access to cultural heritage information.

This case study aims to follow this approach, merging competences from archaeologists, computer scientists and photogrammetry experts for the reconstruction of the agora of Segesta, in Sicily, Italy.

A complete 3D model has been reconstructed, based on real data, archaeological finds and photogrammetry data, following the indications of the researchers also for what concern the environmental data, like trees, hills and geographical position.

The model could be visited in a 3D immersive CAVE-like (Cruz-Neira, 1992) system, walking between the columns of the virtual agora.

4.1.2 Data acquisition

The 3D models employed have been produced from computer graphics and close- range photogrammetry.

3D Reconstruction

The excavations carried out by the Laboratory of Science of Antiquity of the Scuola Normale Superiore of Pisa (Ampolo , 2012) have brought to light a large part of the architectural appa atus of the agora, still found in connection despite the collapse of the structures, but also reused in the buildings of later historical periods.

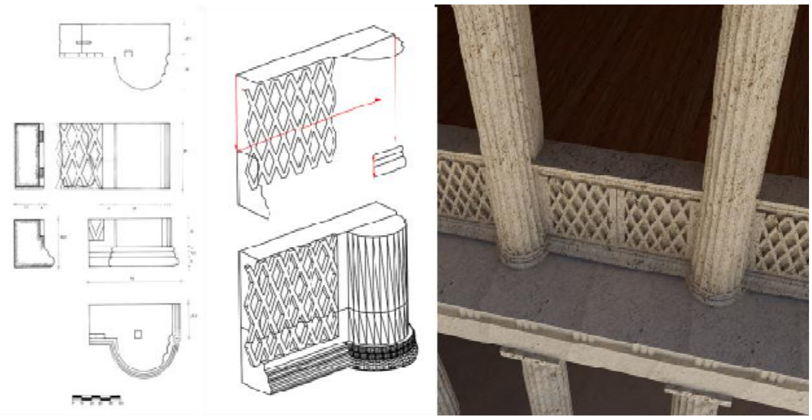

Figure 4.1.1 Architectural element: from 2D to 3D

The drawings of these architectural elements, which have been made by using traditional manual techniques, after being acquired with a

2D scanner and vectorized, are transformed into 3D models, thanks to simple operations as extrusion, revolution, loft and sweep, getting objects more or less complex with Boolean operations (union, subtraction, intersection, fig. 4.1.1) (Taccola, 2012).

Through the study of the elevations, which is achieved by comparing metric values and proportional relationships of the structures with similar examples best preserved in Sicily and in Mediterranean area (Agata, 2012), it is possible to extract useful information on architectural volumes, from which we get reliable data for the 3D reconstruction of the monumental complex.

In this way we can place the 3D models of architectural elements in their respective positions, using as a basis the general planimetry of the excavation area (fig. 4.1.2).

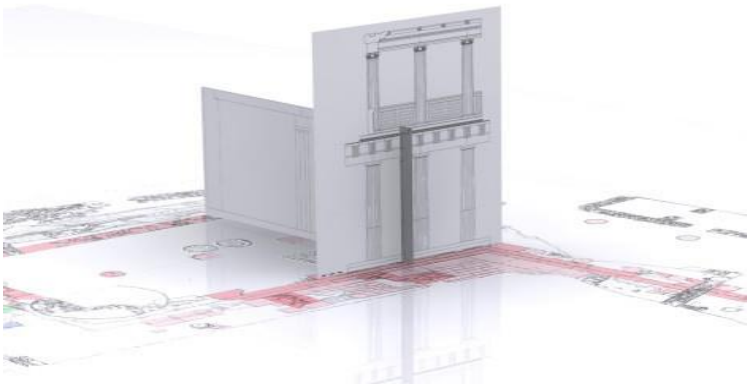

Figure 4.1.2 The 2D reconstruction set on the planimetry

The whole model is finally texturized, using as maps the images acquired on the field of materials used for the edification of the building (fig. 4.1.3).

By interpolating the contour lines extracted from the archaeological cartography of Segesta (Camerata, 1996) it is generated the digital model of the surrounding environment (DTM), to place properly and contextualize the reconstruction of the agora (fig. 4.1.4). The corresponding satellite image derived from Google earth is projected on it as a texture.

Figure 4.1.3 Texturized model

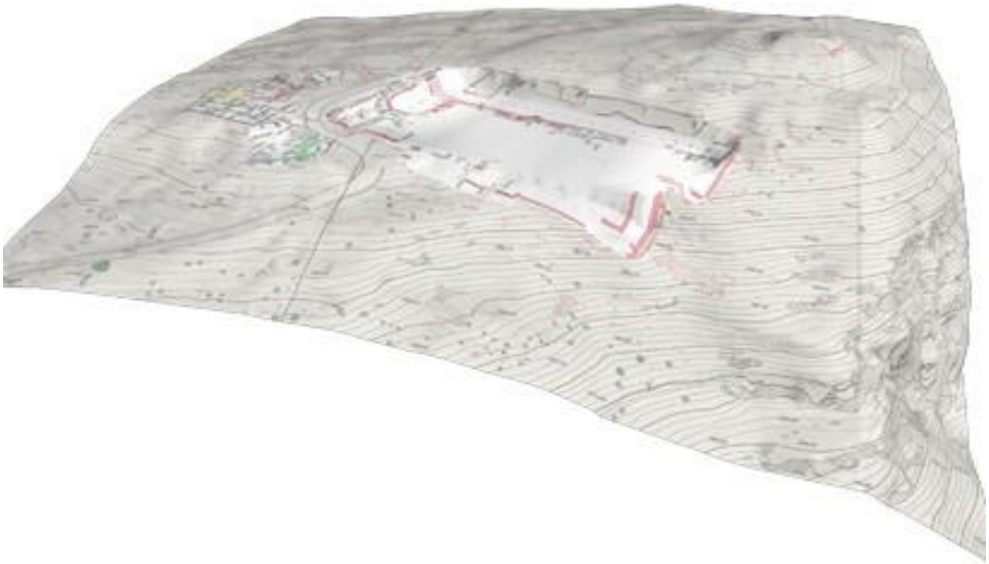

Figure 4.1.4 DTM derived from contour lines

Close-range photogrammetry

Photogrammetry is the science that, using passive optical sensors, allows obtaining metric information of three-dimensional objects by means of the interpretation and the measurement of photo images (Mikhail, 2001). Regarding the agora of Segesta it was performed a semi-automatic procedure defined “Structure from Motion” (SfM).

This method is relatively simple and normally it involves the following steps: camera calibration, images acquisition and pre-processing, images orientation, point cloud generation, generation of the polygonal model (mesh) and texturing (Remondino, 2006, Barazzetti, 2010, Russo, 2012).

In the context of close-range terrestrial photogrammetry a series of convergent shots is acquired, by moving around the object to be surveyed, with an overlap between the images of 60-80% (fig. 4.1.5). It is necessary to calibrate the camera in advance, depending on the software used (in our case Agisoft PhotoScan Professional).

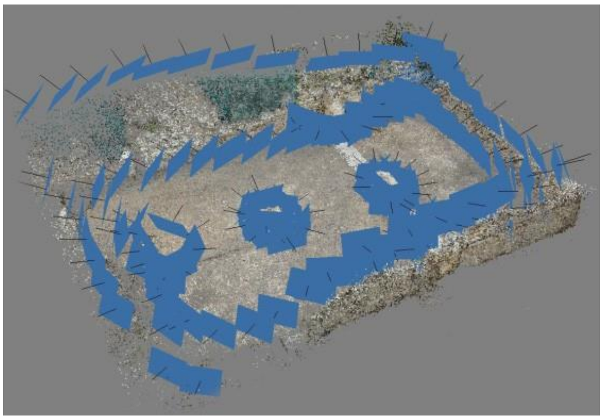

Figure 4.1.5 Photo shoots position

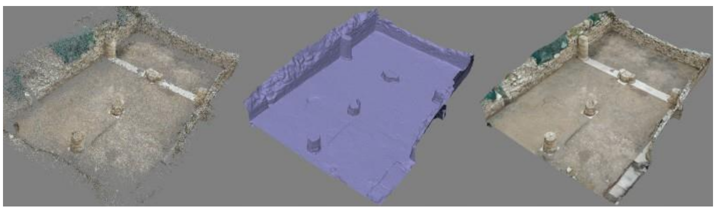

Figure 4.1.6 The 3D model from the point cloud to the textured mesh

Calibration is a procedure for calculating the internal orientation parameters of the camera (focal length, principal point on the sensor and other parameters useful to solve more systematic errors, e.g. those related to the distortion of the lens).

PhotoScan estimates automatically the calibration parameters, but, since the software applies the model of Brown for the radial and tangential distortion correction (Brown Duane, 1971), the automatic calibration works perfectly only for the "standard" optics (i.e., with 50 mm focal length).

Otherwise, if the source data is acquired with ultra-wide-angle lens, the operation is likely to fail, so it is advisable to use the free software Agisoft Lens, in order to obtain the calibration parameters of the camera.

Regarding the image orientation and the point cloud generation, the software detects up to 40000 tie points per photo.

The next step to the point cloud (which it is still a model unstructured) is the creation of the geometric model structured (mesh), of which it is possible to set some parameters (especially the quality of the model and the total number of triangles).

The last step involves the generation of photorealistic texture, and the mesh decimation, if needed (fig. 4.1.6).

The resulting model must be scaled and oriented, by setting a known distance or entering known coordinates both absolute and relative, thanks to ground control points (GCPs) appropriately distributed on the survey area and measured with a total station or a GPS.

Following this 3d reconstruction pipeline, it has been surveyed the southeast corner of the stoa, and created a model whose properties are shown in the table 4.4.1.

Camera	Focal lenght	Images n.	Resolution (m/pix)	Error (pix)	Mesh triangles	Texture resolution (pix)
Sony DSC-W510	4,7 mm (26 mm equivalent)	137	0.0120808	1.15138	4650000	32768x32768

Table 4.1.1: Camera and Model properties

4.1.3 Digital Library

The prototyping of the reconstruction produced a huge amount of heterogeneous data.

It is very important to safeguard these data into a digital library which can be used for the study, the digital files preservation and the further refinement of the hypothetical reconstruction.

The digital heterogeneous database of the agora aims to provide a comprehensive database of archaeological, historical, architectural evidences acquired during the survey campaign used for the virtual reconstruction.

It also contains three-dimensional information as geometric data, textures, materials, models which can be shared by experts with the purpose of develop further hypothesis about the reconstruction of agora.

The database is linked to a virtual reality application, usable in real time, in order to simplify the analysis and the exploration of real data sets in their spatial context.

Users can obtain information about a specific point of interest through some labels positioned in the virtual environment. The interaction provides the possibility to display the scanned 3D model overlapped with the reconstructed model of agora, so the user can make an instant comparison and receive real-time visual feedback.

The information about the different level of consistency adopted in the reconstruction can be retrieved from the database and visualized on the 3D model.

The reconstruction can be based on objectivity, testimony, deduction, comparisons, analogy, and hypothesis data.

The consistency criteria allow users to understand the base of a specific reconstruction (Dell'Unto, 2013).

The database system is based on Research and Innovation for Cultural Heritage (RICH) system (Barone, 2012) ;RICH is an integrated platform for cultural heritage preservation which enabling the management, the enrichment and the sharing of stored data on the infrastructure using distributed storage and web services.

4.1.4 3D Printing and Real-time applications

Advanced 3D technologies have been used as a valuable tool in the formulation of new hypotheses on the reconstruction of the agora of Segesta.

3D Printer

A 3D reconstructed model was printed in order to reproduce the complex geometries and small architectural details.

Because architectural designs are scaled down, details are commonly lost during printing.

To overcome this limit the printed model was realized with an high-definition 3D printer which is able to print thin walls of 0.2mm.

The small details can be of primal importance to a complete understanding of the form of the agora.

The 3D prototype model was prepared using 3D modeling free software as Blender and MeshLab.

After checking the volume, the size, the holes, the normals, and manifoldness, the model was divided into three parts which were printed separately. The choice of dividing the printing allows users to better appreciate the geometric details within the complex structure (Fig.4.1.7).

The agora of Segesta is 51 meters width, 104 meters length and 14 meters height, the scale used for printing is of 1:2000 (25.5 cm, 52 cm, 7 cm).

The printed model is used with augmented reality applications, to enrich the real 3D object with additional information loaded in real time by the database.

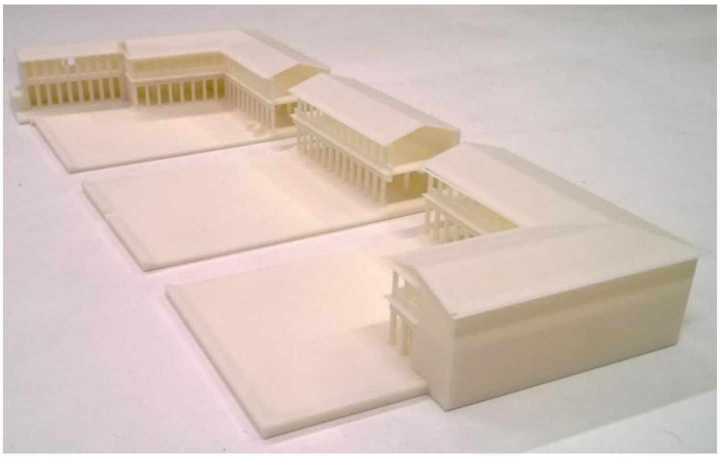

Figure 4.1.7: The printed model

Virtual Reality applications of the agora of Segesta

The creation of a virtual environment on a CAVE-like system has allowed historians to explore the agora of Segesta in a completely natural way.

3D model was simplified in such a way that it can be used for real-time applications.

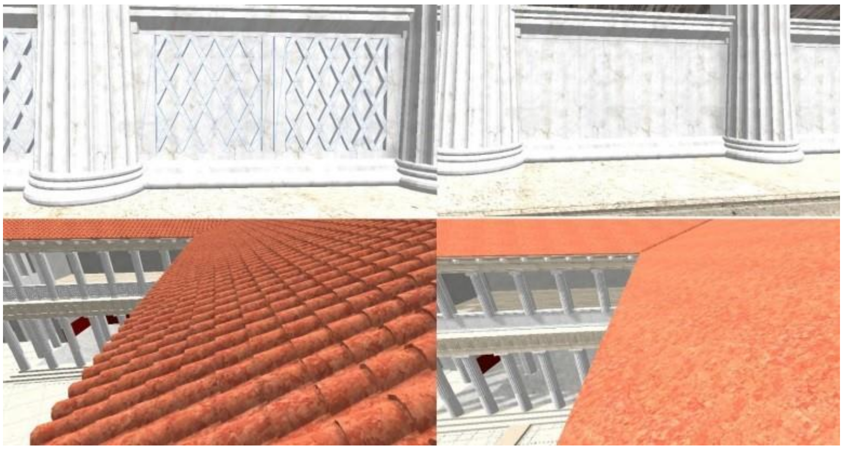

Figure 4.1.8: Comparison between some details of high-resolution and low-resolution model

The model of the agora was composed of about 6 million polygons, a number definitely too high for real time use.

Polygons number was reduced to 600k using reduction techniques such as the decimation of polygons, and scripts for appropriate representation on game engine (Fig.4.1.8).

Surrounding environment was recreated starting from real photos.

The reconstruction was made also on the surrounding area, populated by trees and vegetation, in order to increase a realistic feeling of the virtual environment. The spatial audio allows reproducing the natural sounds of the environment.

The immersive virtual reality applications of the agora of Segesta were developed on Unity 3D Game Engine suitably modified to be used in the CAVE-like system.

By using of the Unity SDK, it has been possible to create a virtual environment that interfaces with very different devices, such as the CAVE, Holographic Viewer and Tablet.

Especially for the CAVE was developed a natural interaction with the agora model, which users can walk as if you were in the Hellenistic age (Fig.4.1.9).

The user movement inside the CAVE is transposed into the virtual environment through an ultrasonic tracker mounted on the 3D glasses.

This application allows to the users to navigate in space and time, observing the agora through its evolution over time.

Figure 4.1.9: The agora in the CAVE- like system

Mixed-reality application

The augmented reality allows overlapping of artificial information on the real world. The Dreamoc mixed-reality display was used to move toward a new form of augmented reality application.

The content for the Dreamoc systems is seen as floating holographic objects inside a pyramid shaped glass chamber.

Dreamoc is normally used as powerful way to showcase commercial products and the public can not interact with it.

An innovative real-time application for Dreamoc XL2 devices was developed exploiting Unity 3D SDK, allowing comparison between the printed model of the agora and the virtual information retrieved by digital library of agora.

In details, users can compare the 3D model of current excavation with the 3D printed reconstruction and interact with the virtual information about agora in natural way through the Leap Motion.

The Leap Motion Controller tracks both hands with high precision, allowing users to interact with the Dreamoc device by waving a finger or hand.

4.1.5 Conclusion

This work is a starting point to create an advance system where experts and specialists can discuss and develop further hypothesis of 3D reconstruction of the original Hellenistic-age building visualizing and managing heterogeneous data in the same immersive virtual environment .

In particular, the model of the agora of Segesta allows users to explore and walk inside the agora, appreciating all its details as in the Hellenistic age and making instant comparisons with the current excavation (the ruin).

An innovative system for augmented reality is proposed for the time evolution study of the agora using a mixed-reality display. This device is also used to project the color information on the printed model.

The results presented from this work were made possible thanks to the continuous exchange of information and expertise between experts and specialists with different background.

It is developing a version of the application dedicated to the virtual reality helmets, like the Oculus Rift, that will deliver a highly immersive and portable experience.

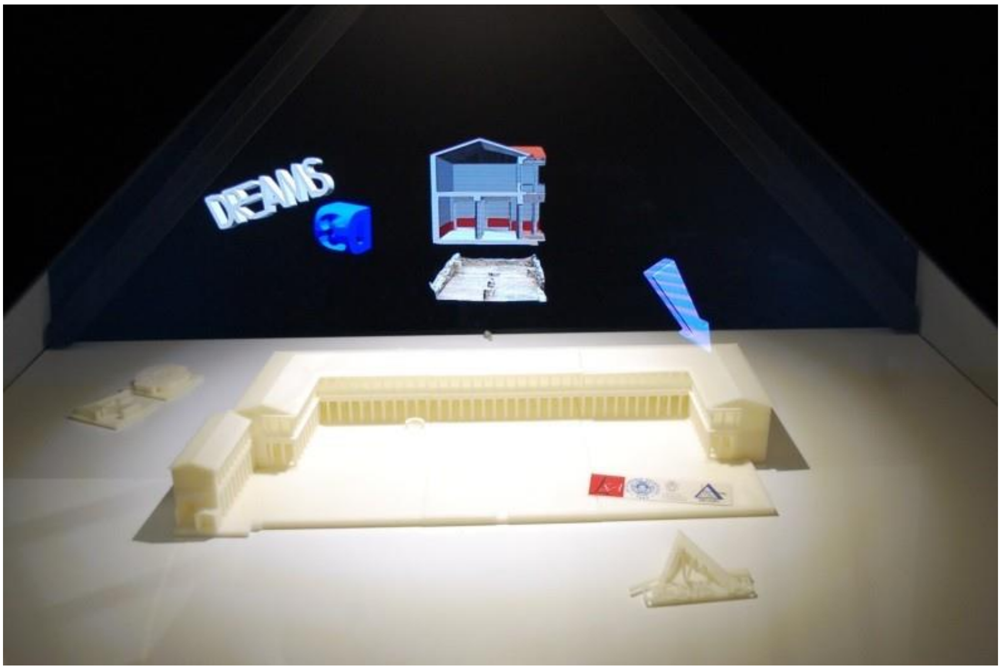

Figure 4.1.10: Augmented reality in Holographic Viewer

4.2 The use of Head Mounted Display in archaeological reconstructions: the example of Haghia Triada

4.2.1 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.

Visualization of scientific data has to 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.

New mass technologies such as smartphones, tablets, or 3D cinemas have established new visualization standard that can be applied to research.

Virtual reality technologies can improve hypothesis assessment, data understanding, and large data analysis by establishing new paradigms of analysis.

4.2.2 Head Mounted Display

A Head Mounted Display (HMD) is usually made 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.

The old HMDs, in fact, were cathode-ray tubes and now are obsolete.

The old tools for Virtual Reality were big and bulky tools, uncomfortable and difficult for the user to understand (Sharples, 2008).

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 market 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 on the outside, all for a much lower price.

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).

4.2.3 Interaction and visualization

Figure 4.2.1: The reconstruction of Haghia Triada on Oculus Rift

In a first project (Albertini, 2014), 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. (fig. 4.2.1)

Figure 4.2.2: Analysis of a scanned 3d find with text metadata

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 high learning step for the user.

With the joypad, movement is now handled through the two analog sticks: the left adjusts the movement while the right is for navigational view.

In conclusion, it's now possible to look around 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.

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

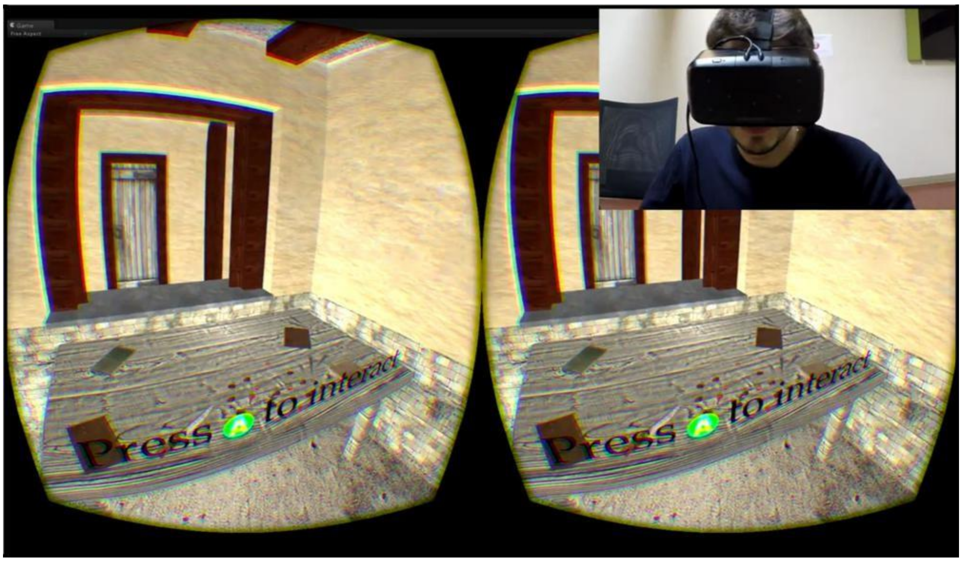

Figure 4.2.3: Interaction through visual interface

4.2.4 Future developments

The application will be implemented with additional content and metadata, where the missing rooms will be contextualized; it will also 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.

A possible implementation consist in the integration of 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 it will be possible 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 gaze.

This would replace the joypad with head movement, moving by observing points of interest and related metadata.

4.2.5 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 available can be explored not through a screen, but directly immersed in the reconstructed context, a factor that makes understanding closer to our perceptual sensitivity.

New reconstructions will be made available to both the general public and experts, with scalable content depending on the skills.

Currently Haghia Triada's site is visible directly within MUSINT (Albertini, 2016).

4.3 A hand-free solution for the interaction in an immersive virtual environment: the case of the agora of segesta

4.3.1 Introduction

Since 2001 the archaeological investigations in the agora of Segesta, in northwestern Sicily, have brought to light a large part of the buildings which bordered the ancient public square (Ampolo, Parra 2012).

In particular, the most interesting acquisitions of planimetric, architectural, and monumental nature are related to a large stoa with two projecting wings, which was built in the Late-Hellenistic period (end of the 2nd century BCE).

The accurate architectural study of the stoa (Abate, Cannistraci 2012) led to the formulation of a hypothetical reconstruction of the vertical development of the building.

Within this articulated monumental complex, during the very last years it has been possible to use new digital techniques of documentation, which have allowed for a significant improvement in the data acquisition phase, in the graphic documentation, and in the following elaboration processes.

4.3.2 Workflow

The 3D models of the agora were created with computer graphics (fig. 4.3.1) and aerial and terrestrial close range photogrammetry techniques, using software like AutoCAD, 3ds Max, Agisoft PhotoScan and Geomagic (Taccola 2012, Olivito, Taccola forthcoming).

The distinction between these two methods is obvious: in the first case, although there were reliable measured data and consolidated studies of the elevations, the buildings been reconstruct as we presume they had to appeared in a given historical period.

In the second case, reality-based procedures have been used use in order to record objects and structures in their current condition.

In so doing, it is possible to enhance the quality of the scientific research on the Segestan public square, improving the level of interaction between user and digital models to be visualized within the virtual environment suitably created for the project.

A Virtual-Archaeological approach

In a first experimental project (Albertini et al. 2014), the reconstruction of the agora of Segesta was imported in Unity 3D Game Engine, using techniques of polygons decimation, but preserving the high resolution textures without compromising the real-time visualization.

The model was implemented in a dedicated application for a CAVE-like System. Within this virtual environment, a "walk" interaction metaphor was developed to make the exploration as natural as possible.

The interaction metaphor, limited to small movements, solved the conflict between a very large virtual environment (100 meters ca.) and the actual environment of the CAVE, that is much smaller (3 meters) (fig. 4.3.2).

Figure 4.3.1: 3D model of the agora within the CAVE

Overall, the interface ensures excellent functionality and immediacy of use.

Obviously, this 3D reconstruction, realized with computer graphics, has positive and negative features.

As to the positive ones, the possibility to visualize and walk within the virtual environment allow to think about issues that are hardly investigable by using traditional 2D tools.

For instance: possible solutions adopted in the carpentry; physical and spatial relations between the stoa, its internal space, and the other monuments of the public square; relations between architecture, decorations, and documentary apparatus (e.g. statues and inscriptions); peculiar functions of the different sectors of the agora; the role played by natural and artificial lighting in different moments of the day.

On the other hand, this model was firstly conceived as a reconstruction more than a simulation (Clark 2010), with a limited level of interaction.

As a result, at present, it neither allows to extrapolate or draw in real time information and data from the visualized elements, nor can be continuously modified.

A Cyber-Archaeological approach

With the most recent techniques used during the fieldwork activity and in the labs, a new approach was proposed, mainly oriented towards simulation and Cyber-Archaeology, as suggested by literature (Forte 2010, Forte 2012).

In this sense, the 3D model of the agora could represent a basis for further studies or, quoting Jeffrey Clark, a Simulation Slice.

The starting point of this new research methodology is constituted by the introduction of techniques of close range photogrammetry, both aerial and terrestrial, used for the real- time documentation of the fieldwork activities and the digital drawings of the elements discovered during the excavation (Dell'Unto 2014).

As to the aerial photogrammetry, in the case of the agora of Segesta a MikroKopter Hexacopter UAV was employed, for whom an automatic flight plan was set up (fig. 4.3.3).

The survey of the whole area of the stoa has required 3 flights, with a totalof 664 shoots.

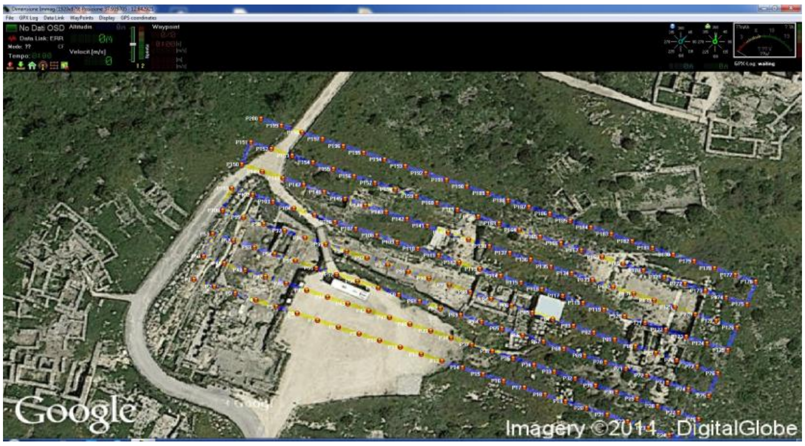

Figure 4.3.2: Flight plan for the aerial photogrammetry

The images acquired were turned into a 3D model of the entire agora, which constitutes the necessary basis for the positioning and alignment of all the surveys created with SfM terrestrial procedures.

In fact, an appropriate number of GCPs was positioned and measured with total station to obtain the coordinates relative to the reference system used within the area of excavation.

During the last campaign of excavation on the site of Segesta, 6 image-based models were created (fig. 4.3.4), following the progressive development of field activities.

The excavation levels include the most superficial layers, up to the traces of medieval re-occupation of the area and those relating to the collapse and abandonment of the Late-Hellenistic stoa.

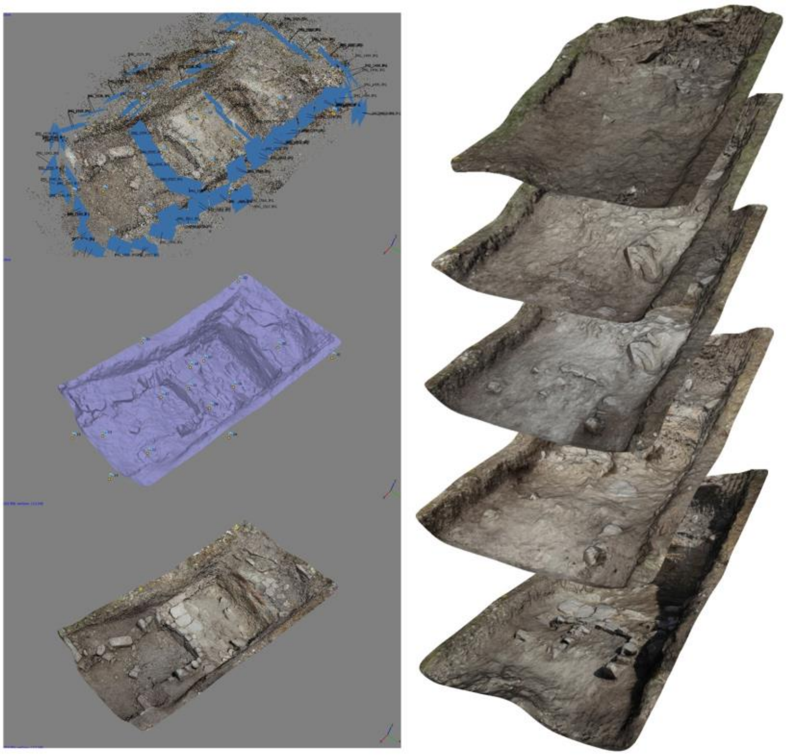

Figure 4.3.3: Some of the image-based models realized during the fieldwork activities

Each 3D model consists of several stratigraphic layers. In this first phase of the fieldwork, the nature of the stratigraphic deposit, simplified and uniform, did not required a work of semantic segmentation within the single model.

However a first segmentation process has been started and will be enhanced in the next campaigns.

At this stage, the selection of the isolated elements has been entirely subjective and based on the needs of the research activity but also on the simplified stratigraphic features of the archaeological context.

As a result, in the case of the new application, individual and separated models of two meaningful elements were realized: a limestone ionic geison (or dripstone) of the second floor of the portico, that was discovered during the excavation of the collapse layers of the stoa; and a medieval well-preserved oven of the Svevian period (fig. 4.3.4).

Figure 4.3.4: Image-based model of a medieval oven

The time required on the field to achieve a single model was about 20 minutes, including the acquisition of approximately 60 images for each level and the measuring of Ground control points with total station.

The application

Similarly to the 3D model of the agora realized with computer graphics, a virtual environment was created, in which the image-based models were loaded with Unity 3D Game Engine.

Although still in progress, the application used to display and interact with models has already positive aspects, both from the scientific and technical point of view.

In the first phase the issues related to hardware were addressed, trying to figure out how to best use the tools of tracking.

A support for glasses was modeled and printed in 3D, allowing for the use of an ultrasonic sensor and hand position sensor at the same time (fig. 4.3.5).

Figure 4.3.5: 3D glasses with the mounted leap-sensor

In fact, the use of the sensor applied on the user's head is not standard, since it has been designed to remain on a flat surface.

Despite this, the device is used in a non-invasive way, thanks to the compactness and light weight of the Leap.

In particular, some of the new features of the 2.0 sdk leap sensor were employed as, for example, "automatic orientation", which allows for the automatic correction of the orientation of the hands, and "image acquisition", which allows for the use of the images that come directly from the infrared cameras in addition to the raw data tracking.

At this point start the study phase of 3D interface and gesture linked to the exploration of the layers of the excavation.

The process of creating a gesture is structured as follows:

- Creation of base gestures (fig. 4.3.6): analysis on raw data input provided by the "leap sensor" and improvement through algorithms for data interpolation. Analysis of the data already processed and programming of "gesture base" (as the rotation of the hand, swipe, grab, etc.).

- Creation of Complex gesture (fig. 4.3.7): merging multiple "gesture bases" were created interactions in the environment, such as touch and rotation of objects, scroll and analysis between different archaeological data, etc.

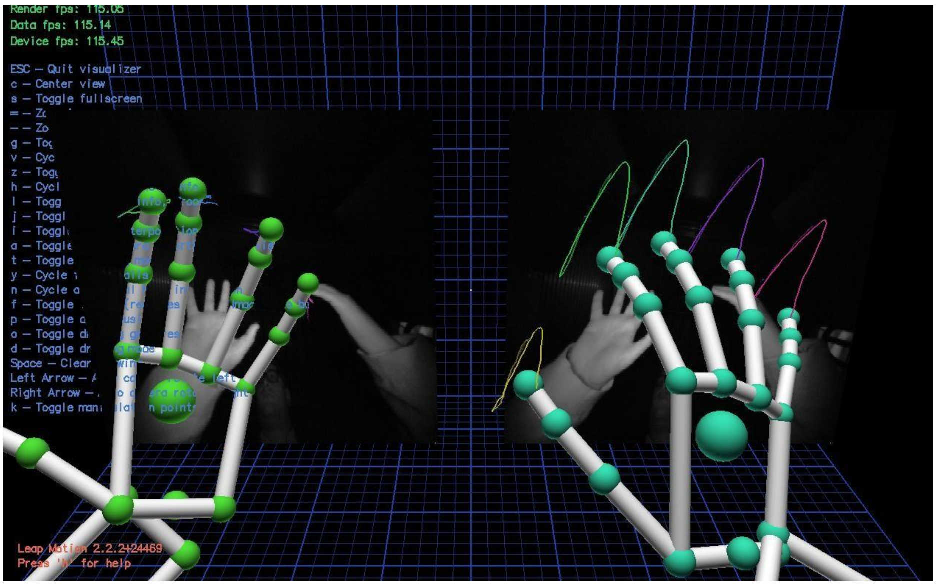

Figure 4.3.6: Snapshot of the creation of base gestures

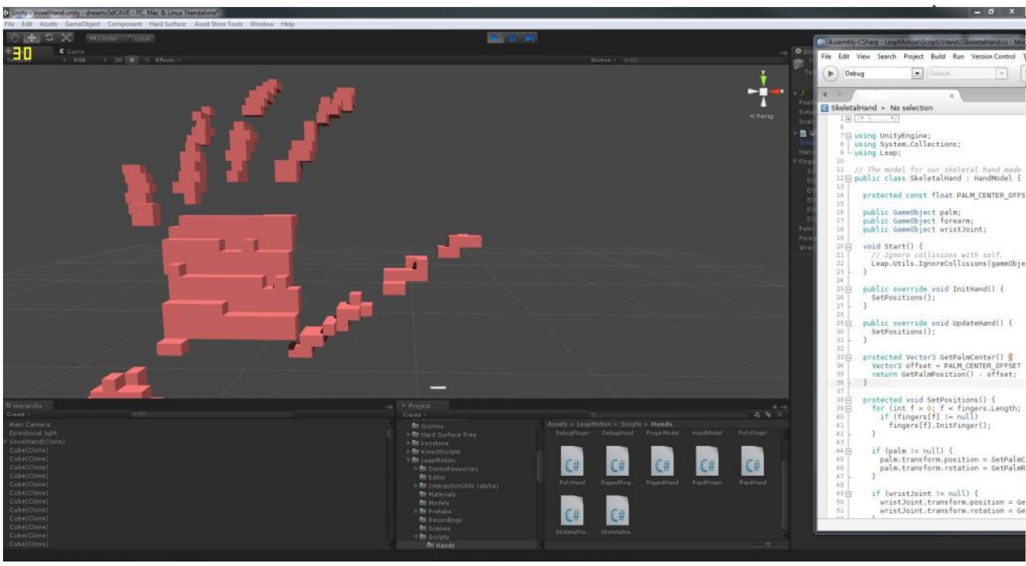

Figure 4.3.7: Snapshot of the creation of complex gestures

- Evaluation: study of gesture designed to understand which would allow better interaction with the data at a theoretical level, according to usability principles redesigned for the 3D world (understanding of the interaction, ease of use, effectiveness, etc.).

- Implementation (fig. 4.3.8): implementation of gestures valued as realizable in the virtual environment through dedicated script. A plugin for the game engine was developed, that allows to change the gesture with a graphical editor.

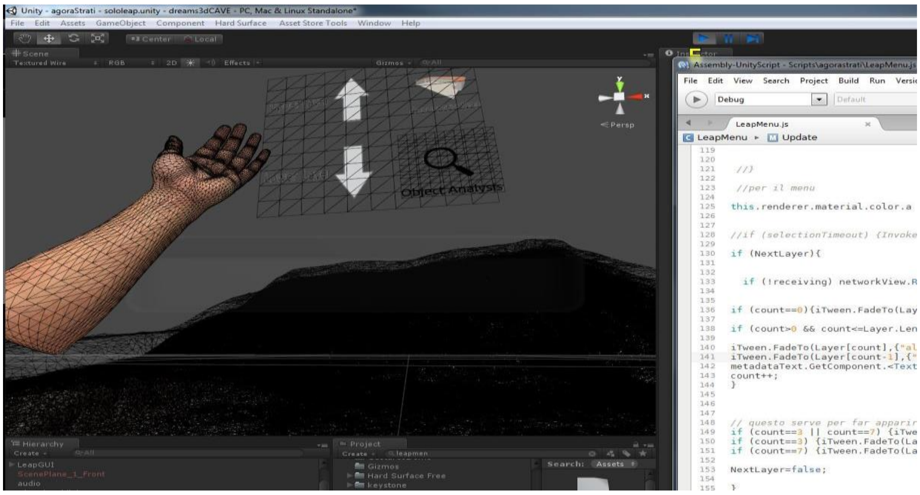

Figure 4.3.8: Snapshot of the Implementation phase

- Study of user behaviour (fig 4.3.9): testing phase on different users with different skills to analyze the actual effectiveness of the gestures. Through a real-time feedback the gestures were corrected and revised according to the behaviour of the users.

Figure 4.3.9: Snapshot of the study of the user behaviour

- Review: revision of gestures based on user experience and new cycle evaluation, implementation and study of user behaviour.

Through this process it was possible to remove all the gestures too complicated for the device (for example pinch to zoom or rotate with the fingers) or too complicated for the user (gestures tiring or unnatural), thus implementing an interface the most natural and efficient as possible.

4.3.3 Results

The purpose of the new application is to enhance the number and quality of functions that the operator can use and, as a consequence, the embodiment within the virtual environment.

For this reason special attention is paid to the gestures available in the simulation.

In particular, the application aims at improving the level of interaction between users and virtual environment, thanks to the possibility to visualize the perfectly overlapped and aligned digital models of the stratigraphic sequence realized during the fieldwork activity, to scroll between them within the virtual environment, and to query and interrogate the relative metadata only with hand-gestures (fig. 4.3.10)

The interface which has been realized is usable in a natural way, by hand movements. This makes the application friendly and easy to use.

At this stage, the control of gestures is limited to one user, whereas the visualization in the virtual environment is multi- user (3 or 4 people depending on the size of the CAVE).

As to the leap, the detection of the position of the hand is very accurate, due to a lightweight and non-invasive device. Obviously there are some features still to be developed, such as the possibility to increase the number of users that can interact through gestures.

Nevertheless, these problems will be overcome with the introduction of wireless hand trackers that will make simpler to perform gestures in the virtual environment.

At the same time, the introduction of the new tracker will increase the level of complexity of gestures, such as the rotation of the models or the measuring of distances, areas, volumes and so on.

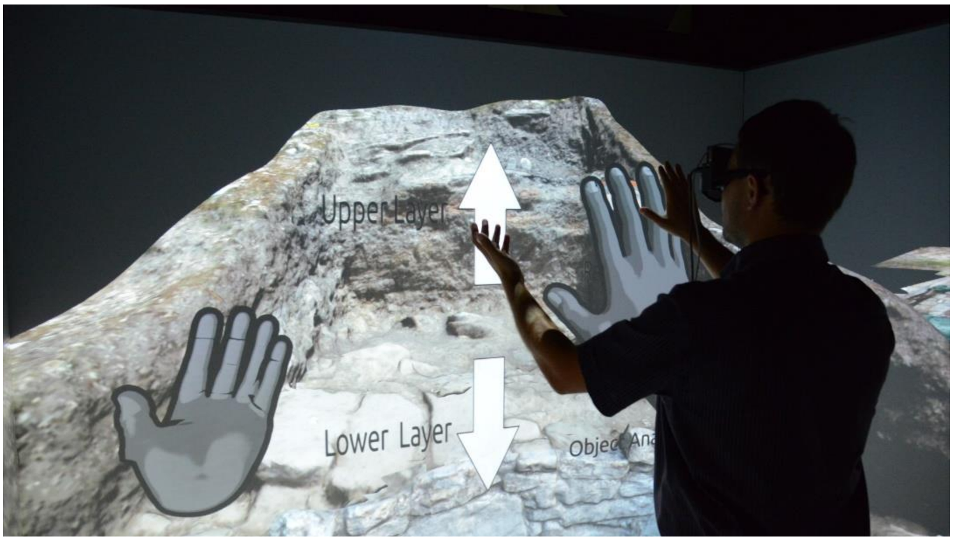

Figure 4.3.10: The new application within the CAVE

A further element that has been tried to solve is the difficulty to visualize large amounts of text and metadata in the virtual environment (for instance records of the individual layers, records of architectural elements and artefacts found during the excavation).

In fact, only the essential information, such as the layer number, the date of acquisition, or a brief description of the main objects visualized, are displayed within the CAVE.

However, the problem of the analysis of large amounts of data was solved by creating links to the metadata that can be viewed through additional gestures.

The links connect to the database used in the phase of data collection, allowing for the examination of layers records, text files, and information on finds and objects visualized inside the CAVE, but on an external device (for instance tablet).

In this way, the different users may view the models and at the same time interact directly with them, acquiring information on individual elements or modifying in real time the interpretations of the excavation data.

With regard to the models of the main objects found in the archaeological levels, both these elements were isolated within the single layers and perfectly overlapped into the stratigraphic sequence.

Then, thanks to an interactive icon that appears only when the elements are visualizable, it is possible to pop up the models, rotate them, and zoom-in for a closer view of the objects.

Due to the future and obvious increase of the number of models, an extension of the natural interface will be introduced allowing for the rapid selection of single layers and for a quick browsing of the stratigraphic sequence.

In this sense, an excessive semantic segmentation would involve the creation of a large amount of data and, consequently, a larger complexity of the database to be managed within the virtual environment. Nevertheless, this is still an open question that will require further and wider reflections, both from the theoretical and the technical point of view.

4.3.4 Conclusions

In studying the agora of Segesta we can now rely on a 3D model that allows to have a more articulated and interactive idea of the ancient square and its buildings at the end of the 2nd century BCE.

As a result, it is possible to shed new light on issues of great importance such as physical and spatial relations between objects and monumental context; internal and external visibility; relations between open and closed spaces; lighting inside the building.

This 3D model is enhancing a better scientific knowledge of the Segestan agora and a wider dissemination of the collected data to both the experts and the non-experts.

At the same time, although in the development phase, the new application allows to reach a higher level of interaction with the digital models, to interrogate them, visualize the metadata available for the single items, and, due to the hand-free nature of the application, to use external devices in order to examine records and texts while staying inside the CAVE.

In so doing, it will be possible to virtually reproduce the field-work activity, working in an autonomous or collaborative way.

Among future, the main task will be the improvement of the quality and quantity of visualizable models and data; in addition to this, and aware of the limits of devices such as the Oculus Rift, the possibility to use this approach on this kind of device is evaluating, the final aim being a further reduction of the gap between the phases of data collection and elaboration, and that one of interpretation, even during the fieldwork.

4.4 Designing natural gesture interaction for archaeological data in immersive environments

4.4.1 Introduction

We say archaeology and we think of history and events.

We see ancient remains and we imagine palaces and battles, involving historical personalities and entire nations.

Studying and working in this field opens the fantastic opportunity to travel back in time but also to be immersed in a very complex environment, made of pictures, numbers, remains, books and places, where hypothesis and research are driven by details.

As scholars, we could see this huge amount of data as a heterogeneous database, strongly interconnected with and linked to their representation. The growing amount of scientific information creates problems of interpretation and understanding which are often solved by using graphical methods, since the human brain activates one-third of its neurons when processing visual information.

Manipulating and visualizing this kind of data has always been a limiting factor in research and scientific history is full of new graphical conventions enabling new perspectives and understandings of data.

Given the increasing computational and graphical power of modern computers, the focus of research has been shifted from 'how to represent' to 'what should be represented', in every research field, from engineering to chemistry, from cultural heritage to medicine (Brickmann, Exner, Keil, & Marhöfer, 2000).

Archaeology is a field that more than others may take advantage from this innovation.

Imagination may leave space for exploration, if we can efficiently transfer data from an excavation or other research to a virtual reconstruction.

This process has to start from scholars, defining their needs and the limit of the available tools, and giving directions to technicians for designing solutions.

In particular, our ability to understand the archaeological materials relies on our ability to interact with and manipulate them.

The theory of embodied cognition (Kirsh, 2013) stresses the importance of our interactions with the world in our cognitive understanding of it. The ability to rotate an artefact in our hand helps us to see it better from different perspectives, the ability to hold a tool helps us to understand how it can be used.

Relative to our ability to manipulate physical artefacts, our manipulations of virtual artefacts are very unnatural and poor: indirect rotation via sliders and buttons and limited degrees of freedom.

This case study presents a virtual reality representation of archaeological data that includes a gestural interface that enables researchers to interact with data immersively, using their hand movements, without the intermediary of desktop interface devices such as mice or touch screens.

This work comes straight from archaeological researchers and their curiosity toward virtual technologies.

The idea is to transfer actions from the excavation to the virtual environment, without going through the desktop computer.

The aim is not to have buttons and sliders in 3D, a virtual replica of the desktop interface, but placing the archaeologist in a working replica of the excavation area, where they can access and manipulate the data, edit and consult information, moving around the reconstruction and the actual area.

A very important issue will be to design such interactions with these virtual reality representations in a way that they feel natural and familiar to archaeologists, in their imaginative concept of acting on the excavation area.

A key aspect of our system is that the process of gesture design is very rapid, involving recording one example of each gesture (though they may be re-recorded to refine the interface after testing).

This makes it possible to record highly personalised gestures for each individual using the system and so adapt it to ideosynchratic ways of working, cultural differences or disabilities.

This case study describes the whole design process leading to the prototype application, used by the archaeologist to access the excavation data from inside the virtual reconstruction of the site, visualized in 3D in a CAVE-like system (Cruz-Neira, Sandin, Defanti, Kenyon, & Hart, 1992).

An innovative gesture recognition library has been used for letting them record and re-use natural and simple gestures for the tasks they designed.

Motivations

The aim of the application is to contribute to the development of a new approach to the exploration and analysis of stratigraphic archaeological data.

The application represents a further step in an already existing project, which is now enriched by new and more elaborate interaction tools, based on the requirements and practical experiences of archaeologists.

The first experiment was in fact based on a leap-sensor attached to a pair of 3D glasses, to be used within a CAVE-like system.

This enabled interaction with the models through an interface consisting of a small set of gestures (Olivito, Taccola, & Albertini, 2015).

Although activated by hand movements, the gestures looked quite artificial because the user had to continuously interact with a selection menu, which mimicked a desktop or touch-screen interface.

In addition, since the 3D glasses and the leap-sensor were not wireless, they severly limited the freedom of movement within the CAVE.

In this new phase, thanks to a new wireless tracking system, it has been possible to develop hand gestures only by using 3D glasses and movement trackers.

The design of the gestures and their functionality is the result of a continuous debate between archaeologists and system developers, whose main goal has been to satisfy two specific requests by the archaeologists.

On the one hand, to use a limited set of gestures that is easily memorizable because they are natural.

On the other hand, to reproduce through these gestures the movements an archaeologist usually carries out, not only during the field activity but also in the cognitive process activated during the excavation and the interpretation phases.

The case study is the agora of Segesta, in the north- western corner of Sicily, Italy.

Here, archaeologists have discovered the remains of a huge Late-Hellenistic portico (stoa) which bordered the ancient public square of the city (the north side was 82 m long ca., the west and east side were 20 m long).

In May 2014, during the three- week campaign of excavation on the site, archaeologists started a project of photogrammetric documentation of the digging activity.

In the first phase of this project six 3D image-based models of the stratigraphic sequence were created, following the progressive development of field activities.

The excavation levels included the most superficial layers, up to the traces of medieval re-occupation of the area and those relating to the collapse and abandonment of the late Hellenistic stoa.

The complexity of the stratigraphic sequence and the architectural context represent an excellent field test for the different requirements and questions that an archaeologist has to deal with during the research.

As a consequence, although the case study does not fill the full range of possible interactions, it still constitutes a valid basis that could be applicable to all the contexts in which a stratigraphic investigation is carried out.

In this sense, the application aims at supporting the traditional tools used in the archaeological field, so as to enrich the interpretative process due to the use of 3D data and to simulate the activity of excavation, which is by its nature destructive.

It does this while operating within an immersive virtual environment that allows for full embodiment and interaction with the digital models that is as natural as possible.

A further benefit is the possibility of re-creating, from an emotional and perceptive side, the mental dynamics which an archaeologist processes during the field activity and after.

This can help to validate, re-examine, or even modify the interpretations elaborated in the very moment of the excavation, so as to fill a gap that traditional tools leave open.

4.4.2 Background

Virtual reality (VR) for archaeology

Usually, in the archaeological practice, the data related to the excavation are managed by 2D investigation, collection, and consultation tools. The use of 3D image- based recording procedures, facilitated by easy-to-use and low-cost software (even open-source) has increased.

This has recently stimulated a wide debate on the necessity to employ, in addition to traditional tools, a new methodology able to take advantage of all the possibilities offered by 3D acquisition methods, particularly by interacting with them in real time (Pietroni & Pescarin, 2010; Pietroni & Rufa, 2012).

This approach, known as Virtual- or Cyber- Archaeology, has produced some very interesting examples (Forte & Siliotti, 1997; Forte, 2010; Forte, 2014).

Among these, is the case of Çatalhöyük where a team from Duke University conducted investigations in which 3D documentation played a key role.

The result of this activity is available on different levels of interaction and immersion: by using portable devices that allow users to visualize and interact with the models in 3D (i.e. Z-space and Oculus Rift), but especially by using a 3 x 3 x 3 m CAVE-like system in which the user can interact with the models by a "magic wand" interface.

Although the application aims at continuing the work that was begun with the case of Çatalhöyük, nevertheless it is significantly different from the above- mentioned case study.

Indeed, our application is almost exclusively based on natural hand gestures which do not require any further device, apart from 3D glasses and hand-tracking sensors.

As a result, other digital devices (e.g. tablets) can be handled by the user during the activity within the virtual immersive environment.

Natural interaction in VR

VR and 3-D visualization enable researchers to perceive data in new and more natural ways.

In some cases,graphs are better than tables, and different graphs emphasize different aspects of the same dataset.

It all depends on what data we are observing and what we are looking for in the data.

3D data should be easier to understand if visualized in a tridimensional and stereoscopic system.

An immersive visualization adds new modalities to the perception of data, adding to sight the proprioception of our own body (Taylor, 2009) and inducing natural reactions during the exploration of the virtual objects (Lackner, 1988; Brogni, Caldwell, & Slater, 2011).

This will help to recognize shapes and dimensions, distances and spatial relationships between elements of the scene, bringing our space perception closer to everyday reality.

In the case of archaeology, for example, seeing an artefact in a 3D reconstruction and comparing it with others, is more intuitive and efficient than watching pictures or columns of numbers.

The whole design should enable researchers to understand the data and test hypothesis, acting with a focus on the task itself and not on how to perform the task.

Motion capture devices improve the capability of virtual reality systems, in terms of performance and affordability, enabling so-called natural interfaces: interfaces that are effectively intuitive and easy to learn, but transparent to the user.

Natural interaction does not mean 'interacting in a human way' or 'imitating the physical world,' but it means designing an interaction that is going to be invisible and effective for the user in the task they are working on.

Gestures and hand manipulations are actions that we perform every day without thinking, and in many cases, they can be far more effective than traditional computer interfaces.

For example, to rotate a 3-D model, it is more 'natural' (and effective) to grab it with the user's hand, rotate it, and perceive the rotation with their proprioceptive system, than to use a slider or other interface widget.

The user's experience of doing similar actions every day will help make the interaction more effective and quick to learn.

Merging 3-D stereoscopic visualization and natural interaction could bring enormous advantages in different areas, where the visualization and the perception of data are important for the results.

A key part of this is allowing users to interact with the visualized data in real time in a natural and comfortable way.

Being able to switch between different representations, highlight specific features, hide the less relevant aspects and interactively compare different datasets (or different representations of the same entity) helps the processes of understanding and insight.

Gestural interaction

Physical gestures and actions are a natural way to interact with our external environment.

However, designing gesture interaction still involves important challenges such as defining a relevant and application- compatible gesture vocabulary, as well as designing an accurate gesture recognizer that allows for taking into account expressive components of the performed gestures.

Gesture design

Gesture design has been investigated following two distinct approaches. The first approach is designer- centered.

Previous works consider ergonomics and technical constraints (Nielsen, Störring, Moeslund, & Granum, 2003).

Ergonomics form the underlying metrics for characterizing ballistic movements like pointing (Grossman & Balakrishnan, 2005) or reaching (Nieuwenhuizen, Aliakseyeu, & Martens, 2010).

Specific features of recognition systems can steer the design of gesture vocabularies to guarantee high recognition success rates (Nielsen et al., 2003). The second approach is user-centered.

Long, Landay, Rowe, & Michiels (2000) asked users to rate similarity between shape-based gestures to define a vocabulary avoiding ambiguity.

Wobbrock, Morris, & Wilson (2009) asked participants to perform gestures corresponding to a given command in order to arrive at a tabletop gesture vocabulary. Kane, Wobbrock, & Ladner (2011) sought to better understand the difference between gesture vocabularies created by sighted and blind people. Bragdon, Nelson, Li, & Hinckley (2011) extend this approach by looking at environmental demands on attention. Ouyang & Li (2012) have developed an evolving gesture library collected by a large user population.

A key challenge for gesture design is variability between people.

People may perform gestures in different ways for a wide variety of reasons.

These might be due to physical characteristics such as body shape or gender difference as well as different levels of physical ability due to age or disability.

Difference might also be due to non-physical factors such as learned idiosyncratic ways of performing gestures.

One approach to handling variation is to have a sufficiently general set of gestures (and a sufficiently general recogniser) that most people are able to do them.

However, these general gestures might not be confortable for all people. Also, there may not be a single gesture that is applicable to all people. Gestures can be highly culturally specific: a vertical head nod might be an appropriate gesture in most western countries but a very different gesture is used in India.

Also, a type of gesture might be impossible for people with certain disabilities, and they might require a very particular gesture performed in a particular way.

For this reason it is often better to allow easy personalisation of gestures by individuals.

Gesture recognition

There exist a number of techniques for gesture recognition.

Template-based methods typically rely on a single exemplar in order to define a gesture class.

These include Dynamic Time Warping, the $1 Recognizer (Wobbrock, Wilson, & Li, 2007) and $N Recognizer (Anthony & Wobbrock, 2010).

These methods are mainly used in systems designed to recognize simple shapes and are not robust to noise and missing values.

Methods based on machine learning make use of multiple examples to derive gesture classes handling uncertainties within such classes due to different types of noise.

Established methods include Hidden Markov Models (HMM) (Lucchese, Field, Ho, Gutierrez-Osuna, & Hammond, 2012) for time-dependent signals and k- Nearest Neighbor (Varona, Jaume-I-Capò, Gonzàlez, & Perales, 2009; Gillies, Kleinsmith, & Brenton, 2015) or Support Vector Machines (SVM) for static pattern.

A training procedure is needed to estimate model parameters that fit best the data. Building up comprehensive databases, however, are time-consuming and are not well suited for user-centric approaches.

Gesture recognition methods that use a single template for all people provide little possibility to personalise gestures.

Machine learning methods allows for variation by generalising from a large data set of people performing a gesture.

However, these datasets can still be biased and limited, for example, to a data set trained on North American people might not recognise Southern European gestures.

Nor will a general database be able to adapt to the specific requirements of a disabled person.

This kind of personalisation requires a method that allows rapid learning of a gesture from few, or even one examples.

Template methods such as the $1 Recognizer (Wobbrock et al., 2007) and $N Recognizer (Anthony & Wobbrock, 2010) allow for this, as do methods such as Caramiaux, Montecchio, Tanaka & Bevilacqua's (2014) Gesture Variation Follower (discussed below).

Most recognition systems output however results in discrete time, typically upon gesture completion.

There are some systems that continuously report estimation on gesture classes or characteristics (Mori et al., 2006; Bevilacqua et al., 2010), allowing for prediction and "early recognition" meaning that the ability to recognize before the end of the gesture execution.

Still, all these methods considered variation in input data as variability, in other words noise.

For example, Varona et al. (2009) normalise gestures on a number of dimensions to eliminate variation.

However, variation is a key feature to allow for user-center approach in gesture interaction design as it allows for exploration.

Adaptation procedures that modify the class description during recognition having been described for both template- based methods (Kratz, Morris, & Saponas, 2012) and those using statistical learning (Wilson & Bobick, 1999; Wilson & Bobick, 2000).

Some work makes direct use of gesture variation in the interaction process (Wilson & Bobick, 1999; Fdili Alaoui, Caramiaux, Serrano, & Bevilacqua, 2012).

These approaches remain largely unexplored and confined to the study of gesture in subjective art performance contexts.

A recent promising approach has been proposed in Caramiaux et al., (2014) where input gesture variations are explicitly taken into account in the model and estimated continuously while the gesture is performed.

This method is called Gesture Variation Follower (GVF) and will be further detailed in Section 4.1.

Participatory design

The approach used in this work is inspired by User Centred Design and in particular Participatory Design (Muller & Kuhn, 1993).

User Centred Design (Norman, 1990) is an approach to designing technology where the needs of users are the key driving force behind any design decisions.

Participatory design is an approach to achieving this by directly involving users throughout the process.

Participatory design is key to multidisciplinary endeavors like digital heritage because it ensures that stakeholders like archaeologists are able to determine the design of their tools, even if they are eventually implemented by computer scientists.

Participatory design generally involves working directly with users in workshop settings to create example designs.

However, it is currently difficult to create real software prototypes in this way as users do not have the implementation skills and developing software takes a long time, so design ideas are generally limited to paper sketches that capture the look of a graphical user interfaces but do not have the feel of a full interactive system, and certainly not a virtual reality one.

A variety of techniques have been used to get over this problem.

Expressing designs in terms of a video can capture more of the feel of interacting with a system (Mackay & Fayard, 1999), but do not allow for actual interaction with the prototype.

Generic interfaces can be used as a "design probe" (Tanaka, Bau, & Mackay, 2013), which can encourage users to think about different modes of interaction, but are still limited to the capabilities of the object.

Rough mock ups and wizard of oz prototypes allow for what Buxton calls "User Experience Sketches" (Buxton, 2010), but may not have the feel of a real interactive system.

Recent advances have made it possible to do interaction design in real time so that it is possible to create working prototypes of novel interfaces during participatory design sessions.

They key enabling technology has been Interactive Machine Learning (Fiebrink, Cook, & Trueman, 2011), the use of statistical machine learning algorithms to allow users to design interactive systems by giving examples of interaction rather than by programming.

This has the advantage that the creation of the system can be much quicker and that it can be done by end users who do not have programming skills.

This makes it doubly suited to use in participatory design sessions.

Caramiaux, Altavilla, Pobiner & Tanaka (2015) have successfully used interactive machine learning during participatory design sessions for novel sonic interfaces.

4.4.3 The gestural interface

Gesture Variation Follower

The Gesture Variation Follower is a technique able to recognize which gesture is being performed and how it is performed (Caramiaux et al., 2014).

The former feature is called realtime recognition (or early recognition), the latter adaptation.

These two features have been specifically designed in order to enable both discrete and continuous interactions.

In practice, GVF relies on two successive phases: a training phase and a recognition phase.

In the training phase, the user provides the system with a set of gestures to be recognized.

Each gesture is given through a single example, making the training of the system simple and light.

Once at least one gesture example has been recorded, the user can switch to the recognition phase.

In this phase, the user's performed gesture is recognized as being one of the recorded example and variations with respect to the recognized example are estimated.

The current implementation of the GVF accepts free space gestures given by their positions and adapts to both temporal and geometric variations.

The temporal variations are: the real-time alignment of the performed gesture onto the recognized example; its relative speed with respect to the same example, an estimated speed equal to 1 means that the performed gesture has the exact same speed at that moment than the example.

The geometric variations are the relative scales (along each axis) and orientations (three angles of rotations for free space gestures).

Therefore, estimated scale equals to 1 means that the gesture has the same size as the recorded example.

GVF relies on a tracking formulation of the gesture and its variations.

The tracking formulation involves latent variables and observable variables.

Latent variables represent the gesture identifier, position, speed, scale and orientation.

Observable variables are the value of the incoming gesture given by the motion capture system and a non-linear function links observable variables and latent variables.

The goal is to estimate in realtime the latent variables.

To do so, a Bayesian formulation of the tracking problem is proposed in order to take into account uncertainties stemming from the noise in capturing the data and the uncertainty in the hypothesis of the model.

Therefore, instead of estimating the values of the latent variables, were estimate a probability density function (PDF) over its possible values.

Several techniques exist to estimate such probability density in real-time, in the current implementation in GVF were use particle filtering.

Particle filtering is a way to estimate a complex probability distribution of a random variable by sampling a large amount of the variable's potential values and by weighting each of these values according to a given likelihood.

Virtual reality gesture design tool

The GVF algorithm was used to develop an interface for designing gestures in immersive VR.

The interface was implemented in the Unity3d game engine and used within a CAVE-like immersive VR system.

Users' hand movements are tracked using an Optitrack optical motion capture system that is situated inside the CAVE and whose coordinate system is aligned with that of the CAVE.

The choice fell on Optitrack because, compared to other systems (such as Kinect), it is much more accurate.

In addition, it provides an application which gives the tracking data directly, without the need to interpolate between the various cameras that would serve to cover the entire area of the CAVE.

The position and orientation of each hand is used as input to the GVF.

Each hand is represented as x,y,z coordinates of position and x,y,z Euler angles for rotation resulting in 6 dimensions per hand and therefore 12 dimensions overall.

A single 3D scale and rotation is estimated for each gesture and applied to both hands.

The aim of the design tool was to make gesture design and personalization as easy as possible, with users only having to record a single example of each gesture.

This enables each user to design and perform gestures in a way that is most natural and comfortable for them and avoids the problem of trying to build gesture vocabularies that generalize across different individuals, professional specialisations, cultures and physical abilities.

Visual feedback is provided to users in order to support them in training and using gestures.

Gestures are represented as graphical trails as shown in Figure 4.4.2.

These visualizations aim to support users in recording gestures and refining the gesture interfaces, as described below.

The gesture design process consists of a number of steps:

1.<u>Recording Phase</u>: Users are able to record an example of each gesture they wish to perform.

As they record a gesture for the first time, a graphical trail is displayed in 3D, following their hands (Fig. 4.4.1).

This allows them to see the overall shape of the gesture.

Once the gesture has been recorded, a thumbnail is created (Fig. 4.4.1).

This is a small version of the trail that is displayed in the virtual environment, in front of, and above where the user would normally stand (roughly at eye height).

The thumbnails allow the user to see all of the available gestures.

2.<u>Recognition Phase</u>: Once multiple gestures have been recorded, they can enter recognition mode, in which the gestures are recognized in real-time.

During this mode, the current recognized gesture is forwarded to other modules of the application (see next section).

In addition, the GVF is able to provide a measure of how much of the gesture the user has currently performed.

In recognition mode, a trail is drawn in the same way as during learning, allowing users to see the shape of the gesture that they are currently performing.

3.Testing Phase: Recognition mode is used for testing the effectiveness of the gesture recognition to see if the system correctly recognizes gestures when they are performed again.

If tests are successful, the system is ready for use, but any errors can be corrected by returning to the recording phase and re-recording the original gestures and possibly redesigning the gestures vocabulary to make the gestures easier for the system to recognize.

This debugging process requires users and designers to understand why gestures are incorrectly classified and how to correct them.

This difficult process is supported by our visualization.

As gestures are recognized, the thumbnails are made partially transparent, each one having opacity proportional to the current estimated probability of that gesture.

This makes gestures gradually fade out if they are not recognized, leaving only the recognized gesture visible.

This makes it possible to easily see cases where two gestures are being confused by the algorithm and therefore support users in understanding why the system may not be working as expected.

This will help users detect cases where the gestures should be rerecorded because they are too easily confused.

In this sense, they are analogous to the interface proposed by Gillies et al. (2015) as a means of supporting users in building a conceptual model of a machine learning algorithm in order to better debug it and the work of Bau & MacKay (2008) who provide dynamic visual suggestions to support gesture design.

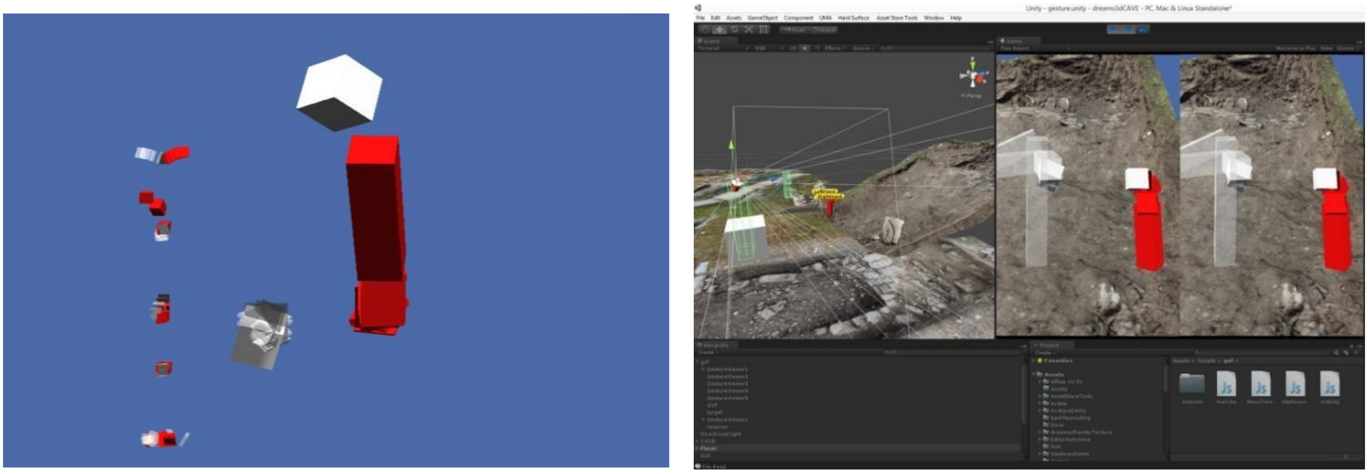

Figure 4.4.1: The visualizations of the gestures: when performing gestures, users can see trails of their movements showing them the shape of the gesture; at the top left of the screen there are thumbnails of the gesture vocabulary.

This design process can be performed in depth on initial design of the application to find a good set of gestures that work that are easily recognized and work well for archaeologists in general.

However, since the process is rapid, it is also possible to repeat it for each new user, allowing them to record personalized versions of the gesture.

The application

The main idea behind the design of the application was to allow archaeologists to think about the data and not the interface.

In particular, the application allows the researchers to interact with the data in a natural way by manipulating them with gestures (see Fig.4.4.2).

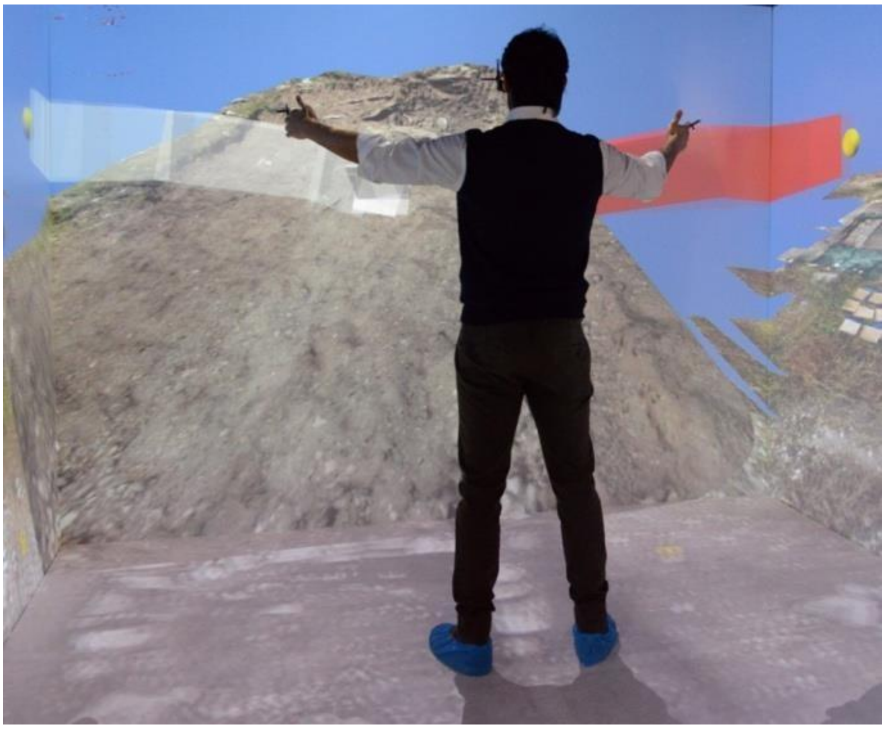

Figure 4.4.2: Using the gesture design system in immersive VR

The first step was defining tasks and gestures.

The archaeologists identified the tasks (e.g. comparison between layers of excavation, analysis of the finds) and they also identified suitable gestures (see below); the tasks are shown in Table 4.4.1.

The first task is selecting the layer of excavation via two gestures to move up and down.

When a layer of interest is chosen, particular finds are selected by touching them (this was not implemented via the gesture system).

Once selected, objects need to be measured and then deselected.

n	*Gesture*	*Task*
1	Rotation of the right forearm from inside to outside	Open contextual menu
2	Rotation of the right forearm from outside to inside	Close contextual menu
3	Slide up of the hand	Slide layer up
4	Slide down of the hand	Slide layer down
5	Arm opening from inside	Measurement
6	Touch object	Selection

Table 4.4.1: Correlation between gestures and tasks

There is also a context menu that displays different data types depending on where you are, this needs to be opened and closed.

For the creation of the scene, were imported 3D models of layers stacked on each other and for each layer were imported 3D models of the most interesting finds, lined up with the excavation.

The scene was integrated with a reconstruction of the entire agora, which can be useful for comparison with the current state of excavations.

4.4.4 Results

Designing gestures

The proposed system was used to design a gestural interface for the virtual recreation of the agora of Segesta.

The system developers worked with two archaeologists over 3 sessions to design the interface.

During the first phase, archaeologists, without the intervention of the system developers, designed a gesture vocabulary that would represent their behaviours and movements on the field.

The first session did not use the gesture design software and primarily aimed to determine which functions of the system would be most suited to a gestural interface.

The typology can be resumed in two main conceptual elements: slide/selection and analysis/measuring (see Table 4.4.1).

Then, the archaeologists linked two gestures to the task and created a diagram that described how the gestures can be integrated and used in the different sections of the application: enabling and disabling a menu, measuring an object, deselecting the currently selected object and moving from one level of the excavation to another.

Selecting an object was considered an important feature, but it was decided not to use the GVF to implement it as there was a straightforward gesture that did not require gesture recognition library to implement: moving the hand inside the object.

The second session was the first to use the GVF tool in practice and started with a discussion of the possible gestures (fig 4.4.3).

The participants used both movements and language to talk through the possible interfaces.

Figure 4.4.3: archaeologists and VR experts who discuss gestures

Acting out the gestures was a key part of this design phase, supporting our hypothesis that a gesture design tool based on performing example movements affords a natural way of working.

The participants then attempted to record some of the gestures.

They were able to record the gestures successfully and some were recognized effectively.

However, some performance issues were identified which were solved before the final session.

The last session was the design of the actual interface.

The participants began by reviewing the gestures they had designed in the previous session and re-recording them, then tested them in practice.

It quickly emerged that certain gestures were easily confused, for example moving the hand up to change layers and rotating and sweeping the hand to open the menu (Figs. 4.4.4).

The open menu command was re- recorded to restrict it to only rotation and therefore removing the common positional movement.

This shows that the system allowed identification of problems with gestures and re-recording of gestures.

Despite these improvements, it was found that many gestures were often confused.

This was because the application responded to gestures as soon as they were recognized, and therefore in the early stages of the gesture where it is still difficult to determine which gesture is performed and where the recognition may oscillate between different gestures.

The application was therefore changed so that responses only happened once a user was 30% of the way through a gesture.

On making this change recognition improved, other problems were solved by re-recording gestures to make them more easily distinguishable (e.g. by using a more clearly different initial movement or using different hands to perform different gestures).

When the system was able to recognize individual gestures and correctly respond to them, it was tested by performing sequences of gestures in a way that simulated actual use of this system.

The archaeologists were able to perform a number of tasks that were typical of their research methods such as: open and interact with the menu, visualize and slide between excavation layers by using an interaction that recalls the practical activity of ground removal, selection and analysis of objects.

The gesture vocabulary

The final set of gestures consists of two sets of two coupled gestures, in which one gesture is the inverse of the other: opening and closing the menu and moving up and down levels.

There are also two single gestures: initiating measurement of the selected object and deselecting an object (Fig.4 .4.4 and Table 4.4.1).

These gestures exemplify a number of gesture design strategies.

The open and close menu gestures are relatively arbitrary, they do not use a particular metaphor, but were designed based on convenience of movement and the constraints of the system (the requirement to ensure that gestures are sufficiently different to be easily recognized).

Figure 4.4.4: Using the gesture design system in immersive VR The gesture vocabulary. 1) initiating measurement by stretching hands out; 2) moving to a lower layer by raising the hand; 3) moving to a higher layer by lowering the hand; 4) rotation of the right forearm from inside to outside for opening the contextual menu; 5) closing the menu with an inverse movement; 6) deselecting the current object with a sharp downward movement of both hands.

The measurement gesture used a fairly straightforward real world metaphor: stretching out the hands in a clear echo of the movement made when using a measuring tape.

The selection gesture was similar, a sharp downward movement of the hands similar to the movement that would be made to throw down and object that was being held or to shake off an object stuck to the hands.

Both of these have clear metaphors from daily life and are generic in the sense that it easy to see them being applicable in many domains, not just archaeology.

The gestures to move between levels, however, are much more specific to archaeology because they use a metaphor derived directly from the archaeological practice.

The gesture to move down a layer is an upward movement of the hand as if lifting earth off the layer to reveal the layer below (the archaeologists explicitly described the movement in this way).

Conversely, movement to the layer above is a downward movement replacing the earth and covering the current layer.

This is particularly interesting as it contrasts directly with the gestures used by the engineers in the team when doing initial testing on the system.

Unlike the archaeologists, they immediately and without thinking about it, used an upward gesture to move up a layer, similar to scrolling a in a graphical interface.

This example clearly shows that, while many gestures are sufficiently generic to be similar and usable across a wide range of domains, certain gestures are specific to archaeologists.

They are gestures that have clear metaphors to the archaeologists' physical practice of digging and handling artefacts (in fact, in later discussion the archaeologists raised the possibility of gestures mimicking the use of tools).

It is therefore important, when designing interfaces for heritage experts (or experts in other domains for that matter) that themselves be participants in the design and as far as possible the design the interface.

Otherwise, the result will be generic interfaces that miss the particular physical metaphors that arise from expert practice.

4.4.5 Conclusions

The application design process forced a reflection on the interaction modalities that archaeologists could use in virtual environments.

This has made it possible not only to visualize 3D models, but also to interact with them using natural gestures, in order to consult data associated with models.

The discussion between archaeologists and software developers during the gesture design process has highlighted two different kinds of criticalities: on the one hand, conceptual differences concerning the configuration of gestures linked to specific tasks.

On the other hand, some difficulties during the gesture recording and recognition phase, due to conflicts between movements which were apparently similar but which were difficult for the application to recognize.

Nevertheless, the GVF has given promising results, both for the efficiency of the application and its future developments.

Archaeologists have emphasized the importance of having the possibility to mentally and virtually reproduce, even after a long time and working in a different place, the field activity, so as to be able to rethink and/or reformulate interpretations, originally elaborated during the excavation.

Besides the ability to operate in a completely hand-free way, thanks to hand- tracking sensors, the system will allow the use of external devices (i.e.tablets) for a wider consultation of metadata linked to 3D models, which are at present hardly visualizable within the CAVE.

4.5 New Methods of Interaction in Virtual Reality for the Study of Archaeological Data

4.5.1 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 case study 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 (fig. 4.5.1), 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 4.5.1: The sanctuary di 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.

4.5.2 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 (fig. 4.5.2).

Figure 4.5.2: 3D model of the Doric temple.

4.5.3 3D data acqusition:

Photogrammetry as a measurement and analysis tool

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% (fig. 4.5.3).

Figure 4.5.3: 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 (fig. 4.5.4).

Figure 4.5.4: 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 (fig. 4.5.5).

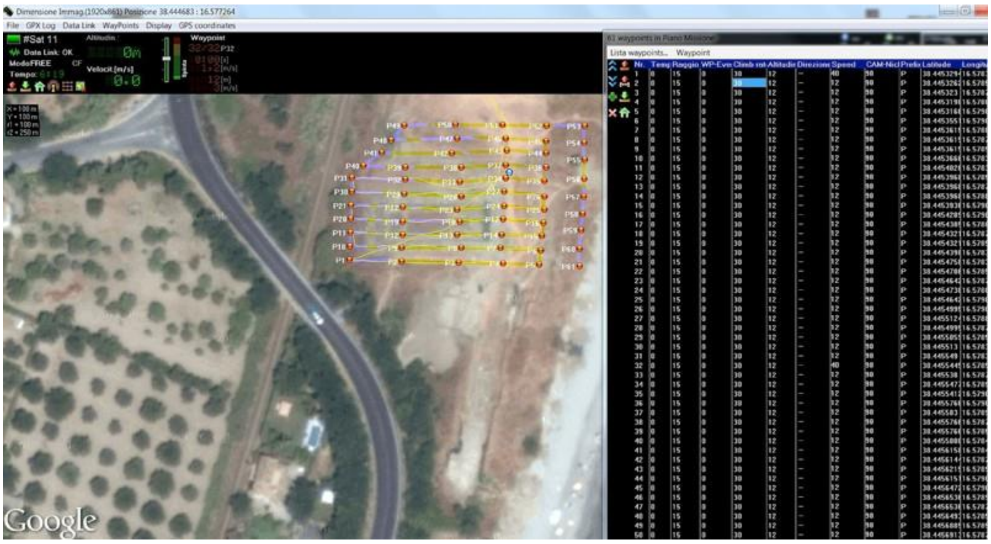

Figure 4.5.5: The position of the UAV along the waypoints, displayed in real time.

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 (fig. 4.5.6).

Figure 4.5.6: 3D model of the bronze weapons deposit, before (left) and after restoration.

4.5.4 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.

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.

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, there was many interaction solutions: there was an attempt 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, was decided to just use a helmet for virtual reality, without any type of input device.

As said before, when the development started 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?

An interaction study has been done to understand, as well as how to interact and how to give feedback to the user on his actions within the virtual environment.

In the end it became clear that the interaction with the eyes was the most natural thing: the user can directly observe what interests him; if his look is stays fixed 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 (fig. 4.5.7).

With these new opportunities, interaction was applied to archaeological data, with interesting developments.

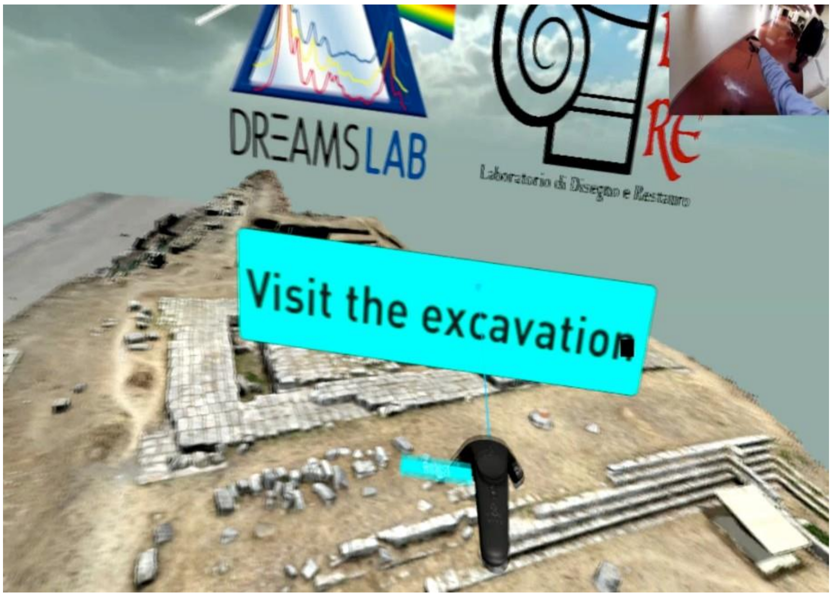

Figure 4.5.7: HTC Vive head Mounted Display with tracking system and controllers

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 (fig. 4.5.8).

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 4.5.8: Findings Metadata and model

4.5.5 Conclusion

The project has reached a good point, but there are already 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.

Conclusion

It is important to remind that Digital Technologies and in particular Virtual Reality might not be the final aim but the way by which to create, disseminate, and share the knowledge in various fields of scientific research.

Without a doubt, new Digital Technologies do allow us to pursue a collection and management of data in a much more accurate, detailed, rapid, and inexpensive way than just a few years ago.

Besides, once the data is collected and visualized in an interactive virtual environment, it allows us to move from the idea of a visualization to that of a simulation, making it possible to continuously operate in order to add new pieces of information and pursue a more dynamic approach to the study.

In other words, the goal is to allow our scientific knowledge to be more accurate, dynamic, not limited to a static and definitive interpretation but rather open to continuous investigations of a multifaceted set of data.

On the other hand, the objective is to share knowledge in a wider, easier, faster and accessible way to both the experts and non-experts.

The huge amount of data represents a heterogeneous database, strictly and strongly interconnected, which can be more suitably interrogated through their visual representations. In this sense, the Immersive and Interactive Virtual Environments, together with the whole set of Digital tools available nowadays, are the best way to query this database and try to answer in a more articulated way to the many issues still open while formulating new questions to be investigated in the next future.

Bibliography

- Abate, A., and O. Cannistraci. 2012. La stoa Nord dell'agora di Segesta: alcune note preliminari sull'elevato architettonico dell'ala Ovest. In Agorai di Sicilia, agorai d'Occidente, ed. C. Ampolo, 305-319. Pisa: Edizioni della Normale.

- Agata, A.; Cannistraci, O.; "La stoa Nord dell'agora di Segesta: alcune note preliminari sull'elevato architettonico dell'ala Ovest", in C. Ampolo (ed.), agora greca e agorai di Sicilia, Edizioni della Normale,2012, 305-319.

- Akeley, K. Reality Engine Graphics, Computer Graphics 1993, 27, 109-116.

- 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.

- 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., V. Barone, A. Brogni, S. Legnaioli, D. Licari, and E. Taccola. 2014. The agora ofSegesta 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.

- 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/

- 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/

- Ampolo, C., and M.C. Parra. 2012. L’agora di Segesta: uno sguardo d’assieme tra iscrizioni e monumenti. In Agorai di Sicilia, agorai d’Occidente, ed. C. Ampolo, 271-285. Pisa: Edizioni della Normale.

- 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/

- Anthony, L., & Wobbrock, J.O. (2010). A lightweight multistroke recognizer for user interface prototypes. Proceedings of Graphics Interface 2010, 245–252.

- Antinucci, F. 2007a. Musei virtuali : come non fare innovazione tecnologica. 1. Aufl. Percorsi, vol. 101. Roma: Laterza.

- Antinucci, F. 2007b. The Virtual Museum. Archeologia e Calcolatori Supplemento 1:79-86.

- Barazzetti, L.; Remondino, F.; Scaioni, M.; "Automation in 3D reconstruction: results on different kinds of close range blocks", in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2010, Vol. XXXVIII (5), ISPRS Commission V Symposium, Newcastle upon Tyne, UK, 55-61.

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

- Barone, V.; Licari, D.; Nardini, F. M.; "RICH: Research and Innovation for Cultural Heritage,Conservation Science in Cultural Heritage", 2012,Vol 12, pp 109-133.

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

- Bartlett, F.C. 1932. Remembering; a study in experimental and social psychology. The Cambridge psychological library. Cambridge Eng.: The University press.

- Bateson, G. 1972. Steps to an ecology of mind; collected essays in anthropology, psychiatry, evolution, and epistemology. Chandler publications for health sciences. San Francisco,: Chandler Pub. Co.

- Bateson, G. 1979. Mind and nature : a necessary unity. New York: Dutton.

- Bau, O., & Mackay, W. E. (2008). OctoPocus: a dynamic guide for learning gesture-based command sets. Proceedings of the 21st annual ACM symposium on User interface software and technology, 37–46. http://doi.org/10.1145/1449715.1449724

- Berggren, Å., N. Dell'Unto, M. Forte, S. Haddow, I. Hodder, J. Issavi, N. Lercari, C. Mazzuccato, A. Mickel, and J. Taylor. 2015. Revisiting reflexive archaeology at Çatalhöyük: integrating digital and 3D technologies at the trowel's edge. Antiquity 89:433-448.

- Bevilacqua, F., Zamborlin, B., Sypniewski, A., Schnell, N., Guédy, F., & Rasamimanana, N. (2010). Continuous realtime gesture following and recognition. In S. Kopp & I. Wachsmuth (Eds.), Gesture in Embodied Communication and Human-Computer

Interaction: 8th International Gesture Workshop, GW 2009, Bielefeld, Germany, February 25-27, 2009, Revised Selected Papers (pp. 73–84). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-642-12553-9_7

- Binford, LewisR.,andG.I.Quimby.1972. Anarchaeological perspective.Studiesinarchaeology. New York,: Seminar Press.

- Bragdon, A., Nelson, E., Li, Y., & Hinckley, K. (2011). Experimental analysis of touch-screen gesture designs in mobile environments. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 403–412. http://doi.org/10.1145/1978942.1979000

- Brickmann, J., Exner, E. T., Keil, M., & Marhöfer, J. R. (2000). Molecular Graphics - Trends and Perspectives. Molecular modeling annual, 6(2), 328–340. http://doi.org/10.1007/s0089400060328

- Brogni, A., Caldwell, D. G., & Slater, M. (2011). Touching Sharp Virtual Objects Produces a Haptic Illusion. In R. Shumaker (Ed.), Virtual and Mixed Reality - New Trends: International Conference, Virtual and Mixed Reality 2011, Held as Part of HCI International 2011, Orlando, FL, USA, July 9-14, 2011, Proceedings, Part I (pp. 234–242). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-642-22021-0_26

- Brown Duane C., Close-Range Camera Calibration, PE&RS, 1971, 37 (8), 855-866.

- Bruner, J.S. 1962. On knowing; essays for the left hand. Cambridge: Belknap Press of Harvard University Press.

- Buxton, B. (2010). Sketching user experiences: getting the design right and the right design. San Francisco, CA: Morgan Kaufmann.

- Camerata Scovazzo Rosalia et. al., Segesta I. La carta archeologica, 1996, Palermo.

- Caramiaux, B., Altavilla, A., Pobiner, S. G., & Tanaka, A. (2015). Form follows sound: designing interactions from sonic memories. Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, 3943–3952. http://doi.org/10.1145/2702123.2702515

- Caramiaux, B., Montecchio, N., Tanaka, A., & Bevilacqua, F. (2014). Adaptive Gesture Recognition with Variation Estimation for Interactive Systems. ACM Trans. Interact. Intell. Syst., 4(4), 1–34. http://doi.org/10.1145/2643204

- Carrozzino, M., and M. Bergamasco. 2010. Beyond virtual museums: Experiencing immersive virtual reality in real museums. Journal of Cultural Heritage 11 (4):452-458.
- Clark, J.T. 2010. The Fallacy of Reconstruction. In Cyber-archaeology, ed. M. Forte, 63-73. Oxford, England: Archaeopress.

- Costopoulos, A, and M.W. Lake. 2010. Simulating change : archaeology into the twenty-first century. Foundations of archaeological inquiry. Salt Lake City: University of Utah Press.

- Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. Communications of the ACM, 35(6), 64–72. http://doi.org/10.1145/129888.129892

- Damasio, A.R. 1994. Descartes' error : emotion, reason, and the human brain. New York: G. P. Putnam.

- Dell Unto, N.; Ferdani, D.; Leander, A.M.; DellepianeM. ; Callieri, M.; Lindgren, S.; "Digital reconstruction and visualization in archaeology: Case-study drawn from the work of the Swedish Pompeii Project", Digital Heritage 2013 International Conference, 2013, 621-628

- Dell'Unto, N. 2014. The Use of 3D Models for Intra-Site Investigation in Archaeology. In 3D Recording and Modelling in Archaeology and Cultural Heritage. Theory and best practices, eds. F. Remondino, and S. Campana, 151-158. BAR International Series 2598. Oxford: Archaeopress.

- Djindjian, F. 2007. The virtual museum: an introduction. Archeologia e Calcolatori Supplemento 1:9-14.

- Fdili Alaoui, S., Caramiaux, B., Serrano, M., & Bevilacqua, F. (2012). Movement qualities as interaction modality. Proceedings of the Designing Interactive Systems Conference, 761–769. http://doi.org/10.1145/2317956.2318071

- Fiebrink, R., Cook, P. R., & Trueman, D. (2011). Human model evaluation in interactive supervised learning. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 147–156. http://doi.org/10.1145/1978942.1978965

- Foerster, H. von. 1984. On constructing a Reality. In The Invented reality : how do we know what we believe we know? : contributions to constructivism, ed. P. Watzlawick, 41-61. New York: Norton.

- Forte, M. (2010). Cyber-archaeology. Oxford, England: Archaeopress.

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

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

- Forte, M., & Siliotti, A. (1997). Virtual archaeology: re-creating ancient worlds. London: Harry N Abrams B.V.

- Freedberg, D., and V. Gallese. 2007. Motion, emotion and empathy in esthetic experience. Trends in cognitive sciences 11 (5):197-203.

- Gallese, V. 2014. Arte, corpo, cervello : per un'estetica sperimentale. MicroMega (2):49-67.

- Gardner, G.Y. Simulation of natural scenes using textured quadric surfaces, Computer Graphics 1984, 18, 11-20.

- Gibson, J.J. 1950. The perception of the visual world. Boston: Houghton Mifflin.

- Gibson, J.J. 1979. The ecological approach to visual perception. Boston: Houghton Mifflin.

- Gillies, M., Kleinsmith, A., & Brenton, H. (2015). Applying the CASSM framework to improving end user debugging of interactive machine learning. Proceedings of the 20th International Conference on Intelligent User Interfaces, 181– 185. http://doi.org/10.1145/2678025.2701373

- Glasersfeld, E. von. 1995. Radical constructivism : a way of knowing and learning. Studies in mathematics education series, vol. 6. London; Washington, D.C.: Falmer Press.

- Grossman, T., & Balakrishnan, R. (2005). A probabilistic approach to modeling two-dimensional pointing. ACM Transactions on

Computer-Human Interaction, 12(3), 435–459. http://doi.org/10.1145/1096737.1096741

- Hodder, I. 1986. Reading the past : current approaches to interpretation in archaeology. Cambridge Cambridgeshire; New York: Cambridge University Press.

- Ihlenfeldt, W-D. "Virtual reality in chemistry." Molecular modeling annual 3.9 (1997): 386-402.

- Kane, S. K., Wobbrock, J. O., & Ladner, R. E. (2011). Usable gestures for blind people: understanding preference and performance. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 413–422. http://doi.org/10.1145/1978942.1979001
- Kirsh, D. (2013). Embodied cognition and the magical future of interaction design. ACM Transactions on ComputerHuman Interaction, 20(1), 1–30. http://doi.org/10.1145/2442106.2442109

- Kratz, L., Morris, D., & Saponas, T. S. (2012). Making gestural input from arm-worn inertial sensors more practical. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1747–1750. http://doi.org/10.1145/2207676.2208304

- Lackner, J. R. (1998). Some proprioceptive influences on the perceptual representation of body shape and orientation. Brain, 111(2), 281–297. http://dx.doi.org/10.1093/brain/111.2.281

- Lake, M.W. 2014. Trends in Archaeological Simulation. Journal of Archaeological Method and Theory 21 (2):258-287.

- Langridge, R., Ferrin, T.E., Kunz, J.D., Connolly, M.L Real-time color graphics in studies of molecular interactions, Science 1981, 211, 661.

- Lee, C., & Varshney, A. (2006). Computing and displaying intermolecular negative volume for docking. Scientific Visualization: The Visual Extraction of Knowledge from Data, 49-64.

- Lesure, R.G. 2005. Linking theory and evidence in an Archaeology of Human Agency: iconography, style, and theories of embodiment. Journal of Archaeological Method and Theory 12 (3):237-255.

- Long, A. C., Landay, J. A., Rowe, L. A., & Michiels, J. (2000). Visual similarity of pen gestures. Proceedings of the SIGCHI conference on Human Factors in Computing Systems, 360–367. http://doi.org/10.1145/332040.332458
- Lucchese, G., Field, M., Ho, J., Gutierrez-Osuna, R., & Hammond, T. (2012). GestureCommander: continuous touchbased gesture prediction. CHI '12 Extended Abstracts on Human Factors in ComputingSystems,1925–1930. http://doi.org/10.1145/2212776.2223730

- M. Chavent, A. Vanel, A. Tek, B. Levy, S. Robert, B. Raffin, M. Baaden: GPU-accelerated atom and dynamic bond visualization using HyperBalls, a unified algorithm for balls, sticks and hyperboloids; J Comput Chem (2011) 32, 2924.

- M. Chavent, B. Levy, M. Krone, K. Bidmon, J. P. Nomine, T. Ertl and M. Baaden: GPU-powered tools boost molecular visualization; Brief Bioinformatics (2011)

- Mackay, W. E., & Fayard, A. L. (1999). Video brainstorming and prototyping: techniques for participatory design. CHI '99 Extended Abstracts on Human Factors in Computing Systems, 118–119. http://doi.org/10.1145/632716.632790

- Maturana, H.R., and F.J. Varela. 1980. Autopoiesis and cognition : the realization of the living. Boston studies in the philosophy of science, vol. 42. Dordrecht, Holland; Boston: D. Reidel Pub. Co. Maturana, H.R., and F.J. Varela. 1987. The tree of knowledge : the biological roots of human understanding. 1st Aufl. Boston: New Science Library : Distributed in the United State by Random House.

- Michael Teschener, Henn C., Vollhardt H., Texture mapping: A new tool for Molecular Graphics, j.Mol.Graphics 1994, 12, 98

- Mikhail, E. M.; Bethel, J. S.; McGlone, J. C.; Introduction to Modern Photogrammetry, 2001,Wiley.

- Mori, A., Uchida, S., Kurazume, R., Ichiro Taniguchi, R., Hasegawa, T. & Sakoe, H. (2006). Early recognition and prediction of gestures. ICPR 2006. 18th International Conference on Pattern Recognition, 560–563. http://doi.org/10.1109/ICPR.2006.467

- Muller, M. J., & Kuhn, S. (1993). Participatory design. Communications of the ACM, 36(6), 24–28. http://doi.org/10.1145/153571.255960

- Niccolucci, F. 2007. Virtual museums and archaeology : an international perspective. Archeologia e Calcolatori Supplemento 1:15-30.

- Nielsen, M., Störring, M., Moeslund, T. B., & Granum, E. (2004). A Procedure for Developing Intuitive and Ergonomic Gesture Interfaces for HCI. In A. Camurri & G. Volpe (Eds.), Gesture-Based Communication in Human-Computer Interaction: 5th International Gesture Workshop, GW 2003, Genova, Italy, April 15-17, 2003, Selected Revised Papers (pp. 409–420). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-540-24598-8_38

- Nieuwenhuizen, K., Aliakseyeu, D., & Martens, J.-B. (2009). Insight into Goal-Directed Movements: Beyond Fitts' Law. In T. Gross, J. Gulliksen, P. Kotzé, L. Oestreicher, P. Palanque, R. O. Prates & M. Winckler (Eds.), Human-Computer Interaction – INTERACT 2009: 12th IFIP TC 13 International Conference, Uppsala, Sweden, August 24-28, 2009, Proceedings, Part I (pp.

274–287). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1145/1753326.1753457

- Norman, D. A. (1990). The design of everyday things (1st Doubleday/Currency Ed.). New York: Doubleday.

- Olivito, R., and E. Taccola. 2014. 3D modelling in the agora of Segesta: techniques and data interpretation. Archeologia e Calcolatori 25:175-188.

- 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. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40 -5/W4 , 31–36. http://doi.org/10.5194/isprsarchives-XL-5-W4-31-2015

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

- Ouyang, T., & Li, Y. (2012). Bootstrapping personal gesture shortcuts with the wisdom of the crowd and handwriting recognition. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2895–2904. http://doi.org/10.1145/2207676.2208695

- 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/
- 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/

- Peachey, D.R. Solid texturing of complex surfaces, Computer Graphics 1985, 19, 279- 286.

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

- Pescarin, S., E. Pietroni, L. Rescic, M. Wallergård, K. Omar, and C. Rufa. 2013. NICH: A preliminary theoretical study on Natural Interaction applied to Cultural Heritage contexts. In 1st Digital Heritage International Congress, 355-362. IEEE.

- Pescarin, S., W. Hupperetz, A. Pagano, C. Ray, and M. Wallergård. 2014. Evaluating Virtual Museums: archaeovirtual test-case. In Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 40th Conference in Computer Applications and Quantitative Methods in Archaeology, Southampton, United Kingdom, 26-30 March 2012, 76-84.

- Pietroni, E., & Pescarin, S. (2010). VR cooperative environments for the interpretation and reconstruction of the archaeological landscape. Virtual Archaeology Review, 1(2), 25–29. http://dx.doi.org/10.4995/var.2010.4680

- Pietroni, E., & Rufa, C. (2012). Natural interaction in Virtual Environments for Cultural Heritage: Giotto in 3D and

Etruscanning study case. Virtual Archaeology Review, 3(7), 86–91. http://dx.doi.org/10.4995/var.2012.4394

- Porter, T., and Duff, T. Compositing of digital images, Computer Graphics 1984, 18, 253-259.

- Proulx, Jerome. 2008. Some differences between maturana and Varela's theory of cognition and constructivism. Complicity: An International Journal of Complexity and Education 5 (1):11-26.

- Remondino, F.; El-Hakim S.; "Image-based 3D modelling: a review", in The Photogrammetric Record, 2006, Vol. 21 (115) 269-291.

- 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.

- Renfrew, C. 1994. Towards a cognitive archaeology. In The ancient mind : elements of cognitive archaeology. New directions in archaeology, eds. C. Renfrew, and E.B.W. Zubrow, 3-12. Cambridge England; New York: Cambridge University Press.

- Russo, M.; Remondino, F.; "Laser Scanning e Fotogrammetria: strumenti e metodi di rilievo tridimensionali per l'archeologia", in: Teoria e metodi della ricerca sul paesaggio d'altura, 2012, SAP, Mantova , 141-170.

- Schmidt-Ehrenberg, J., Baum, D., & Hege, H. C. (2002). Visualizing dynamic molecular conformations. In Proceedings of the conference on Visualization'02 (pp. 235-242). IEEE Computer Society.

- Stanish, Charles S. "Cyber-archaeology and world cultural heritage: insights from the holy land." Bulletin of the American Academy of Arts & Sciences (2013): 27. emanuele.taccola@unipi.it
- Sharples, Sarah, et al. "Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems." Displays 29.2 (2008): 58-69.

- Taccola, E. 2012. Ricostruzioni 3D per l'agora di Segesta. In Agorai di Sicilia, agorai d'Occidente, ed. C. Ampolo, 287-289. Pisa: Edizioni della Normale.

- Taccola, E., Parra, M.C., & Ampolo, C. (2014). The sanctuary of Punta Stilo at KauloniaMonasterace (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

- Tanaka, A., Bau, O. & Mackay, W. (2013). The A20: Interactive instrument techniques for sonic design exploration. In: K.

Franinović & S. Serafin (eds.), Sonic Interaction Design (pp. 255–270). Cambridge, MA: MIT Press.

- Taylor, J. L. (2009). Proprioception. Encyclopedia of Neuroscience (pp. 1143–1149). Oxford: Academic Press. http://dx.doi.org/10.1016/B978-008045046-9.01907-0

- Thompson, E., and F.J. Varela. 2001. Radical embodiment: neural dynamics and consciousness. Trends in cognitive sciences 5 (10):418-425.

- Varela, F.J.,E.Thompson,andE.Rosch.1991.The embodied mind:cognitive science andhuman experience. Cambridge, Mass.: MIT Press.

- Varona, J., Jaume-I-Capò, A., Gonzàlez, J., & Perales, F. J. (2009). Toward natural interaction through visual recognition of body gestures in real-time. Interacting with Computers, 21(1-2), 3–10. http://doi.org/10.1016/j.intcom.2008.10.001

- Watzlawick, Paul. 1976. How real is real? : Confusion, disinformation, communication. New York: Random House.

- Wilson, A. D., & Bobick, A. F. (1999). Parametric hidden Markov models for gesture recognition. IEEE Transactions on Pattern Analysis and Machine Intelligence, 21(9), 884–900. http://doi.org/10.1109/34.790429

- Wilson, A. D., & Bobick, A. F. (2000). Realtime online adaptive gesture recognition. Proceedings 15th International Conference on Pattern Recognition. http://doi.org/10.1109/ICPR.2000.905317

- Witmer, B.G., and M.J. Singer. 1998. Measuring presence in virtual environments: A presence questionnaire. Presence: Teleoperators and virtual environments 7 (3):225-240.

- Wobbrock, J. O., Morris, M. R., & Wilson, A. D. (2009). User-defined gestures for surface computing. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1083–1092.

- Wobbrock, J. O., Wilson, A. D., & Li, Y. (2007). Gestures without libraries, toolkits or training: a $1 recognizer for user interface prototypes. Proceedings of the 20th annual ACM symposium on User Interface Software and Technology, 159–168. http://doi.org/10.1145/1294211.1294238

- Z. Lv, A. Tek, F. Da Silva, C. Empereur-mot, M. Chavent and M. Baaden: Game on, Science - how video game technology may help biologists tackle visualization challenges PLoS ONE 8(3):e57990.

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

Publications

Albertini, N., Barone, V., Brogni, A., Legnaioli, S., Licari, D., & Taccola, E. (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 conference4, 1, 299-304.

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. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(5), 31.

Olivito, R., Taccola, E., & Albertini, N. (2016). Cultural Heritage and Digital Technologies. In Digital Methods and Remote Sensing in Archaeology (pp. 475-494). Springer International Publishing.

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., Brogni, A., Olivito, R., Taccola, E., Caramiaux, B., & Gillies, M. (2017). Designing natural gesture interaction for archaeological data in immersive environments. Virtual Archaeology Review, 8(16), 12-21.

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.