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NATURAL INTERACTION IN VR ENVIRONMENTS FOR CULTURAL HERITAGE: THE VIRTUAL RECONSTRUCTION OF THE REGOLINI-GALASSI TOMB IN CERVETERI

1. Digital media for cultural heritage in museums: state of the art

The final aim of a virtual elaboration is to multiply the communicative potentialities of cultural heritage, re-activating its relations in space and time and meanings. Virtual reconstructions, in fact, can illustrate what is illegible, contextualize what is fragmented or isolated, and put back together cultural ties that have been separated over time and which are essential to reconstruct the cultural identity of the object. These aspects are seldom brought to the attention of the public in traditional approaches to cultural transmission. "Virtual Heritage" is information that cultural heritage represents and this information modifies its value, interpretation and possibility of transmission, producing an interchange between the cultural content and the public. Despite this great potential, however, virtual museums often lack communicative and emotional impact, probably because there is still not enough collaboration between industry and research, that develops tools dedicating little interest to their wide application. Moreover there is the misconception that cultural heritage is self-explanatory in terms of aesthetics and conceptual value and consequently little attention to communication is necessary. On the contrary every cultural object conveys a message that needs to be "decoded" and transmitted to the public and this transmission is not easy for several reasons (Antinucci 2004).

At the origin of the "digital cultural heritage era" the main goal of research was to obtain good digitization of monuments and archaeological sites, topographically and topologically reliable and accurately measured. Advances in the development of new technologies led to the improvement of many more instruments, the integration among technologies and methodologies, thereby achieving better digital pipelines to preserve the original quality of the data, from its acquisition and documentation at high resolution to the final 3D representation (Pietroni, Pescarin 2008). At the same time, geographic information systems have increased their potential in terms of features: data dispersed in multiple archives and in a variety of formats can now be brought together and organized in a unique and coherent 2D or 3D context, with great potentialities of analyses (Pietroni 2009). Bottom up and top down approaches have been integrated to show the 3D representation of an artifact in its actual state of preservation and furthermore, how it could have been in the past, through a virtual reconstruction based on historical sources and interpretative work. The London Charter, the Sevilla Principles and a widespread debate on an international level have focused attention on the need to make the whole methodology and the interpretative process explicit, to create repositories where data can be shared and meta-data opened to verification, criticism and possible re-use by the body of the users. Basically, still today, the scientific value of digital cultural transmission has been identified in these kinds of activities and development focusing especially on digital documentation and preservation.

Despite advances made in this field, most of the digital applications utilized in museums for communication purposes are still lacking in terms of real impact on the public (Pietroni, Rufa, Dell'Unto 2008). They still appear as "experiments" born inside laboratories and their target is not always evident. As learning faculties are deeply influenced by emotional involvement, also other aspects, connected more to the artistic impact and the interaction design, must be taken into account, if virtual museums are to satisfy the needs of a wider public audience (Annunziato *et al*. 2008). Reliable and accurate 3D models and digital archives need to be considered as fundamental but initial steps towards final cultural transmission. Efforts should not be limited to the formal aspects of cultural heritage and to the analytic organization of knowledge, following criteria oriented to classification and taxonomy.

Attention should be centred on the thematic and anthropological contents, as the final purpose. No gap should exist between knowledge and communication; there is no context without communication and there is no communication without a context (Bateson 1979). If we want to definitively transmit to the public stories that are helpful in enhancing the cultural ties of an object, it is clear that we need to focus more on narrative plots, non-linear and interactive storytelling, interaction interfaces, gaming rules applied to CH, user profiling methods and "soundscapes". How these items interrelate with each other should be taken into consideration: criteria and best practices can change according to the final output and the conditions of use. In this perspective cognitive science and art are as fundamental as the other, more consolidated, disciplines; a stronger collaboration between science, art and technology, museums and researchers is doubtlessly recommendable.

One of the critical aspects is that visitors to museums still have problems managing common input devices (mouse, joystick, keyboard, console) for interacting in a VR environment. This condition produces uneasiness and frustration in establishing a contact between the visitor, the digital environment and technologies. Moreover, the users are sometimes discouraged by the absolute lack of information linked to a virtual representation or, on the contrary, by an excessive amount of information that is confusing or misleading. It is extremely important to find a good compromise between freedom of exploration, easy use of the interfaces and the possibility of guiding the public through the learning process (Pietroni, Antinucci 2010).

In the next paragraphs reference will be made to the *Etruscaning 3D* project where research is oriented to the development and experimentation of new, low cost and markless natural interaction interfaces in a VR environment in museums, based only on body movements (Alisi, Del Bimbo, Valli 2006). This solution makes interaction extremely easy and natural for the public, consequently resulting in a longer time of use, more pleasure and a better impact in terms of learning. The choice of natural interaction is not a purely technical solution for input. It strongly influences the user's experience, the perceptive impact of real time exploration, embodiment (the real user and the digital world are in effect in the same space) and sensorial participation, object selection, manipulation interface, the combination of media, the duration of the narrative content and motivation to continue the experience.

2. The *Etruscanning* project

Etruscanning 3D is a two-year project funded by the European Commission within the Culture 2007 framework. It focuses attention on the investigation of new digital documentation and visualization techniques to re-create and restore the original context of Etruscan tombs. Through the cooperation of museums and research organizations from three European countries, the project aims at the digital acquisition, restoration and 3D reconstruction of Etruscan tombs and artifacts and their presentation to the public through innovative VR systems. The applications are proposed for use in temporary exhibitions in the Netherlands, Belgium and for permanent use in Italian museums (Vatican Museums, National Etruscan Museum in Villa Giulia and Agro Veientano Museum in Formello). The main partners of the project are: Allard Pierson Museum, Amsterdam (coordinator), Netherlands; CNR-ITABC, Italy; Visual Dimension, Belgium; National Museum of Antiquities, Leiden, Netherlands; Gallo-Roman Museum, Tongeren, Belgium. The associated partners are the Vatican Museums, the Soprintendenza ai Beni Archeologici dell'Etruria Meridionale, Italy, and the Agro Veientano Museum, Formello, Italy. CNR-ISMA, Italy, collaborated with the project on a scientific basis. The project started in 2011 and concluded in April 2013.

Two important study cases were taken into consideration: the Regolini-Galassi tomb, in Cerveteri, and n. 5 Monte Michele tomb, in Veii. The finds from these tombs are exhibited in museum collections and the existing (empty) tombs are not always open to the public. By making 3D reconstructions of the tombs and of the objects which were originally found inside, we can re-propose the original context. In this paper attention is focused on the first study case, the Regolini-Galassi tomb, located in the Sorbo Necropolis in Cerveteri. It is on private property, which is usually closed to the public but can be visited on request. This tomb hosts two very important personages

Fig. 1 – The Regolini-Galassi tomb today and the room in the Vatican Museums with the artifacts coming from the original context.

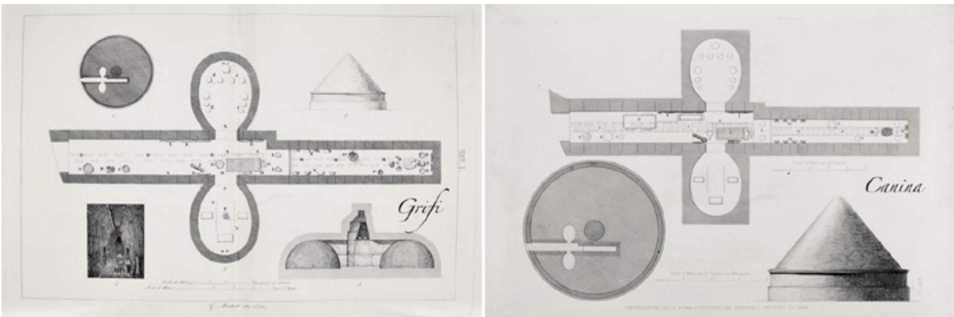

Fig. 2 – Plans of the Regolini-Galassi tomb by L. Grifi (1841) and L. Canina (1838).

(Colonna, Di Paolo 1997), a princess and a warrior, and it has been dated back to around 675-650 BC. It is one of the richest and most famous tombs of the Orientalising period, a time when the exchange of knowledge and ideas among the Etruscan princes and other Mediterranean cultures flourished (Sannibale 2008b). The outstanding quality of the goldsmith's objects and the fact that they remained together after being excavated – which is exceptional for that time – make the Regolini-Galassi tomb one of the most important and best-known of the Etruscan graves (Sannibale 2008a).

All the funerary objects found inside are preserved and exhibited in a specific room in the Gregorian Etruscan Museum at Vatican Museums (Fig. 1). They can be viewed in the showcases but the experience is purely aesthetic, limited to the observation and analyses of their formal aspects.

These two entities, the tomb and its funerary goods, have been put back together, through a 3D reconstruction so that the public can better understand the meaning of an Etruscan burial and tomb. We created a VR environment whose most innovative aspect is the new paradigm of interaction based on natural interfaces. This means that the public has the possibility to explore the 3D space and interact using only body movements, in the simplest and most natural way. This is possible thanks to a simple low cost sensor, a depth camera, that does not require the user to wear any marker and does not need expensive licenses to operate. The availability of such sensors, coming from the video game domain, will most likely stimulate the use of natural interaction solutions in museums in the years to come.

Besides the communicative aspect, the process of digitization and virtual reconstruction revealed another advantage. As the process of the virtual reconstruction of the Regolini-Galassi tomb tries to visualize it at the moment it was closed, very practical questions arose which had to be answered regarding the placement of the objects, their shape and colour. This was not so easy because when the priest Regolini and the general Galassi discovered the tomb, still intact in 1836, they did not document it methodically and the same can be said for Grifi's and Canina's drawings that were made when the objects had already been removed from the tomb. The first descriptions of the tomb are only interpretations of the original state of the tomb as there are no drawings of the excavation. Consequently these sources show some differences in the representation and location of the objects. The creation of accurate 3D models, corresponding to the real dimensions of the tomb and its artifacts (about 80 key objects from Vatican Museums), allowed us to simulate and verify the original layout of the funerary goods, comparing different solutions and hypotheses originating from ancient iconographical and literary sources (Fig. 2).

The possibility to collaborate directly with Museums (especially APM and the Vatican Museums) in the *Etruscanning* framework represented a fantastic opportunity to create a strong and concrete link between research and communication in the field of virtual museums. The application dedicated to the Regolini-Galassi tomb has been presented on many occasions, for short periods, to test the public's reaction. This has helped us to improve, step by step, the general design and the interaction interfaces. On the 4th of April 2013 the final version was presented in the Vatican Museums and it is now accessible as a permanent installation in the Gregorian Etruscan section (Rooms II and XVI).

2.1 *Documentation, 3D modelling, implementation*

Today the original Regolini-Galassi tumulus no longer exists but the actual state of preservation of the inside of the tomb seems to be similar to the original one. For the digital acquisition of the tomb a time of flight laser scanner (Riegl z390i) was used to obtain a 3D model with a resolution of 6

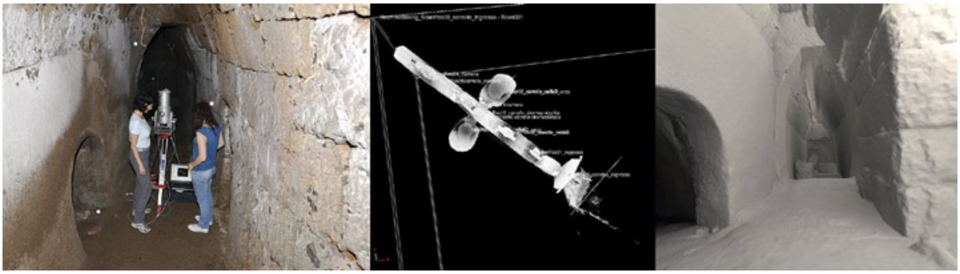

Fig. 3 – Laser scanner acquisition, point cloud and final mesh model.

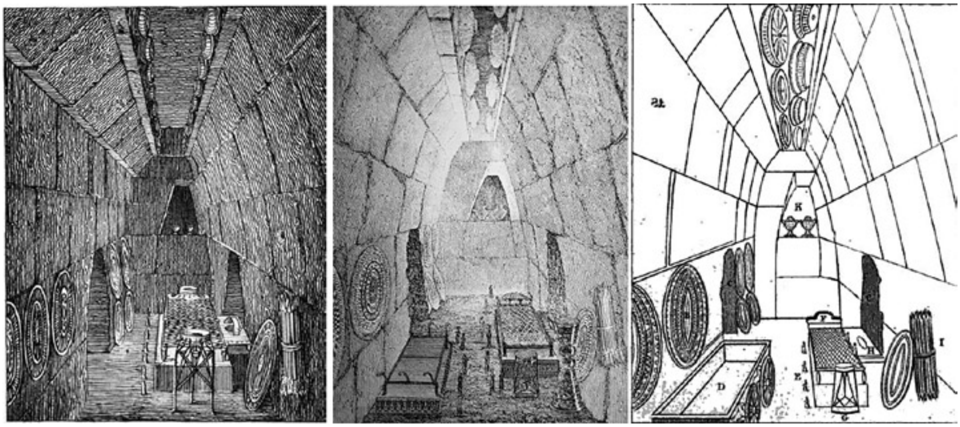

Fig. 4 – Reconstructions made by L. Grifi (1841), L. Canina (1838), and Hamilton Gray (1841).

mm and 2-3 mm of accuracy (Fig. 3). The workflow was typical: scanning, cleaning and filtering of the point clouds, registration using flat and cylindrical reflecting targets, triangulation, correction of the abnormal faces, filling up of the holes, texturing. Starting from this model the two walls were created (today no longer existing) closing the inner chamber and the right cell containing the two bodies, as documented in historical and iconographic sources: Grifi, Canina, and Hamilton (Fig. 4). From the detailed 3D model normal maps were drawn up and were applied to a second simplified model, obtained by decimating the original one.

The objects originally found inside the tomb were digitally acquired in the Vatican Museums. Some existing photos from the archive of the Museums were obtained, but this documentation had to be supplemented by taking new photos of the objects, after they had been removed from the showcases by the internal staff of the museum (curator of the collection, photographer,

Fig. 5 – Golden fibula, 3D model realized by hand in 3D Studio Max.

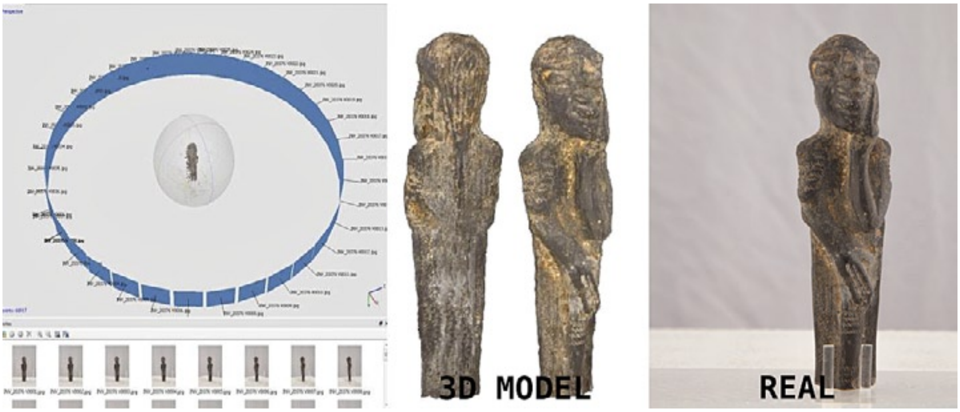

Fig. 6 – Little statuette of a mourner, 3D model realized with dense stereo matching techniques in Photoscan. On the right a photo of the real object.

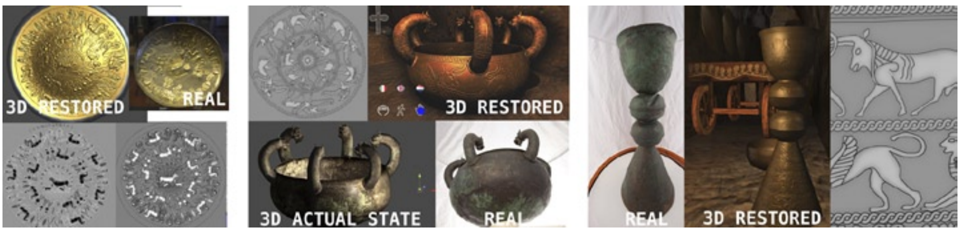

Fig. 7 – Examples of digital restoration: a) golden patera; b) six-headed lebes; c) holmos.

Fig. 8 – Real time rendering of the princess and her funerary goods, inner chamber (Unity 3D).

restorer). The museum did not allow the use of any other equipment, such as a laser scanner. A turntable was used to take photos of each object from all angles (about 36 photos for each object). As almost all the objects are in bronze, silver or gold, a circular white tent was placed over the object and the turntable to avoid reflection of the light (Fig. 1). This acquisition technique was useful both for 3D modelling made by hand using 3D Studio Max (when the objects were too complex to be modelled using only automatic or semi-automatic techniques, see Fig. 5) and for dense stereo-matching techniques using Agisoft Photoscan, which gave the best results in the dense stereo-matching process (Fig. 6). On the basis of iconographic comparisons and similarities and with the help of experts, the work of digital restoration of the missing decorations started (Fig. 7) (Appendix 2).

The 3D models elaborated using several technologies were imported into 3D Studio Max in order to verify their final aspect and quality and then exported again in .fbx format to be implemented in Unity 3D, the real time graphic engine. This software, originating from the video game domain, was used for the final visualisation in a VR environment, where storytelling, behaviours and natural interaction interfaces were developed. Also the final editing and optimization of the 3D contents was obtained in Unity 3D, especially in relation to the final rendering quality, material, shaders, light mapping, occlusion maps, etc. (Fig. 8).

2.2 *Storytelling and "soundscape"*

In the final application the public has the possibility to explore the virtual tomb, to get close up to the artifacts and to listen to the narrative contents directly from the voices of the prestigious Etruscan personages buried inside: the princess and the warrior, to which the precious objects were dedicated. They are like ghosts that speak of the their past life and world seen from the point of view of an aristocrat or ruler of an Etruscan city state. They tell their story to the visitor so that he can better understand their life and opinions, while deliberately avoiding or refusing to talk about some aspects as yet unknown and still to be discovered by the actual experts. The storytelling revolves around the key objects, each story lasting at the most one minute. As the user can explore the tomb randomly, there is no predefined order in which the stories are told. The storytelling has been recorded in Dutch, English and Italian.

Besides, music and sounds are really fundamental to produce an emotional involvement (Castellano, Villalba, Camurri 2007); in this case a "soundscape" that evokes the past and at the same time contemporary culture. Supercollider was used as a generator of synthetic sounds (cymbals, little bells, bass drum) using granular synthesis, and "live" melodic instruments were also recorded: bass flute and alto flute, as a similar timbre is documented in the Etruscan world, especially associated with religious ceremonies. Sounds are combined with noises to evoke the meaning of each object: water, chariot wheels, a galloping horse, fire, etc. In this way each object, when selected, reveals its own story and the universe of sounds enhancing its symbolic value. Anyway all the fragments are related and connected by a similar style. While freely exploring the space when no story is being told, soft background music can be heard.

2.3 *Natural interaction in the virtual Regolini-Galassi tomb*

The exploration of the 3D space and access to storytelling is possible without any traditional interface but simply by moving in the space in front of the projection, in the most natural way. The application is built in Unity 3D and uses the Kinect sensor for motion capture. The system derives from the new generation of games, but this is the first time it has been applied to a VR environment dedicated to Cultural Heritage and experimented in a museum. The Kinect interactive area has a cone shape, 5 m long × 5 m wide (the device constitutes the vertex of this cone). The minimum distance between the sensor and the user is 1 m. In effect, a smaller area is used, as the plan on the floor where the user moves is 2,5 m long × 3 m wide. Different levels of interaction were tested to understand which one was mostly appreciated by the public. So, we implemented two main different versions of the application: the first one which was very easy to use and the second one a bit more complex but more effective. In both cases we tested the public's reactions, during the temporary exhibitions in the Netherlands dedicated to the Etruscans (Amsterdam and Leiden, October 2011-March 2012) (Hupperetz *et al.* 2011), Archeovirtual (November 2011 and 2012), Science Festival, Genova, Italy (October 2012).

The first version was developed just a few months after the beginning of the project. The user walks on a real map of the grave placed on the floor, where some "hotspots" are attached. When he goes to a hotspot and stands there, the camera automatically moves in the virtual world to that position and then the storytelling emerges from the objects that are all around, following a pre-determined path. Every hotspot operates 3-5 "speaking" objects, each one telling its own story. The order in the choice of the hotspot is absolutely free, so any sequence can be followed. While one user is actively operating the system, the other visitors can sit down in the area all around, visualizing and listening to the cultural content in a passive way, always with the opportunity to be engaged in active exploration. The framework to interface Kinect for XBox and the computer (a Mac) was OpenNI, an open source application programming interface (API) developed by Prime Sense and Willow Garage industries for developing applications using natural interaction.

In a very early version of the application, an algorithm of "path finding" for the camera movements among the hotspots was implemented; this resulted in animations being different every time because they were not controlled by the user, or by the programmer through a pre-defined path; on the contrary, the animation between one hotspot and another was calculated directly by the computer. The problem was that some camera movements were very fast and close to the walls (the tomb is a narrow corridor), which for some people could cause a sensation of motion sickness, connected with the degree of embodiment. For this reason some constraints were imposed on the camera; it could move forward and backward according to the user's position and made slow and limited rotations, only in relation to the two lateral cells, controlled by the programmer. This version of the application, developed in a couple of months, represented something halfway between an interactive movie and a VR exploration, controlled by natural interfaces; it was an interactive exploration of a story. The public had only to stand in front of the projection: no gestures were required, or selection possibilities were given. The results were good: not only did this solution make the interaction amazing for the public, it also allowed people of every age and every level of "technical" skill to enjoy the virtual contents (Fig. 9). The medium length of time of interaction for each user was about 12 minutes (the total amount of narrative content is about 22 minutes); a very good result according to our expectations (Pietroni *et al.* 2012).

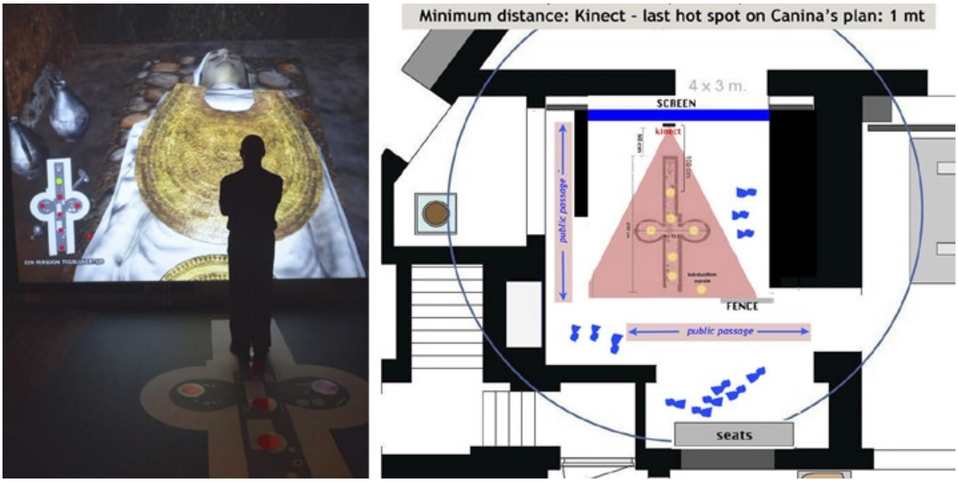

Fig. 9 – The first version of the VR application: installation and scheme of the interactive space (in collaboration with E.V.O.CA.).

However we wanted to go further, making the natural interaction more complex, involving the user with more gestures to enhance his embodiment.

So in the next 4-5 months the second, final, version was developed. This version is no longer based on an interactive map of the tomb on the floor, with automatic movements of the camera. On the contrary the user is left completely free to walk through the 3D model and rotate his viewpoint in any direction, using his arms. A "selection mode" was also implemented that opened up very interesting possibilities. The screen (full HD, 16:9 ratio) was divided up into many viewports, two of which are the most important: the larger one (4:3 ratio) is for the immersive visualization and 3D exploration; the second one, on the right, is a dynamic menu of the objects surrounding the position occupied by the user in the 3D space. This second viewport is necessary for selecting the objects, as their position in the narrow space of the tomb, close one to the other, would render selection very difficult. On the contrary in this menu the objects are aligned and selection is very easy.

The different functions are activated by means of several hotspots on the floor (Fig. 10):

1) hotspot *Languages:* choice of language, Italian, English, Dutch;
2) hotspot *Exploration*: free exploration (using arms to move and rotate on xyz axes);
3) hotspot *Selection and Storytelling:* in this position the visitor is asked to pass his right hand over the objects on the right, in order to activate the storytelling regarding the object he has chosen. Each object has a specific camera

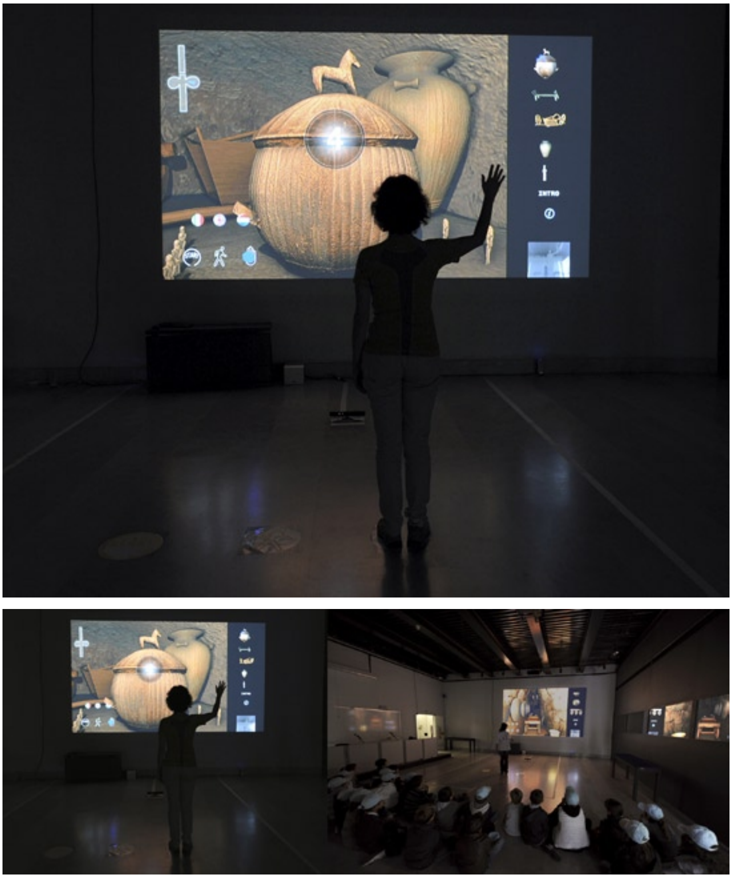

Fig. 10 – Second version of the application "Virtual Exploration of the Regolini-Galassi tomb" installed in the Vatican Museums (in collaboration with E.V.O.CA.).

and spotlight; sometimes it animates and moves forward giving the visitor a close up image of itself while he is listening to its story;
4) hotspot *Start:* a short tutorial explains to the user how to interact inside the 3D space. This section also includes a short historical introduction to the tomb.

This solution appears to be the best compromise, suitable for any kind of public: the user, without the minimum of frustration, can immediately understand how it works and feel much more embodied in the 3D space. Moreover he can find a balance between active interaction and relax, listening to the stories. This solution not only makes the interaction amazing for the public but allows also people of every age and of different levels of "technical" skill to enjoy the virtual contents. The evocative storytelling in first person, the use of lights that gradually reveal the objects, as soon as the space is penetrated, the "soundscape", the physical involvement of the user produce an impression of strong sensorial immersion. The application is built in Unity 3D and uses the Kinect for Windows sensor, with Microsoft SDK to interface Kinect and the PC. It was decided to migrate to the Windows platform because a more powerful graphic card and DirectX able to support beautiful shader in real time was needed; moreover at the actual state of the art the use of the Microsoft SDK produces less noise in the motion capture and a more precise input than the OpenNI or Zigfu framework.

In both versions no calibration is needed, as the skeleton does not require measurements. The application is intended for a single user but it is quite robust and if another user enters the interactive area without stopping on a hotspot, his presence has no effect on the system (even if he is detected); if he enters the interactive area and stands on a hotspot, he will be identified and the system will be guided by him. The second version was installed permanently both in the Vatican Museums and in Allard Pierson Museum in April 2013.

In November 2012 this application won the Best Award in the category "New Interaction" during the international exhibition of virtual archaeology "Archeovirtual", organized by the European Network of Excellence on Virtual Museum, V-Must.Net; on the same occasion it also won the Public Appreciation Award out of a total amount of twenty applications.

3. Conclusions

Natural interaction reconfigures radically boundaries between the natural and artificial world. We could say that the fundamental division between technology and nature, artificial and "human" is beginning to blur (Featherstone, Burrows 1995). The crucial point is the capability, even if still at pioneer level, to establish a relationship and, therefore, communication between natural and artificial entities based on perceptive-sensorimotor dynamics: gestures, images, sounds, a reciprocal exchange of signals in time and space, instead of symbolic codes. Inside a virtual reality environment the user feels spatially embodied in the system; this embodiment is greatly enhanced by the use of natural interaction interfaces and constitutes a new frontier in the communication and learning process.

Embodiment is based on the principle of enaction (Mellet-D'Huart 2006); a term introduced by Bruner (1968) to define knowledge deriving from actions. Later this concept was re-elaborated by Francisco Varela according to a neuro-phenomenologic approach based on the assumption that the cognitive activity is "embodied" in and inseparable from body perception

(Varela, Thompson, Rosch 1991). It seems evident that embodiment depends on the effectiveness of a number of factors inside the cyberspace: communicative capability, the level of sensorial immersion and presence, emotional and cognitive involvement, the feeling of easiness that exists between the real and virtual dimension (Forte, Pietroni, Dell'Unto 2008).

These inputs coming from cognitive science and often re-used in videogames can be of great interest in the digital cultural heritage domain. We believe that embodied behaviour implemented in virtual reality systems together with natural interaction interfaces really represent a new breakthrough, especially in museums (Pietroni, Rufa, Dell'Unto 2008). In other words, they represent a catalyst in the field of learning. Information is organized and integrated in the 3D space, the user is surrounded by digital contents that he can have access to by performing specific actions (Forte, Pietroni, Rufa 2002).

The evaluations carried out on the *Etruscannning* project (Pescarin *et al.* 2012; Pietroni *et al.* 2012) have shown that visitors get very involved in the experience and they continue playing with the objects for several minutes, repeating the actions until they have full control of the system, even listening to narratives several times. Moreover, people perform the required movements in an emphatic way, as if they were playing a game. For this reason the input of natural interaction can be less precise, compared with traditional interfaces (mouse click, keyboard, joystick, etc.) but this limit does not generate frustration in the visitors, on the contrary it encourages people to keep trying, exploring and learning until they finally achieve desired results. It is an on-going process in the definition of a proper grammar of gestures, continuously being testing on the public. In fact gestures need to be really intuitive, responsive and well designed by the authors as not all people have the same perception, coordination and awareness of their own movements. We believe the project can be considered pioneering, as at the moment there are very few projects in the world dedicated to the communication of cultural heritage in museums using natural interaction interfaces in a 3D real time environment.

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APPENDIX

1. *Regolini-Galassi Tomb*

The Regolini-Galassi Tomb is one of the richest and most significant examples of the Orientalising period in Etruria. But its value is not only on an aesthetic level. The formal aspects related to the funerary ritual and the symbolic elements that emerge from the analyses of the individual possessions and their association and arrangement are valuable eye openers on the entire complex ceremony that accompanied Etruscan "princes" in life as in death.

The tomb structure, partly carved into the rock and partly built with blocks, was covered by a monumental mound with a diameter of 48 m. A *dromos* (corridor), acting as an antechamber, leads the visitor to the inner main burial chamber made up of two rooms separated by a low wall that partially closed the passage, forming a ritual open window. Two small elliptical rooms, called *cellae*, are carved on both sides of the antechamber. The cell on the right contained a large ceramic olla containing the remains of an individual cremation: relatively poor grave goods/possessions were located in this *cella*. In the left cell there were no bodies, only grave goods of controversial identification. The inner chamber was reserved for the burial of a woman of high rank, most probably of royal lineage. The rich personal collection consists of refined jewels, silverware and bronze domestic objects, and decorated fabric with golden plates (Sannibale 2008a). In the antechamber there was a funeral bed in bronze and opulent objects which have a ritual use and indicative of aristocratic banquetting practices and power. This earlier tomb, dating between 675 and 650 BC, was later incorporated in a massive mound of a larger diameter, including five other "peripheral" tombs. It was in use at least till the first half of the fifth century BC, probably by the same noble family.

The first publication of the Regolini-Galassi Tomb (after the preliminary report by Grifi and Braun) was by L. Canina in 1838 and reproduces the first map illustrating the layout of the grave goods. The plan drawn by Canina was also used by L. Grifi in his book of 1841. Some differences in the location and characterization of the objects can be noticed: differences in size and shape of some objects, different placement in the tomb, the size of the tomb itself which is represented much more monumental than it actually was.

The reconstruction proposed in this project is neither complete nor definitive, but it is an attempt to find the most reliable solution that can be achieved with the latest digital techniques. It is based on a reinterpretation of the first documentation of the nineteenth century and therefore based on only part of the placement of the grave objects as proposed by L. Pareti in 1947 (Pareti 1947).

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2. *Digital Restoration*

The process of virtual reconstruction demands different skills. First of all it is fundamental to define the process of knowledge that leads from the current state of the object to the reconstructive hypothesis. This process is essentially based on detailed observations and comparisons with other objects of the same period, coming from the same place or referring to the same cultural context or influence. The second step is to use digital tools to recreate the original shape or decoration.

The most interesting application regards engraved and embossed objects, with missing parts, for example a silver and gold *patera* from the Vatican Museums. This bowl was broken due to the collapse of the *cella* roof of the tomb and is about 70 percent intact. The decoration consists of soldiers on foot and horseback in Egyptian style and was created by engraving and embossing the bowl. Starting from the line drawing previously made by the restorer and referring to the actual state of preservation, the line drawing was completed mostly by copy-pasting the figures, as the decoration is quite repetitive. The remaining missing parts were completed by symmetry and by comparing it to a very similar bowl in the National Museum of Antiquities, Leiden, Netherlands. This completed line drawing was used to simulate the different creation processes of engraving and embossing as different layers of a "depth map", represented as a greyscale image in Photoshop (Fig 7).

Several objects were digitally restored in this way. This not only yields a well-documented and easy digital restoration method, but provides also the opportunity to visualise the object fluently in a real time system by converting this "depth map" into a "normal map" for efficient real time visualisation in Unity 3D. On the other hand, a "depth map" can also be used as a "displacement map" to create a very detailed 3D model of the object, for example to make a real replica of the restored object.

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Visual Dimension

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ABSTRACT

Etruscanning is a European project (Culture 2007) whose aim is to re-create and restore the original context of Etruscan graves. The main objectives are: digital acquisition, digital restoration, 3D representation and implementation of innovative VR environments related to Etruscan tombs and collections in European and Italian Museums. We focused on the Regolini-Galassi tomb in the Sorbo necropolis in Cerveteri, one of the most remarkable Etruscan graves. It was discovered still intact in 1836 and is famous not only for its rich contents but also for the objects showing the Orientalising influence. The finds from this tomb are kept in the Gregorian Etruscan Museum in the Vatican Museums and the empty grave at the site is not always open to public. By making 3D reconstructions of the tomb and the objects we can re-create the archaeological context of this Etruscan tomb.

As the process of virtual reconstruction of the Regolini-Galassi tomb tries to visualize it at the moment it was closed, we needed to recompose the original placement of the objects and their ancient appearance. This was not easy as we had to reconsider some contradictory historical plans and iconographies (Grifi, Canina, etc.) and to answer some difficult questions. The Regolini-Galassi tomb was implemented in a VR environment and a permanent installation was presented in the Vatican Museums in April 2013. A key aspect is the development of natural interaction interfaces: visitors use body movements to explore the 3D space and to access contents without the need for any traditional interface. This solution not only makes the experience more engaging but also allows people of every level of skill to enjoy and learn. This "embodiment" constitutes a new frontier in the communication and learning processes and we believe that it represents a crucial element in museums.