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Virtual Heritage: new technologies for edutainment

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Acknowledgements are like a small cake at a party. If the cake is too small many guests will not eat it, if it is too large it may nauseate. So why not to just make a cake based on the exact number of guests? Mmmm... have you ever tried to make a cake of an exact size? Especially in Italy? Impossible: some invites could be not come or bring other friends with them, someone might want a second slice, or could be in excess for others. Impossible! And then? Well, luckily I do not have to make a cake right now, but I have to thank. And I will try to thank people who really helped me and supported me during these years of PhD, so that each of them could have a generous slice of cake, without be nauseated!

To understand why PhD students - as also undergraduates - thank people in their thesis, you must first understand what is the entire process that leads to the end of an academic term. To explain this, I'm going to use another metaphor: no, not that of the mountain path, too overused, but I invite you to think about a sand castle. You have a great project in mind: a castle, 4 towers plus the main one in the middle, a moat, water and some plastic fishes that simulate crocodiles. Leveled the sand you can start digging. Make a hole, add sand and start modelling. Take the bucket: it's too small! You do not want small towers for your sumptuous castle. Looking around you find a bigger bucket. Make a tower: done. You do others, but some are ruined. You remake them, and then again. At the end you get 4 towers and the central one. Then the walls, raising the sand you annoy the lady on the right: please, apologize. Redo the walls, the last one makes a tower collapse. You remake the tower. Then dig the moat but the north wall slides. You redo the wall, containing the moat. At the end you add the water, hoping that it does not erode the walls. When you get to put the plastic fishes, the thesis is completed.

At this point it is better not to turn around: your neighbour has just finished a castle with 6 towers!

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ABSTRACT

Cultural heritage represents an enormous amount of information and knowledge. Accessing this treasure chest allows not only to discover the legacy of physical and intangible attributes of the past but also to provide a better understanding of the present. Museums and cultural institutions have to face the problem of providing access to and communicating these cultural contents to a wide and assorted audience, meeting the expectations and interests of the reference end-users and relying on the most appropriate tools available.

Given the large amount of existing tangible and intangible heritage, artistic, historical and cultural contents, what can be done to preserve and properly disseminate their heritage significance? How can these items be disseminated in the proper way to the public, taking into account their enormous heterogeneity?

Answering this question requires to deal as well with another aspect of the problem: the evolution of culture, literacy and society during the last decades of 20th century. To reflect such transformations, this period witnessed a shift in the museum's focus from the aesthetic value of museum artifacts to the historical and artistic information they encompass, and a change into the museums' role from a mere "container" of cultural objects to a "narrative space" able to explain, describe, and revive the historical material in order to attract and entertain visitors. These developments require creating novel exhibits, able to tell stories about the objects and enabling visitors to construct semantic meanings around them. The objective that museums presently pursue is reflected by the concept of *Edutainment*, Education + Entertainment. Nowadays, visitors are not satisfied with '*learning something*', but would rather engage in an '*experience of learning*', or '*learning for fun*', being active actors and players in their own cultural experience.

As a result, institutions are faced with several new problems, like the need to communicate with people from different age groups and different cultural backgrounds, the change in people attitude due to the massive and unexpected diffusion of technology into everyday life, the need to design the visit by a personal point of view, leading to a high level of customization that allows visitors to shape their path according to their characteristics and interests.

In order to cope with these issues, I investigated several approaches. In particular, I focused on Virtual Learning Environments (VLE): real-time interactive virtual environments where visitors can experience a journey through time and space, being immersed into the original historical, cultural and artistic context of the work of arts on display. VLE can strongly help archivists and exhibit designers, allowing to create new interesting and captivating ways to present cultural materials.

In this dissertation I will tackle many of the different dimensions related to the creation of a cultural virtual experience. During my research project, the entire pipeline involved into the development and deployment of VLE has been investigated. The approach followed was to analyze in details the main sub-problems to face, in order to better focus on specific issues.

Therefore, I first analyzed different approaches to an effective recreation of the historical and cultural context of heritage contents, which is ultimately aimed at an effective transfer of knowledge to the end-users. In particular, I identified the enhancement of the users' *sense of presence* in VLE as one of the main tools to reach this objective. Presence is generally expressed as the perception of *'being there'*, i.e. the subjective belief of users that they are in a certain place, even if they know that the experience is mediated by the computer. Presence is related to the number of senses involved by the VLE and to the quality of the sensorial stimuli. But in a cultural scenario, this is not sufficient as the *cultural presence* plays a relevant role. Cultural presence is not just a feeling of 'being there' but of being - not only physically, but also socially, culturally - *'there and then'*. In other words, the VLE must be able to transfer not only the appearance, but also all the significance and characteristics of the context that makes it a place and both the environment and the context become tools capable of transferring the cultural significance of a historic place. The attention that users pay to the mediated environment is another aspect that contributes to presence. Attention is related to users' focalization and concentration and to their interests. Thus, in order to improve the involvement and capture the attention of users, I investigated in my work the adoption of narratives and storytelling experiences, which can help people making sense of history and culture, and of gamification approaches, which explore the use of game thinking and game mechanics in cultural contexts, thus engaging users while disseminating cultural contents and, why not?, letting them have fun during this process.

Another dimension related to the effectiveness of any VLE is also the quality of the user experience (UX). User interaction, with both the virtual environment and its digital contents, is one of the main elements affecting UX. With respect to this I focused on one of the most recent and promising approaches: the natural interaction, which is based on the idea that persons need to interact with technology in the same way they are used to interact with the real world in everyday life.

Then, I focused on the problem of presenting, displaying and communicating contents. VLE represent an ideal presentation layer, being multiplatform hypermedia applications where users are free to interact with the virtual reconstructions by choosing their own visiting path. Cultural items, embedded into the environment, can be accessed by users according to their own curiosity and interests, with the support of narrative structures, which can guide them through the exploration of the virtual spaces, and conceptual maps, which help building meaningful connections between cultural items. Thus, VLE environments can even be seen as visual interfaces to DBs of cultural contents. Users can navigate the VE as if they were browsing the DB contents, exploiting both text-based queries and visual-based queries, provided by the re-contextualization of the objects into their original spaces, whose virtual exploration can provide new insights on specific elements and improve the awareness of relationships between objects in the database.

Finally, I have explored the mobile dimension, which became absolutely relevant in the last period. Nowadays, off-the-shelf consumer devices as smartphones and tablets guarantees amazing computing capabilities, support for rich multimedia contents, geo-localization and high network bandwidth. Thus, mobile devices can support users in mobility and detect the user context, thus allowing to develop a plethora of location-based services, from way-finding to the contextualized communication of cultural contents, aimed at providing a meaningful exploration of exhibits and cultural or tourist sites according to visitors' personal interest and curiosity.

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CHAPTER 1 – WHAT, WHY, HOW

1.1 INTRODUCTION

Which was the last museum you visited?

Can you tell me at least 5 elements that you saw there?

If I ask you these two questions, are you able to answer me? I assume that you can reply to the first question. But it is also likely that you, as any other person this question is asked, have difficulties in answering to the second question. Why? Because many are the problems about the fruition and dissemination of cultural contents. An emblematic example can be the visitor's analysis performed by Francesco Antinucci at the Musei Vaticani in Rome. This museum is the most visited in Italy, with 5.5 millions of visitors in 2013, and one of the most popular in the world. Antinucci chose two among the most important halls of the gallery: the Raphael's hall (with important paintings as "La Trasfigurazione" and "L'incoronazione della Vergine") and the Caravaggio hall. Immediately outside the two rooms, the researcher asked visitors if they remembered that they just visited those two rooms. 31% of them answered negatively. A third of the visitors didn't remember the two most important rooms just visited. Then he showed visitors the images of 6 paintings, 4 of which were in those halls and he asked which paintings they recognized. 10% of visitors didn't remember any picture. 32% only 1 painting and 21% remembered paintings that were not displayed in the museum. From this analysis we can conclude two aspects: visitors didn't pay attention to artworks and the museum was not capable of involving people in an engaging and captivating learning experience. And it is mainly for this last reason that generally most of people couldn't answer to the second question I posed in the beginning of this section.

Another key factor can be well explained starting from a tragic event. On March 4th 2001, this news was published on the New York Times[1] *"The Great Buddhas of Bamiyan priceless artifacts that 800 years ago survived the wrathful cannon fire of Genghis Khan -- are being steadfastly destroyed bit by bit with hammers, spades and explosives, Afghanistan's Taliban militia stated officially today for the first time"*. Some hours before, indeed, Taliban government in Afghanistan ordered the implosion of the two statues of Buddah, 38 and 53 meters high, in the Bamiyan Valley. Two among the greatest pieces of early Buddhist art that survived at least 1,500 years, were powdered in a pile of ruins for political and religious reasons. *"The Buddhas have lived through great damage and still survived"* said Rakhaldas Sengupta (75 y.o., a retired archaeologist in New Delhi). *"Some things can be restored. But if they are brought down in chunks and then ground into bits, what will be there left to do?"* Exactly, what can be done to preserve the heritage significance? Can a heap of mud and stones transfer artistic information and emotions as the two huge and ancient statues did until their destruction? This question can be more generally asked to the entire scientific community. In fact, one of the main objectives that cultural heritage researchers have to cope with is how to communicate the value of ancient ruins and artistic treasures to the world, whether they can still be visited, or no longer visible - like the statues of Buddha. First of all, indeed, art pieces have to communicate and hand over the significance to people and not just be seen as untouchable objects in theca, shown only to be observed as a mere aesthetic treasure.

The Museum, according to the ICOM's (International Council of Museums) definition, is a *non-profit, permanent institution [...] which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment* [ICOM, 2007]. The museum's main function, as that of any other cultural institution, is to communicate the research results to the public, meeting the expectations of the reference audience and using the most appropriate tools available. The last decades of the 20th century witnessed a substantial change in this role, a change driven by the evolution of culture, literacy and society. The museum shifted its focus from the aesthetic value of artifacts to the historical and artistic information they encompass [Hooper-Greenhill, 2000], and its role from a mere "container" of cultural objects to a "narrative space" able to explain, describe, and revive the historical material in order to attract and entertain visitors. These changes require creating new exhibits, able to tell stories about the objects, enabling visitors to construct semantic meanings around them [Hoptman, 1992]. The objective that museums pursue is reflected by the concept of Edutainment: Education + Entertainment.

[1] http://www.nytimes.com/2001/03/04/world/over-world-protests-taliban-are-destroying-ancient-buddhas.html - (Last accessed February 2014)

In light of the strong changes of cultural institutions' role and value, the visitor’s involvement problem, well explicated with the visitor’s analysis at the Musei Vaticani, can be resolved. The Cleveland Museum of Art, for example, in 1996 decided to undertake a major change in the management of the museum, moving towards a visitors-centric approach. New services, exhibit paths, laboratories and café allowed an increasing of visitors’ satisfaction. Moreover last year, with a huge investment, the museum opened the new 39,000-square-foot atrium, the technology-driven “Gallery One”, the north wing galleries and new programming initiatives for children and families. In particular the “Gallery One” exhibition presents masterpieces by Pablo Picasso, Auguste Rodin, Viktor Schreckengost, Giovanni Panini, and Chuck Close through hands-on and technology-based activities, besides of *ArtLens*, the museum’s new app for iPad. The results were amazing: in 2013 the museum attracted more than 500.000 visitors, marking a 39% increase from the previous year, and an increment in memberships and donations. Moreover a recent community-wide survey revealed that now the Cleveland Museum of Art is the favorite museum in Cleveland, garnering 38.5% of the vote compared to its nearest competitor at 19%.

Furthermore the museums’ transformations also allowed to answer to Mr. Sengupta question (“What will be there left to do?”). The Technische Universität Muenchen (TUM) has tried to respond. Starting from the ruins of the two Buddah statues, researchers have analyzed, digitized and catalogued all the left pieces. Thanks to the some photos taken before the destruction, they have mapped all fragments, obtaining the possibility to reconstruct, not only digitally, but also physically the two statues. But studies have gone beyond. The analysis of the ancient chunks have revealed historical and artistic information never known before. Scientists have discovered that in the past the statues were painted with bright dyes, which the weather erased over the centuries. Moreover the construction methods of the statues were discovered and the tests on the materials proposed new ways for a better preservation. Finally it was possible to date with a better precision the two huge artworks. Researchers have therefore answered to Mr. Sengupta. The demolition of the monument have only caused the end of the physical part of the art piece, but it even allowed a step forward to a more complete historical and artistic significance that the two statues represented.

But as indicated by ICOM [2007], one of the principal missions that cultural institutions have to achieve is to properly communicate researches to the public, meeting the expectations of the reference audience. Indeed, nowadays visitors are not satisfied with ‘learning something’, but would rather engage in an ‘experience of learning’, or ‘learning for fun’ [Packer, 2006]. Hands-on and interactive exhibitions, allow visitors to interact with archive material, to learn while they play with it [Caulton, 2002] and to transform them from passive viewers and readers into active actors and players [Wojciechowski et al., 2004]. As a result, institutions are faced with several new problems, like the need to communicate with people from different age groups and different cultural backgrounds, the change in people attitude due to the massive and unexpected diffusion of technology into everyday life, the need to design the visit by a personal point of view, leading to a high level of customization that allows visitors to shape their path according to their characteristics and interests.

Recent advances in digital technologies offer archivists and exhibit designers new interesting and captivating ways to present and disseminate cultural objects, meeting the needs of personalization and interactivity requested by visitors [Addison, 2000]. In particular, Virtual Reality (VR) and Mixed Reality (MR) allow creating novel exhibition paradigms, rich in those informative and emotional contents often missing in the classic ones. The objects in the museums have lost their original context, which can be re-created through a multimedia environment, where visualization, sounds and perfumes can be used to increase the sense of immersion and presence. VR allows enjoying unavailable objects as well. Such objects can be lost in time, or cannot be shown without compromising their preservation, or are simply "buried" into dusty archives. The same concept applies to architectural objects, allowing to virtually restore lost buildings and their rooms.

The integration of cultural heritage and ICT technologies, in order to develop powerful tools to display cultural contents, is often referred to as Virtual Heritage (VH). VH allows the development of virtual museums, which, according to the Encyclopaedia Britannica, can be defined as *"a collection of digitally recorded images, sound files, text documents, and other data of historical, scientific, or cultural interest that are accessed through electronic media"*. This general definition takes different realizations according to the application scenario, the technologies involved and the users' involvement, ranging from the presentation of a digital collection over the Web, to the development of interactive immersive installations on the museum site [Sylaiou et al., 2009].

Virtual museums and virtual environments represent powerful tools that cultural institutions can use to involve visitors. Over the years their potentialities have increased and will continue to do so, allowing new and more efficient interaction modalities. The first generation of virtual environments was characterized by low resolution, poor graphic displays and inadequate interaction mechanisms, which resulted in a poor user experience and, therefore, in a rapid disaffection towards the VR applications [Bowman et al., 2008]. Such limitations have been overcome with new technological devices, like high definition displays, 3D monitors, holographic projectors and holotouchs, immersive environments, natural interaction through gestures, expressions and movements [Burdea & Coiffet, 2003]. However, such devices are often expensive, while museums are confronted to limited budgets for designing and creating the exhibit, and therefore, especially for small realities, they often cannot afford to buy and maintain costly technological structures or apply them on a large scale. The same limitations apply to creating contents and developing real-time interactive environments, which require the use of specific, and often expensive, authoring and management tools.

Fortunately, the horizon is slowly changing, mainly due to some factors:

- the improvement of technological devices. The industry produces many different kind of technological devices - as notebooks, smartphones, tablets - with increasing quality and shorter time to market. Hardware performance continues to grow and combined with increasing resolution of screens allow a better content fruition. In addition, the enlargement of the market of technological devices has caused a drastic reduction of costs, allowing a greater diffusion of them;
- the availability of efficient high quality mobile devices (smartphones and tablets). The computing power and the continuous connection to Internet in mobility have enabled the development of many location-based personalized services. Moreover devices are always with owners and this has allowed companies and institutions to only develop apps without warring about the hardware, with a consequent reduction of costs;
- the increasing of speed and bandwidth of Internet connections. The speed of 4G and fiber optics enable the exchange of huge amounts of data allowing the enjoyment of complex multimedia contents as movies, interactive environments and 3D materials;
- new interaction modalities. New devices allow to interact in new ways with greater ease and improving the user experience. Multi-touch screens, AR devices and natural interfaces permit to interact with the digital world in more engaging and effective ways;
- the increasing availability of Open Source and freeware software solutions allows to drastically reduce the costs of developing applications. Furthermore with those tools also non-technical people can create effective digital experiences.

The use of new technologies, especially Virtual Reality, allows cultural institutions to propose contents in new and captivating ways, able to meet people’s needs and preferences. The main aim is to exploit the possibilities that technologies offer to intrigue users and engage them in a complete cultural experience.

1.2 MOTIVATION AND OUTLINE OF THE THESIS

According to Addison [2000], there are three main stages that characterize the development of any Virtual Heritage application: (i) documentation, (ii) representation, (iii) dissemination.

Documentation involves gathering data about the object under study. Researchers have to collect and analyze all the available sources they found, taking measures, photos and video footages of the art piece. They have to do their utmost to accumulate the maximum number of information with the highest degree possible of accuracy. Data can be collected through simple methods as the analysis of ancient paintings or maps or compering different written documents [Yahedu, 2008], up to complex technological techniques as laser scanning, digital photogrammetry and image-based acquisition. [Debevec, 2003; Yastikli, 2007; Rüther et al., 2009].

Representation deals with the virtual reconstruction of heritage objects. Based on the data acquired, cultural entity can be artificially re-created with scientific rigor and with a level of details depending on the aims of the project. Automatic 3D modeling procedures [Pitzer et al., 2010], advanced texture extraction techniques [Remondino & Niederoest, 2004], photorealistic rendering [Happa et al., 2012] are just some of the research in this domain.

Finally, *dissemination*, also called *presentation*, refers to how the 3D reconstructions are presented to users by means of interactive digital media. According to the final goals of the cultural heritage project, the target of users and the available tools, different devices, new interaction paradigms, storytelling and innovative fruition methods can be used in order to meet the users' expectations.

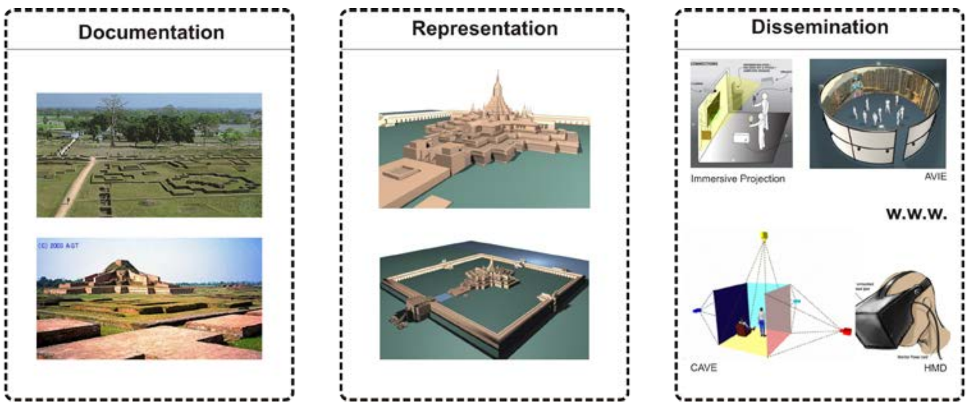

Figure 1. The three domains of Virtual Heritage [Digital Heritage Interpretation, 2010].

The main aim of this thesis belongs to the third part. Although undertaking the first two steps was clearly essential for my research, my studies focused on analyzing, developing and experimenting new ways to disseminate cultural contents through ICT and VR approaches.

The main objectives can be summarized as follows:

- study and implementation of VR and MR applications for Cultural purposes;
- analysis and development of Virtual Learning Environment for education and entertainment;
- study and development of novel interfaces for Virtual Heritage fruition.

Technologies are, indeed, in support of culture, helping historians, archivists and exhibit designers to communicate cultural information in best ways. As illustrated in the chapters below, through their analysis and users' evaluation tests we could identify issues and strong points of each of them, especially according to the specific scope of the project and the reference target of users. Another objective that I have ambitiously pursued is the composition of a thesis that could be of service and incentive to cultural institutions. Studies here reported wanted to offer new presentation and fruition methods that can be easily used in the artistic field. I hope that these processes, technologies and results can encourage these entities for an autonomous development of new cultural identities, with low costs and high impact and utility.

In the next chapter, it will be described the methodological approach used for the realization of the projects reported later. In multidisciplinary areas it is really important to define and follow a rigorous approach, in order to decrease the amount of errors and lacks and to reduce the complexity already inherent in the communication among different scientific fields. The methodological approach proposes a process for an appropriate development of Virtual Learning Environment, from the research of historic and artistic sources to the creation of three-dimensional objects and environments, with a specific attention to the final user's interaction. This method has been modified and refined during the years of my research activity.

Chapter 3 presents the key concepts on which my thesis is based on.

Chapter 4 briefly describes the projects we developed during my research. All this projects, as later reported, have allowed to deeply analyze the main and most effective aspects of Virtual Heritage. The projects are shortly shown here in order to recall them later when the different studies are explained in details.

The main concept of the VLE is the possibility to carefully reconstruct any environments in order to recreate the original historical and artistic context of any cultural object or historical characters. Chapter 5 faced with this problem, investigating different methods and possibilities to enhance cultural significance.

In chapter 6 in order to provide effective learning environments, we studied ways to enhance the users' sense of presence and involvement. Different approaches were studied, as the maximization of the quality of visual feedback, the maximization of the audio component, and the population of the virtual environments.

Chapter 7 takes a step forward respect to the content presentation. Here we deal with how give to users more freedom on information and how to relate them in order to engender more curiosity and incentive for discovering information. In this way people perform the lead role as active actor of their learning experience.

Once identified contents and designed the way to present them, it is necessary to find the most appropriate mode of interaction between users and information. Modalities can be many as many are the available interfaces, as touch screens, joysticks, tablets, etc... For research purposes, in the eighth chapter of this thesis, we tackled with the most recent and most promising approach: natural interaction.

In chapter 9 a scope now of fundamental importance is presented: the mobile scenario. Although it represents one of the possible options which would fall into the other previously chapters, we wanted to separate it in order to give greater visibility to an area that revolutionized and continue to do so the cultural and touristic panorama. Moreover the projects here described include and well-summarize most of the aspects of my research activity.

Chapter 10 tackles with the important aspect of the narration of contents in a gamification way. This approach allows to better engage users using gaming methods applied to cultural scenarios.

Finally, conclusion shows the motivations about our research and future targets in the field of Virtual Heritage and Virtual Learning Environment.

CHAPTER 2 – METHODOLOGICAL APPROACH

Following the ramification of topics explained in the section *1.2*, my research activity has led to the development of many projects. Crucial importance was initially assigned to outline a process for the development of Virtual Heritage projects. From the identification of sources to the integration of technologies, from the creation of appropriate content to the development of the IT infrastructure, in Virtual Heritage activities all the components that works together for a unique goal comes from interdisciplinary areas. Although that difference, in our opinion, is a point of strength, entails additional problems, e.g. the difficulty of dialogue between IT and artistic methodologies, the scientific rigor often impossible to adapt on historical and cultural approaches and the integration of concepts belonging to different discipline. A rigorous methodological approach was of fundamental importance in order to reduce issues. This process has been properly modified and refined during the years of my research activity, and it was followed for the studies and implementations of all the projects described later.

We want to underline again the substance of the definition of this concept. In an area of interest so beveled, on the borderline among different academic worlds and where end users play the most important role, a methodological approach well-structured is quite equal important to the whole creation of the user experience. If the process had been wrong or missing some parts, results would have suffered strong consequences, and final users would have judged the experience with drastic criticism.

This approach is so structured:

1. Research and digitization of historical/artistic/technical sources
2. Validation and cross-check of the sources

3. Creation of contents and environments
4. Creation of the cultural experience
5. Users' evaluation tests

For the development of our projects we mainly relied on open-source software. The reasons for this choice were twofold. Firstly, because we believe that the panorama of open-source software can properly be compared with the commercial one. The final quality of works is generally equitable, leaving, however, to artists and technicians higher freedom in the process of creation of contents. Secondly, especially in this period where in all over the world cultural institutions receive less founds from governments and they have to reduce costs, we wanted to demonstrate how can be realized ambitious Virtual Heritage projects at very low costs, [see Bottino & Martina, 2010].

Finally, since the main goal of cultural applications is to transfer cultural knowledge to users – anyone they are – we followed usability design principles, in which the user is in the center of the development. Furthermore, through a Usability Engineering approach, we aimed at maximizing the User Experience and, thus, at reaching high levels of usability. Where possible, we also used an iterative design process, where, at each cycle, the usability of the design choices is validated through sessions of user testing.

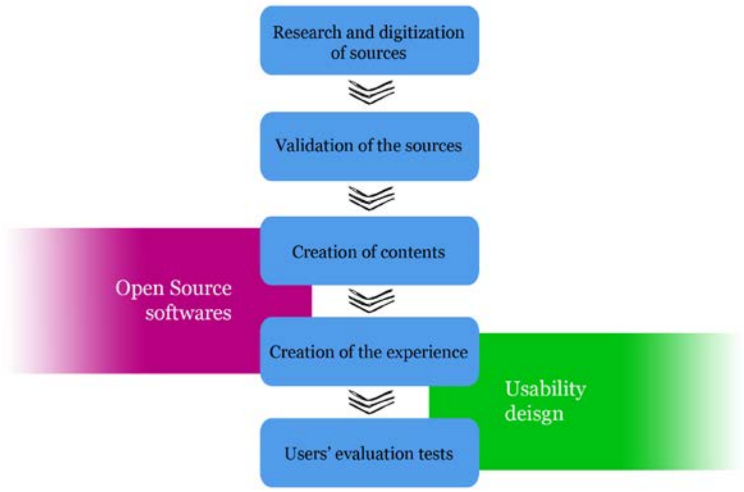

Figure 2. The methodological approach

2.1 RESEARCH AND DIGITIZATION OF SOURCES

The first step in any Cultural Heritage project is the research and analysis of all the related historical, artistic and technical documentation. Once identified the aims of the project, research of historical and artistic materials represents the main important task: without a good base of sources, everything that comes later will become frivolous. This stage can be complex depending on the subject of the research and the depth of information we want to present to users. It is certainly right to find the highest number of sources in order to have a wider panorama of choices for the following steps. However, it is also true that all sources need to be properly evaluated: not all the found materials can be useful, right or pertinent with the project.

London Charter (LC) [2009] – an important document that states standard criteria to follow in order to ensure a rigorous realization of Virtual Heritage applications – in the third principle said:

> *In order to ensure the intellectual integrity of computer-based visualization methods and outcomes, relevant research sources should be identified and evaluated in a structured and documented way.*

Each book, article, photo, picture, ruin that we found need to be critically checked. An accurate analysis has to be done in order to identify possible historic and artistic mistakes, which would invalidate the entire project. It is therefore appropriate ask advices to experts, with respect also to assess sources with reference to current understandings and best practice within communities of practice (LC, principle 3.2).

Moreover for the *Transparent principle*, later explained, all sources and their provenance should be disseminated (LC, principle 4.5).

Since "*documentation should be disseminated using the most effective available media, including graphical, textual, video, audio, numerical or combinations of the above*" (LC, principle 4.11), a precise digitization process should be carried out. Each particular media needs a different digitization method. From the scan of textual and photographic documents, to the transposition of audio tracks, from the recording of oral interviews, to photogrammetric footages, each technique has to obtain as result the digital resource at the highest quality possible. That because, even if materials will be used at lower resolutions, the long and onerous digitization process is better if occurs only once. Downgrade quality process is irreversible and can be easily followed out, the inverse process, instead, is impossible: in terms of technical specifications, a low quality sources can't be enhanced.

2.2 VALIDATION OF THE SOURCES AND THE TRANSPARENT PRINCIPLE

Next step is the validation of sources. As early said, not all the found sources are appropriate or historically right. In archives, libraries, universities and Internet there are plenty of documentation but often, especially on the web, information is missing or incorrect. A key element of Virtual Heritage application is the historical and scientific accuracy, therefore a precise validation process is mandatory. Experts can really help, not only judging if a document is authentic and properly dated, but also recommending how to link the analyzed content with all the others.

An effective way to control sources is the cross-check. During my research activity many times happened that different content reported opposite information. In particular the living memories of people who lived or worked in heritage places were different from the pictorial or written resources. In those cases a further investigation clarified that both were right: in different times the environment/object were modified. This has allowed us to better date all the changes occurred during the past. Memories of people are an excellent source, often forgotten by researches.

But when we choose a source over another, or when we link two of them giving a specific significance on their relationship, we are presenting to users a specific point of view. Of course this is inevitable: when someone narrates something, we are listening to only his point of view. But in a Virtual Heritage application, where education is the principle goal, a unique perspective could be a serious problem. The LC deals with this with the *Transparent principle*. Since it is impossible to illustrate cultural events, buildings, objects in a totally objective way, the best approach is to firstly give users a point of view of an expert without any ideological, historical, social, religious and aesthetic factors (LC, principle 3.3). Secondly give to viewers the access to all the documentation thus allowing them to personally interpret contents. Significance, hypothetical dependency relationships, implicit knowledge, reasoning and outcomes disclosed in the application have to be properly disseminate (LC, principle 4.4), so that user can independently evaluate them. Then, the Virtual Heritage application should be properly designed to enable rigorous and comparative analysis and evaluation (LC, principle 4.2).

2.3 CREATION OF CONTENTS AND ENVIRONMENTS

The collected information was then used as a reference to create the 3D models of the spaces in the environment as well as all the objects, furniture, and elements included therein. Several authors, such as Debevec et al. [1998] and others in Bhagawati [2000], proposed photogrammetric approaches for the 3D reconstruction of architectural environments. These methods can be powerfully used if we have a sufficient number of images depicting the elements to be reconstructed, and of course with a suitable quality. If we can't match these requirements, these approaches could not be applied. A reconstructive modeling has to be used. Based on architectural plans, blueprints, visual measurements and historical literature the main volumes (walls, rooms, streets, gardens) were defined. Thanks to the possibility offered by modeling software to import images as reference, a precise reconstruction becomes an easy task. A real important consideration in virtual projects is the weight of the model. Less complex is the final environment, better it is for the application: a huge amount of polygon consists in possible problems as delays and slowness in the real-time reproduction.

During the modeling process a high level of details for geometry must be used. This for two reasons, first because, as previously stated about sources, the upgrade of the quality is an impossible task, and second because from a detailed model it is possible to generate a sharp displacement map, that can be later used for the lighter version of the model. Obviously, when the final model is exported for real-time viewing, the number of faces has to be reduced. The textures need to be created based on photos taken in the real environment or on the pictorial materials found. When images are ruined or modified from time, a digital restoration can be applied. Finally, the lighting design of the environment aimed at reproducing the original atmosphere depicted in the iconographic materials through an accurate qualitative comparison between available images and photo-realistic renderings of the environments.

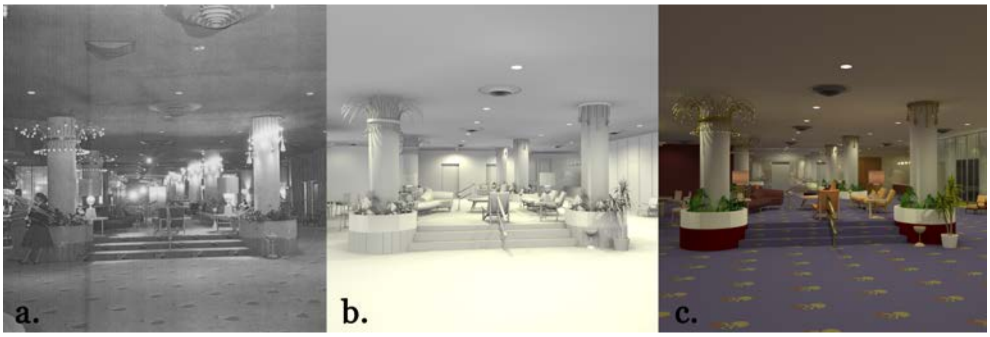

Figure 3. The modelling process of the Riviera Casino: (a) a photograph of the hall of the casino, (b) the 3D model and (c) the texturing and lighting process.

Only for object or restrained surfaces another technique can be used: reality-based modelling. This method use two or more images of a subject, taken under some requirements as prospective and slant, to automatically reconstruct the 3D model (*Figure 4*).

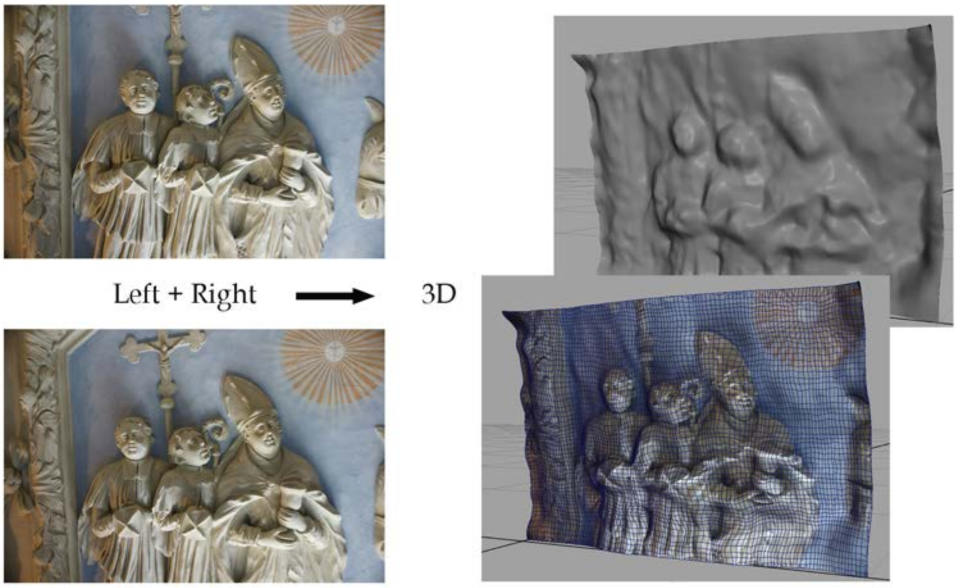

Figure 4. An example of reconstruction of the 3D model of an artifact from multiple images.

2.4 CREATION OF THE CULTURAL EXPERIENCE

This is the most complex part of the entire project. According to the digital contents available we have to find the proper way to present and disseminate them to the audience. Different presentation and interaction modalities cause totally distinct experiences, and this can represents the success or not of the application. Obviously how to create a complete and engaging experience depends on different aspects that we have to outline at the beginning of the project: the aims, target of users and possible interaction means. The goals and scopes identified how the application will be enjoyed, in situ, online or in mobility. These different possibilities determine the potential interaction methods. From an online presentation to the natural interaction all these choice have pros and cons, and the final decision has to represent the best and proper option for the conditions of the project. Moreover also the context in which the application will be experienced – a museum, school, own home, outdoor – establish influential characteristics, as the educational value, the fruition modalities, the collaborative or not environment.

Essential element is the identification of the target of users. Based on that we can better choose the interaction and the presentation layer. Contents, texts, narration and the aesthetic of the application strongly depend on the users' characteristics. Also particular categories of users with some difficulty must be considered, for the visually impaired, dyslexic and other forms of problems some solutions have been found and adopted, in order to improve the accessibility of applications.

The possibilities offered and the relationships among them can create countless case studies. We therefore believe that it is more effective to illustrate these choices within the research projects that we carried out. This phase will then be fully described in later chapters, showing different modalities and achievements.

2.5 USERS' EVALUATION TESTS

As will be better explained in the section *2.7*, users' evaluation must be kept in constant consideration for the success of the project. In order to reach high level of usability and satisfaction, during all the development process we have to perform cyclical tests sessions. The result will be used to modify and enhance the various aspects of the experience. But evaluation methods are many different, and we have to choose the appropriate applicable ones which better fit our requisites. According to Jakob Nielsen [1993] we have:

- *Heuristic evaluation*, that is a usability analysis where specialists judge whether each element of the application follows a list of established heuristics. There are some advantages, like quick and inexpensive feedbacks also at the beginning of the design process, and some disadvantage, as the difficulty in find experts and the arduous aggregation process of the multiple experts' evaluations.
- *Performance measurement*, it is used to obtain quantitative data about the performance of the application during users' usage. Any interaction between participants and tester is prohibited, in order to not affect the data. For useful results at least 5 users are needed, while 8 or more participants would be more desirable.
- *Thinking aloud*, it is a direct observation method where participants have to think aloud, expressing their thoughts, feelings, and reactions while they are enjoying the application. This method turns tacit users' behaviours—

such as interpretation and elaboration — into explicit actions that the observer can analyze. This method is particularly helpful for determining what aspects of a system are confusing.

- *Observation*, it allows the observer to view what users actually do in context. This technique involves an investigator that constantly observes participants while they are performing. The observation may be either direct, where investigator is present during the task, or indirect, where all is recorded and later analyzed, but in both cases the observer shouldn't be obtrusive.
- *Questionnaires*, they represent the most frequently used tools for usability evaluation. Many different are available for diverse scopes and they may be submitted to users before and after the task. Some of them will be explained later.
- *Interviews*, it is a famous method for wheedle participants' opinions and thoughts. Generally the interview is done by one interviewer speaking to one informant at a time. This one-to-one way allows to quickly identifying mistakes and misunderstandings and cleared them up.
- *Focus groups*, they have the power to bring out users' spontaneous reactions and ideas. A group of approximately 6-8 participants of the chosen target discuss together about their feelings, ideas and opinions about a specific topics. A moderator observes, give input to people and take notes.
- *Logging actual use*, computer automatically collects statistics about the use of the application and the frequency of use of some features. Those data can be used to optimize the application. This method is useful because can collect a huge amount of data from many users in a short time and with extreme accuracy.
- *User feedback*, similar to questionnaire, is used to get opinions about a specific project.

All these evaluation methods can also be applied in a combined version. During my research activities we used different of them for diverse goals. They will be better illustrated, with the relative results, in the following chapters.

2.6 OPEN SOURCE TOOLS

Until the last decade, most of the software were professional and often expensive software, hampering their diffusion and use by everyday users. This situation has radically changed with the introduction of the Free Software (FS) and Open Source (OS) concepts by Richard Stallman and its GNU project in 1983 [Stallman, 1999]. The FS/OS idea refers to practices in software production and development in which the source code is available free of charge to the general public for use and/or modification from its original design. Typically, Open Source code is created as a collaborative effort in which programmers improve the code and share their changes within the community. It's important to point out that the term "Open Source" does not absolutely mean the contrary of "professional". Several programs developed under OS/GNU/Creative Commons[2] licenses have been shown to be comparable, in terms of available features and quality of the results, with commercial software, while OS enthusiasts often claim being even better.

Nowadays, many free applications, libraries and complex authoring systems are available. As a result, the costs of creating digital contents, designing and developing applications have reduced considerably. Furthermore, recent products emphasize the simplicity of use in order to allow their usege not only by skilled but also by non-professional users. Virtual Heritage can obviously significantly benefit from all these technological improvements, since they allow the development of complex environments, supporting highly realistic visualization, providing a natural interaction through pervasive devices and that can be enjoyed on different platforms, from Internet to immersive environments, PDAs and smartphones. Therefore, the possibility to manage these applications in real-time on low-cost consumers' hardware, the possibility to use appropriate interaction devices and the availability of free software tools enable, on one side, the development and the execution of effective and, most of all, affordable edutainment solutions and, on the other side, a wide diffusion, in the near future, of VH approaches in museums.

Generally speaking, three main steps are necessary in order to develop effective VH solutions:

- to collect, or to create, the digital versions of all the cultural objects and other elements that will populate the virtual exhibit;
- to design the VH application, that is to design contents management and their presentation method;

[2] https://creativecommons.org/ - (Last Accessed February 2014)

- to design the interaction for interactive/immersive applications, focusing on how computers can sense visitors, understanding their actions and wills and giving them a proper feedback.

These points will be detailed in the following subsections, focusing on showing how OS software and hardware, low-cost devices and the computer games world can contribute to the development of affordable VH solutions.

2.6.1 Contents creation

The Digital Content Creation (DCC) includes not only the creation of digital contents, such as images and videos, audio, 3D models, etc..., but also the processing and adjustments required before being presented to the end-users. Therefore, DCC involves several media and requires appropriate and specific software tools. Depending on the contents to be created, several OS tools are available. A short list of them will be presented in the following.

One important thing to underline is that the same digital contents can be exploited in different applications and displayed through different output devices. For instance, the 3D model of a building can be used to develop an immersive virtual environment that allows navigating it, to create photorealistic renderings for enhanced panoramic views or even displayed on a mobile phone for an AR application. Each environment has its own requirements, in terms of quality and resolution of the contents it can handle. However, despite the different types of Virtual Learning Environments that can be designed, the process of DCC, if properly handled, can be performed only once. Actually, if the contents are created at the highest level of detail and quality, they can be easily scaled down and adapted to different media, from personal computers to mobile devices, allowing to amortize in the best way the expenditure of human resources for content creation. The inverse process, that is up-scaling an original low-resolution object, is often impossible, and it usually requires creating from scratch a new version of it.

2D Image creation and editing

Digital images are at the foundation of many new two and three dimensional documentary techniques, since they provide not only the digital equivalent of traditional photography, but they can also be used to create panoramic images, videos, 3D object reconstruction and texture maps for 3D modeling. 2D images can be obtained as the result of document scanning, which converts text and graphic paper documents, photographic film, photographic paper or other files into a digital format. Images can also be created with vector graphic drawing software, which allows representing images in computer graphics through geometrical primitives such as points, lines, curves, and shapes. Free/Open Source high-quality vector graphic editors, like *InkScape* and *Synfig*, are available. Some programs, like

KToon, *FlashDevelop* as well as *Synfig*, allow also developing interactive 2D animations.

Operations like exposure and color correction, sharpening, noise reduction, dynamic range extension, correction of optical distortions, resizing and cropping, combining multiple images, converting between different image formats and preparation for web distribution are commonly performed on digital images. Robust image processing tools are widely available. The most known of them is *Adobe Photoshop*, a commercial tool that is the defacto standard for photo retouching. However, many FS/OS valid alternatives are available, like *GIMP* (GNU Image Manipulation Program) and *Paint.net*.

Strictly related to digital images are videos, whose educational use in museums is rapidly increasing. At the same time, thanks to the technological development, the portability of media assets—the mobility of access to the resources and to their distribution channels—is accelerating exponentially. Digital video repositories can be built form analog (VHS) existing material, or created from scratch combining shots, images, text, 3D and 2D animations. Several OS programs are available for video capturing, processing and editing, like *VirtualDub*, *CineFX*, *Cinelerra*, and the Video Sequence Editor of *Blender*, a program for 3D modeling that will be described in details in the following.

3D contents creation

A realistic three-dimensional virtual world is the result of a composition of several elements that must be properly design and developed. Some valuable OS 3D modeling software, which can count on a large group of enthusiastic users, are *Meshlab*, *Art of illusion*, *K-3D*, *Moonlight|3D* and *OpenFX*, but the most important and famous of all is by far *Blender*. It is available for many different platforms (Windows, MAC OS and Linux), supporting a variety of geometric primitives. It has an internal rendering engine and it can be easily integrated with external ray tracers. Key-framed animation tools, including inverse kinematics and armature, soft and rigid body dynamics with collision detection, fluids simulation and particle systems are also available. More features can be added integrating plug-ins developed in Python. Despite being a powerful and constantly evolving tool, some of its features still need development.

Digital 3D models can be also created from real artifacts with 3D scanners, which are devices that can capture their shape and appearance (i.e. color) using different techniques, like laser, modulated or structured lights, handled probes or volumetric techniques (i.e. using CT scans). While 3D scanners are often expensive devices, there is some OS software, like *ARC3D*, *Insigth3D* and *Photo-To-3D*, that allows the reconstruction of 3D objects from multiple images taken around them. The quality and the precision of the results are not comparable with that of 3D scanners, but they are often sufficient for the majority of uses.

In order to produce high quality 2D images and animations from 3D models, several photorealistic renderers, like *Cycles*, *Yafaray*, *Aqsis*, *Indigo Renderer* or *POV-ray* can be used. For many applications, like architectural illustration, experimental animation and educational videos for children, a non-photorealistic rendering (NPR), like the one obtainable with the *Freestyle engine*, is preferable. NPR is a technique that attempts to capture the elements of different expressive styles, such as painting, drawing, technical illustration, and animated cartoons, and apply them to reproducing 3D contents on screen [Masuch & Röber, 2003]. In virtual heritage, this can be used, for instance, to show a cartoon-like world, probably more appealing to kids.

Audio

As our perception of an environment is not only what we see, but may be significantly influenced by other sensory input [Chalmers et al., 2009], is important to mention the role of sound. Sound and localized (3D) audio make an important aid to the cultural experience and are the keys to create the atmosphere within which to immerse visitors. To handle sound processing, a powerful tool like *Audacity* can be used. It is a free software, cross-platform digital audio editor and recording application. Its main features cover audio recording, sound files editing and mixing. *Ardour* is another OS software available for MAC and Linux distributions.

When the application requires handling interactive sounds, that is, an audio reacting to user inputs and/or changes in the environment, software platforms like *MAX/MSP/Jitter*, *Processing* and *SuperCollider* provide an intuitive graphic environment for combining input from the environment and sound generation/processing routines.

2.6.2 Contents management

VR is a complex simulation of a "reality", requiring 3D graphics, physics, 3D audio, user interaction, avatar management and artificial intelligence (AI) handling. Designing such an application requires designing each of its components. This is a complex task, which involves complex programming skills. Again, OS solutions and computer games industry provide valuable contribution to this process.

Several OS packages/libraries are available for covering all the aspects of the development of a VR application. Virtual Engines, like *OGRE*, *OpenSceneGraph*, *OpenSG* and *Ultimate 3D*, can be used to render in real-time the 3D environment. These engines usually provides limited features, but can be expanded by integrating them with other libraries. In order to manage collision detection, rigid body and fluid dynamics, physics engines that provides simulation of physical systems, like *Open Dynamic Engine* (ODE), *SOFA* (Simulation Open Framework Architecture) and *Tokamak*, can be used. Audio 3D can be managed by libraries that directly interface with the sound card, like *Open Audio Library* (OpenAL). The Artificial Intelligence component required to define avatars and characters behaviour can be implemented with libraries like *CHARACTERISE* (Virtual Human Open Simulation Framework) and *SmartBody*.

The drawback is that putting all these pieces together is not always simple. Each of these libraries has been developed as a stand-alone element, using different programming languages and calling conventions, which may cause compatibility issues during the integration.

The solution to the need of all-in-one simple development environments for VR is offered by the computer game industry [Lepouras & Vassiliakis, 2005]. Usually a computer game is a VR application. Current videogames provide reach 3D interactive environments that can be used as collaborative tools for educational and learning purposes. Therefore, they can be used not only for leisure but also as a powerful tool for supporting cultural heritage. The term “serious games” refers to applications where game technologies are used in non-entertainment scenarios, such as flight simulators, business simulation and strategic games.

Seriuos games involve both entertainment and pedagogy, that is activities that educate and instruct [Zyda, 2005]. Their use in cultural heritage has been emphasized by the recent works of Anderson et al. [2009], and by several international conferences and workshops.

Game development is a complex and labor intensive task. It takes years to complete a game from scratch. Gaming industries crave for reducing time to market and nowadays game development is based primarily on Game Engines (GEs). A GE is the software that forms the core of any computer game, handling all of its components: image rendering, physics and collisions management, audio 3D, and support for AI and for all other game aspects. *Unreal*, *Cry Engine* and *Unity3D* are the most famous commercial engines. The *Unreal Development Kit* is a version of the *Unreal Engine* that can be used free of charge for non-commercial and educational purposes. Many OS GEs are available as well, like *Spring Engine*, *Nebula Device* and *Crystal Space*. Game Engines for OVEs are also freely available over Internet for the most common Web3D players. There are several advantages of using GEs for developing complex VR applications. First, while a game can be certainly developed by modifying the GE source code, many GEs can be completely customized using scripting languages, which are easy to learn and do not require an expertise in programming, allowing non-skilled users to easily adopt them. This way, development costs are extremely reduced, since they are limited to the creation of the digital contents and of the game logic. Second, most of the GEs provide network capabilities and communication support, allowing the development of collaborative applications involving several (and possibly remote) users. Third, unlike applications designed with Virtual Engines, the developed products are often directly portable on different execution environments (such as PC, game consoles, browsers, PDA and mobile devices). Finally, *UDK* and many other GEs have a built in support for stereoscopic displays and they also can be easily modified (like in Jacobson, 2002, and Juarez et al., 2010) to support complex immersive environments like CAVEs.

Using GE to develop virtual environments for VH applications have proven to take almost half the effort than with traditional techniques, requiring a heavy programming effort especially for developing the necessary interaction support [Lepouras & Vassilakis, 2005].

Developing MR/AR applications usually requires:

- combining the rendering of 3D and multimedia contents with images taken with a video camera, and
- tracking the position of the user in the real world.

While the first component can be easily managed by Virtual Engines like *OGRE* and *OpenSceneGraph*, the second usually involves direct user input, GPS or images of markers/fiducials taken with wearable camera and recognized by proper algorithms. Some OS libraries for marker recognition and tracking are *ARToolKit*, *ARToolKitPlus*, *SSTT* and *BazAR*. Some of them have been developed for different platforms, in order to allow the implementation of MR/AR applications over Internet (like *NyARToolKit*, *FLARToolkit* and *SLARToolkit*, porting in, respectively, Java, Flash and Silverlight of the *ARToolKit* library) or on mobile devices (like *Andar* and *Mixare* for the Android platform).

Finally we briefly mention that OS libraries and authoring tools are also available for developing enhanced panoramas viewers (*PanoTools* and *FreePV*) and content galleries (*Omeka*, *OpenCollection* and several OS Content Management Systems, like *Droopal*, *Joomla* and *Plone*).

2.6.3 Interaction design and development

The final step in creating a virtual application it is to design and implement the interaction between the users and the VR system. For online projects the interaction is generally limited to standard devices, like desktop displays, mice and keyboards. More challenging is the case of immersive VR or MR environments, which can benefit from the large variety of input and output devices that are currently available on the market.

Managing interaction in a virtual environment is a particularly complex task, especially in museums where technologies must convey a cultural message in the most appropriate and effective way. Recently, there has been significant development in the design of controllers, devices and software that offers new possibilities for educator and learners in 3D immersive environments. The interest in the scientific and industrial communities is in developing innovative devices providing a natural interaction with machines. The basic idea is that if people naturally communicate through gestures, expressions, movements, and discover the world by looking around and manipulating physical stuff, they should be allowed to interact with technology in the same way [Valli, 2008].

An example of natural interaction is the use of spatial 3D gestures, as those provided by the *WiiMote* or the *Kinect*. WiiMote, the controller of Nintendo Wii, is shaped like a remote control, and therefore it is simple to use also for not regular gamers. It contains multiple accelerometers, providing position and orientation tracking and giving it the ability to sense user's motion. It also includes several buttons and provides haptic feedback. WiiMote has a lot of potential for educational uses due to its affordability, adaptability and popularity as game controller. Moreover, thanks to its Bluetooth support and assortment of sensors, many devices, known as *WiiHacks*, have been built exploiting the WiiMote capabilities. Instructions on creating head and finger trackers, sensible gloves, multitouch interactive whiteboards, and MIDI instruments can be found on the many sites dedicated to the so-called Wii Brewing. Sony in 2012 released *Wonderbook*, a new software/motion controller for the PS3, which looks like a wand and a physical book. User holds the controller and casts spells, helps in investigations and analyzes dinosaurs' skeletons. All just moving his/her hands and watching an AR scene on the screen. The various *Dance Pad* and *Wii Balance Board* are other controllers that exploit human motion for interaction. These devices have been used in VH as intuitive navigational interfaces in virtual environments [Fassbender & Richards, 2008; Deru & Bergweiler, 2009].

Using users' actions to control the interaction can be done also exploiting computer vision techniques to analyze images of the user's movements and translate them into actions in the virtual environment. In order to allow algorithms to work also in very dark environments, camera and lights in the Near-Infrared are often used [Valli, 2008]. The *Sony EyeToy* device, using a color digital camera, was the first attempt to use computer vision for gesture recognition in computer games. And of course the famous *Microsoft Kinect*, a peripheral for the Xbox 360 console allow user to act as game controller through gestures and spoken commands. The device includes a color camera, a depth sensor and multi-array microphone. Many VH applications can benefit from this device, interfacing the software libraries with other applications, as game engines. A different approach is that taken by *CamSpace*, a computer program that can turn any object into a game controller using a webcam for tracking it. The approach is cost effective, since the software can be downloaded for free, and the available SDK allows integrating the tracker in any other program.

Research on Human Computer Interaction has demonstrated that sensory immersion is enhanced and intuitive skills are best exploited through tangible user interfaces (TUI) and intuitive tangible controls [Xin et al., 2007; Butler & Neave, 2008]. TUI is also fundamental for providing a richer interaction in MR/AR environments. In addition to visual markers, several low cost solutions exist for developing tangible interaction. *Arduino* is an OS hardware platform for physical computing that can be easily integrated with any software running on a PC connected with the board. *I-CubeX* is another family of sensors, actuators and interfaces to construct complex interactive systems from very simple and low-cost components. Also Radio Frequency IDentification (RFID) can be used to create interactive objects. RFID tags are small sensor that can be hidden into objects. They are sensible to (or emitting) radio frequencies, and therefore can be recognized through apposite antennas integrated in the environment in apposite locations.

A remarkable example of TUI is the *Microsoft Surface*, a multi touch interactive table (*Figure 5*) whose surface is a display where objects can be visualized and directly manipulated by the users. Its appearance on the market gave birth to a lot of projects trying to build similar devices built from off-the-shelf low cost components, like standard PC, near-infrared cameras, IR emitters and OS computer vision libraries. The pioneering development of the *Reactable* [Jordà et al., 2005], the release as OS software of its tracking technology, reactiVision, as well as the definition of TUIO, an open protocol that defines properties of finger and hand gestures and controller objects, like fiducials, on the table surface [Kaltenbrunner et al., 2005], made the development of these devices available to almost anyone. Many of these OS products have been already deployed in public spaces or embedded in art installations [Hornecker, 2008; Fikkert et al., 2009; Hochenbaum, 2010]. As for the output displays, the cutthroat competition in consumer market allows the availability of large size high-definition displays at very low prices and the cost of high resolution projectors, necessary for creating immersive VR environments, is also in constant decrease. The recent introduction of 3D in cinema and television is bringing on a revolution in consumers' market. The sense of immersion and presence produced by three-dimensional images clearly exceeds that of simple two-dimensional images, with the user becoming part of the on screen action.

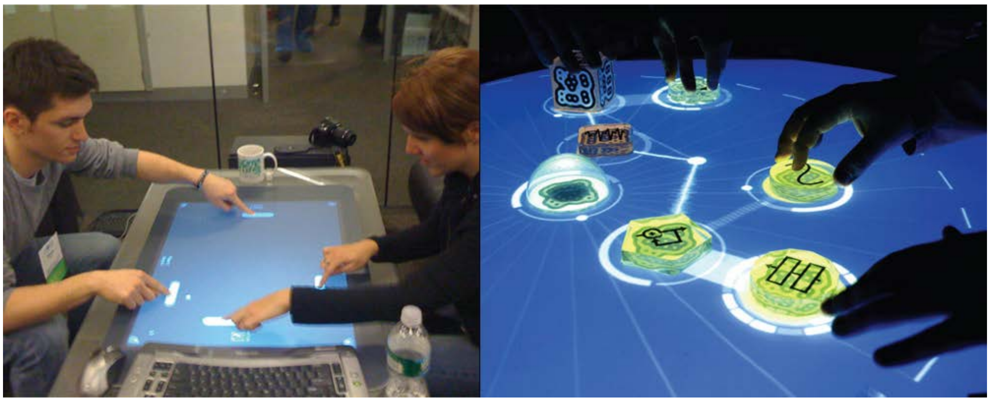

Figure 5. Examples of interactive table (left) and use of fiducials for interaction (right).

3DTV and 3D projectors are becoming largely available at a price slightly higher that of corresponding 2D products. Low cost solutions for gaming environments, like the *NVIDIA 3D Vision*, are available as well. The majority of these products require the use of active glasses for viewing 3D images. Such glasses are fragile, expensive and there is not yet a standard communication protocol for the synchronization with the display device, requiring using different glasses for different hardware products. This is a clear drawback for their wide diffusion, but the 3D scene is rapidly evolving and changes are foreseen in the near future. An alternative is represented by autostereoscopic displays, which can be seen in 3D without requiring any kind of glasses or external devices worn by the subject. Autostereoscopic vision is provided by means of particular optical devices laid upon the screen, like parallax barriers and lenticular lens, allowing each eye to receive a different image at an optimal distance. This technology is not yet mature, a standard format for autostereoscopic contents has not been defined yet and many of the available devices are still expensive, with the exception of the recent Nintendo 3DS, the first autostereoscopic portable game console. It shows that affordable solutions can be expected in the near future.

2.7 USABILITY DESIGN

Last but not least, the Usability Design. And “not least” is the right appellation for this stage, because the usability design is a process that lives in parallel with all the other stages. As the name itself shows, the basic concept is the *usability*. Many are the definitions, the one of the International Organization for Standardization (ISO) in its Guidance on Usability [ISO 9241-11] is:

the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

Nielsen [1993] details that usability is not a one-dimensional characteristic, but a multi-dimensional concept, which is based on:

- *Learnability*, how it is easy for users to accomplish their tasks, included the first time they use the interface. The system should be immediately clear and understandable.
- *Efficiency*, once users have learned how to interact, how quickly they can perform tasks.
- *Memorability*, after a period away from the system, which are the probabilities users right remember the interaction rules? People always easy remember good systems.
- *Errors*, how many and how severe are errors that users make? And how easily can they recover from the errors? Mistakes should be fewer and easily remediable.
- *Satisfaction*, measures the pleasant of interaction. System should allow a likeable user experience.

Creating an intuitive, easy and functional system, the learnability, memorability and efficiency are facilitated.

Numerous authors proposed different characteristics of the usability, but all of them have concepts comparable to those expressed by Nielsen. An in-depth review can be found in [Madan & Dubey, 2012].

A really famous approach in order to reach high level of usability is the use of a *User Centered Design (UCD)*. This term was conceived by Donald Norman in 1986 in his book “The Design of Everyday Things”, to indicate the principle that everything has to be though on users’ needs and interests [Donald, 1988]. More recently, the ISO 9241-210 (2010) outlines advices and characteristics for the development of interactive systems, based on UCD approaches. Generalizing UCD is based on the idea that final users are active actors in the realization process and their involvement is required along all the progression stages.

In his book [1988], Norman identify 7 principles of the UCD:

1. Use both knowledge in the world and knowledge in the head.
2. Simplify the structure of tasks.
3. Make things visible: bridge the gulfs of Execution and Evaluation.

4. Get the mappings right.
5. Exploit the power of constraints, both natural and artificial.
6. Design for error.
7. When all else fails, standardize.

Without going deep into those principles, important to note is the overall idea that all should be easy, visible and understandable by users. As mainly followed by the Natural Interaction, the main aim is to not force users at doing some action, but the opposite, think to the possible users' activities and properly implement the system in order to easily manage them.

In fine one of the key elements of the Usability Design is the *iterative design* process. Product is cyclically rethought and modified according to the user's evaluations until the desired level of satisfaction. Final users are involved up to the early stages of the concept design, both for the definition of goals and specifications and for tests on prototypes.

CHAPTER 3 - GENERAL BACKGROUND

In the following subsections the key concepts on which this thesis is based on are presented. Their description and the current state-of-the-art illustrates the starting point of my research activity and serves as base for a better explication of my research projects.

3.1 CURRENT TOURISM AND VISITORS

Today tourism is one of the world's most important and profitable sectors [Kabassi, 2010]. WTTC data [2012] show that the overall impact of tourism in 2011 has contributed to 9% of global GDP, corresponding to more than $6 billion and provided 255 million jobs. Over the next ten years, this sector is expected to grow by an average of 4% per year, reaching 10% of global GDP. By 2022, estimates indicate that it will represent 1 of every 10 jobs on the planet. The importance of tourism worldwide has become even more clear in recent years with the global economic crisis of 2008-2009. According to UNWTO and ILO research [2012], between 2008-2009 there was a drastic lowering of global economic resources and a reduction in purchasing power which caused a 4% decrease of arrivals of international tourists worldwide and tourism revenue fell by 6%. However in 2010 there was, a strong recovery (tourist arrivals grew by 7%). The strong resilience of tourism represents a powerful support for the economy and bring many benefits especially for the host regions [Theobald, 2004].

Several studies [e.g., Williams & Montanari, 1995; Mathieson & Wall, 2005] have identified changes in global tourism, especially in terms of needs and preferences of the public. Tourists' requests have changed on the concept of experience, rather than visit. Current tourists do not just want to *"learn something"* but they want a *"learning experience with fun"* [Packer, 2006]. "The era of mass communication has transformed the tourist gaze" [Urry, 1990] In order to meet the visitors' preferences, technologies can strongly help by supplying specific tools. Interactive installations can present historical and archival materials in new and more fun ways [Caulton, 2002], transforming tourists from passive visitors to active creators of their own experience [Wojciechowski et al., 2004]. Cultural institutions must then quickly recognize these significant changes and meet the demands of tourists, by taking advantage of what ICT can offer. This union can be referred to as *'eTourism'* [Buhalis & Deimezi, 2004].

The main technological change that has occurred in the last decades is the advent of wireless networks and mobile devices. The ability to be constantly connected to the world has brought a change in needs, especially for tourists. The concept of *"mobile tourism"* has recently emerged to identify the users' access to tourist content through mobile devices [Brown & Chalmers, 2003]. Paper guides can only present static and outdated information [Yu & Chang, 2009], while mobile tourist guides enhance the tourism experience by presenting features like online maps and location-based services [Cheverst et al., 2000]. Moreover, to support this digital transformation, the European Commission has recently forced network operators to decrease prices of roaming services [EU, 2011], so that users can benefit from a constant access to Internet, even when they are abroad.

If we focus the attention on the characteristics of *new travellers*, WTM research [2011] can help us, identifying the main current trends worldwide. *Rent-a-garden*[3], for example, is a new way of traveling based on the idea that the owners of houses with gardens rent it to tourists for camping. People says that staying at a local home increases their travel experience, thereby incrementing the chances of living a full experience within the whole local community. In the *"Americas Mystery Trips"* the user purchases a vacation package at a very affordable price with hidden characteristics. Several companies have proposed these packages also through auctions[4] or online quizzes[5]. As data demonstrate, curiosity and game experience constitute a leading role for current tourists. The last aspect analyzed is identified as gamification. The integration of game mechanics in a non-entertainment field, has led to the creation of new paradigms capable of improving desired goals. The tourism environment has recently tapped this idea, trying to merge the decision-making process, the purchase and the travel experience with the features of a game, in order to increase tourist satisfaction and therefore revenue.

[3] http://campinmygarden.com/ - (Last Accessed February 2014)

[4] http://www.luxurylink.com/last-minute-travel-deals - (Last Accessed February 2014)

[5] http://about.americanexpress.com/news/pr/2011/nextpedition.aspx - (Last Accessed February 2014)

Another important aspect to take into account is the relationship between Internet and new tourists. The Eurobarometer [European Commission, 2012] reports that in 2011 in European countries 40% of people considered Internet second in importance as the main source of information on travel, preceded only by the advice of friends and relatives (52 %). In Italy, and in four other countries, it jumped to the first place. Web is the most used tool for organizing holidays (53%). Therefore it is not only used to collect general information, but is now mainly used for travel planning and booking. So, it represents an excellent vehicle of tourist and cultural information.

3.2 VIRTUAL REALITY & AUGMENTED REALITY

Multimedia applications are based on the integration of multiple types of media. These include text, graphics, images, audio, video, etc. Generally multimedia applications provide a basic level of interaction with users. On the other hand, Virtual Reality (VR) recreates an (interactive) entire artificial environment that is presented through different devices, like display screens, wearable computers and haptic devices, in order to immerse the user in a believable simulation of reality. Mixed Reality (MR) refers to the merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects coexist and interact in real-time. The most well-known example is Augmented Reality (AR), where the user visualizes a composite view, given by a combination of the real and a virtual scene, which is generated by the computer in order to augment the perceived reality with additional information.

Figure 6. An example of Augmented Reality.

VR is by far the most compelling of these technologies and in the late eighties and early nineties there was an extraordinary level of excitement and hype about anything to do with it [Rheingold, 1991]. However, VR soon failed to live up with such high expectations. According to Jaron Lanier [2003], a VR pioneer, three of the main reasons why VR did not become commonplace are the following. First, VR applications are based on real-time and interactive simulation, where 3D geometry has to properly react to the user's input and the software has to manage scene's features, lights, shadows, fluids, dynamics, etc. This requires a lot of computational power, which only high-end specialized workstations could provide at the time. Second, the lack of high quality interfaces, especially high resolution displays and suitable interaction devices, resulted in a poor user experience. Third, proper software standard platforms for designing, developing and managing the complexity of a virtual environment were not available. As a result, there was a large disaffection of the general public, while the dream of making VR a reality kept on being carried out only by a closed group of research centers.

From the late nineties, however, we witnessed a rebirth of the VR. One of the most important contributing factors was the enormous improvement in PC hardware, both in terms of CPU and PC-based graphics card, which became faster and faster. The capabilities of computing elements are described by the well-known Moore's law, which states that their performances double every 18 months. Graphic Processing Units (GPUs) were even better than Moore's prediction, to such an extent that in 2001 the performances of an off-the-shelf consumer PC matched that of a high-end graphic workstation, at a cost of ten to hundred times lower. Nowadays, GPUs are capable of handling several hundreds of millions of textured polygons per second, have a storage capability of several gigabytes and a memory bandwidth of hundreds of GB/sec, are highly parallel structures based on a unified shaders architecture. Shaders are small programs that run on the graphics card and are primarily used to calculate rendering effects (like reflections, depth of field, atmospheric effects, automatic mesh complexity modification) on GPU in real-time.

Not surprisingly, one of the driving forces for such a revolution was the computer games industry. Games became more and more complex, since demanding players required a constant increase of the visual realism and immersion. On the other side, the enormous incomes of global majors in terms of sales revenues involved huge investments in research and development. The technological advancement of computer games combined to bring about the need for newer and more powerful hardware to handle them, and led to an increase in processing capabilities of consumer PCs and graphics cards paralleled by a reduction of their costs. A further development comes from the fierce competition between game console vendors. Nowadays, game consoles, like Microsoft XBOX 360, Sony PlayStation4 and Nintendo Wii, outperform high end PCs for their computational and graphics processing power. Moreover, since revenues come from game sales and not from hardware, these consoles are often marketed at cost price, that is they are often cheaper than a netbook.

Significant advances have been made also in the field of interaction devices. Especially for computer games, the development of innovative control devices, which focus on providing a more natural and intuitive control, allows improving the usability of computer applications and the users' experience, and ensures the availability of new low-cost and consumer-grade products. Sensing hardware, coupled with specific algorithms and programs, allows the computer to "hear" and "see" its surrounding environment and to interpret the user actions. Recent products provide state of the art motion control, have haptic feedback and ensure freedom of movement in the environment. Many of these devices can be easily integrated into different applications and, therefore, provides a very interesting mechanism for improving the interaction possibilities in Virtual Learning Environments [McLaughlin et al., 2000; Severson et al., 2002; Hirose, 2006]. Furthermore, they are sold, like game consoles, at cost price representing a valid alternative to the often expensive devices typical of the VR, like trackers, sensing gloves and 3D probes. Computer displays, TV screens and projectors are constantly increasing their size, resolution and quality, improving the sense of immersion in the Virtual Environment. This is further enhanced by the recent introduction of 3D displays, which are radically changing the way we enjoy digital contents. Moreover, the strong competition on the consumer market ensures a constant drop of their cost.

The last years have witnessed a dramatic and capillary diffusion in the society of more and more powerful tablet and smartphones. Recent products provides enhanced multimedia features, like high quality displays, video cameras, touch screens, advanced audio support and 3D rendering capabilities. Their processing power and available memory are slowly reaching that of traditional computing platforms, like netbooks and desktop computers. Their communication capabilities, including high-bandwidth Internet connections, enable the development of complex networked applications. Moreover, mobile phones are personal devices that users carry with them most of the time and are, therefore, particularly suited for developing applications supporting moving users with interactive multimedia information.

3.3 VIRTUAL HERITAGE

Virtual heritage (VH) is a combination of computer-based interactive technologies focused on the creation of visual representation of cultural objects -

monuments, buildings, statues - to deliver to global audiences [Stone & Ojika, 2002]. The main motivation of VH research is to facilitate conservation, historical research, reproduction, representation and display of cultural evidence with the use of virtual reality. During the past years, the main aim of VH changed from a mere virtual recreation of object to display, to create an entire virtual environment able to disseminate and teach culture [Ott & Pozzi, 2008]. The idea is the opposite of a "dead museum": users don't have to see an accumulation of 3D heritage objects, but feel and understand another culture through those items [Jacobsen & Holden, 2007].

According to [El-Hakim et al., 2004], there are several motivations for Virtual Heritage reconstruction:

- reconstruct monuments and buildings that no longer or only partially exist;
- interact with precious and fragile objects, without compromise them;
- document existing artefacts for future reconstruction in case of damage;
- present a new educational paradigm;
- provide different point of view of past, present or future historical events;
- provide virtual tourism.

An important aspect is the relation between VH and education. This new way to present Culture enhances the learning process, encouraging students and researchers through stimulating methods of presentation of archival materials and historical events. Users can therefore travel through space and time without moving from their home [Roussou & Efraimoglou, 1999]. Moreover VH makes possible to interact with ancient, fragile objects, maybe located far away, that cannot be handled in the real world [Paquet & Viktor, 2005].

VH also represents a new and important element for cultural tourism. With regards to that, many are the advantages that VH produce. For example, through the virtual reconstruction of cultural destinations, it becomes possible to offer a visit of sensitive environments that cannot cope with demand [Hobson & Williams, 1995], proposing visitors a simulation without any risks of damage [Arnold, 2005]. Moreover VH can be a possible solution for a significantly decrease of the impact of visitors on destinations [Cheong, 1995] besides to a non-destructive public access to cultural heritage sites [Refsland at al., 2000].

Two international charters deal with the subject of Virtual Heritage. The London Charter [2009] relates a list of rigorous guidelines for a properly use of 3D technologies in the creation of virtual heritage applications. Its main principles recommend a scientific rigor for the presentation of cultural content to the wide public, an accurate study for a clear distinction between evidences and hypothesis and a way to ensure the long-term sustainability of cultural heritage-related computer-based visualization outcomes and documentation. The ICOMOS Ename Charter [ICOMOS, 2007] states that digital media can communicate users respect for the authenticity of art, safeguard of culture and facilitate the understanding, as well as to promote and delineate technical guidelines for cultural heritage sites.

Many are the VH projects realized during the past years, that have as subject important cultural objects. Some examples are the Michelangelo's statues of David [Callieri et al., 2004] and the Florentine Pietà [Bernardini et al., 2002], Angkor temples in Cambodia [Kenderdine, 2004], Terra Cotta Warrior statues from China [Zheng & Zhang, 1999], the Hawara pyramid complex [Shiode & Grajetzki, 2000], the Hagia Sophia Mosque of Istanbul [Foni et al., 2002] and the Sarajevo City Hall [Rizvic´ et al., 2008].

One of the most important VH project, is surely *Rome Reborn* [Dylla , 2010]. It represents the city of the imperial Rome in A.D. 320, with all the most important building reconstructed also inside, and a total amount of more than 5.000 buildings. Users can interact in real-time with the environment, walking across the streets or flying over buildings. The project involved an international team of experts including architects, archaeologists, classicists, and engineers and it was realized in two versions: a high quality and detailed one for desktop fruition, and a lighter variant available on Google Earth. The main aim of this project was to create a valuable educational tool for student but the environment has been also used for two different applications. *TimeMachine* is a hand-held audiovisual guide that shows users the virtual reconstructions of all the Roman Forum [Barras, 2008]. *Rewind Rome* is a museum where visitors can see a stereoscopic animated video that explains the ancient city [Brown, 2008; Owen, 2008; 3D Rewind Rome, 2009].

3.4 VIRTUAL LEARNING ENVIRONMENT

A Virtual Learning Environment (VLE) is a computer generated 3D environment where users can navigate and interact with. There are many different type of VLE that can involve one or more of the user's five senses, but there is a characteristic that have to be present in all VLE: a real-time interaction [Vince, 2004; Gutierrez et al., 2008]. Different multimedia information can be presented in a VLE, all of them transferring knowledge to visitors and allowing a multidimensional interpretation of the environment [Bowman et al., 1999]. The real power of VLEs is the ability to engage users with their entertainment qualities [Allison et al., 1997; Roussou et al., 2006] while educating them. VR, indeed, offers an excellent potential as educational tool, as noticed by educators [Jacobson et al., 2005], especially for school subjects [Bowman et al., 1999; Salzman et al., 1999; Shelton & Hedley, 2002; Trindade et al., 2002; Song & Lee, 2002; Kerawalla et al., 2006; Minogue et al., 2006; Mikropoulos, 2006]. The educational value of VLE was firstly reported by [Youngblut, 1998] who analyzed more than 60 educational projects, and later also by other researchers who confirmed better students' performance in VLE than the traditional processes [Chen, 2006; Lee et al., 2009]. Harrington [2011] also suggested that high visual realism and navigational freedom produce positive learning gain. Moreover Chen [2006] noted a sense of satisfaction, enjoyment and easy understanding produced by VLE.

In Virtual Heritage context, storytelling, cultural interpretation, contextualization and an emotional response by visitors, are the key elements for a successful experience [Roussou, 2004; Pujol-Tost & Economou, 2006]. In this sense, two important characteristics of a VLE surely are *immersion* and psychological *presence* [Gutierrez et al., 2008]. *Immersion* refers to the feeling of being inside and a part of a world, interacting with it in meaningful ways. We can have a "fully immersive system", where users are completely absorbed by the virtual environment, without any contacts with the real world, and a "semi-immersive system", where participants have some contacts with the real world [Gutierrez et al., 2008]. The level of immersion determines the user's feelings of '*presence*' [Baños et al., 2004]. The concept of *"presence"* can be explained as the subjective belief of being in one place but physically situated in another. Slater [1999] defined it with the idea of "*being there*". In VLE it refers to live an experience in a virtual environment rather than the physical one. *Cultural presence* represents not just a feeling of 'being there' but of being - not only physically, but also socially, culturally – "*there and then*" [Champion, 2011]. The explication of presence has been often related to the number of senses involved by the Virtual Environment and to the quality of the sensorial stimuli [Roussou, 2008]. This is however insufficient since the environment must be able to transfer not only the appearance, but also all the significance and characteristics of the context that makes it a place. The basic concept can be summed up in '*a place is more than just a space*' [Dourish & Harrison, 1996; Champion, 2005; Champion, 2006; Ghani et al., 2012; Devine, 2012]. This is particularly true in Virtual Heritage scenarios, where the '*cultural presence*' plays the main role. Thus, the main aim in Virtual Heritage is to experience culture as a mental process of acquisition of knowledge through places and time [Champion, 2005]. To this end, the environment and the context become tools capable of transferring the cultural significance of a historic place [Howell & Chilcott, 2013].

Cornerstone of the concept of presence is the *Constructivism theory*. It is a philosophy of learning that consider that people generate knowledge and meaning from the interaction between their experiences and ideas [Fosnot, 1996]. Everyone construct their own understanding of the world experiencing things and interacting with the world. The learner constructs his own conceptualizations and finds own solutions to problems, in autonomy and independence. Jean Piaget, founder of Constructivism, wrote that through processes of accommodation and assimilation, individuals build new knowledge from their present and past experiences. When we encounter something new, we have to reconcile it with our previous ideas and happenings, maybe changing what we believe or discarding the new information as irrelevant. In any case, we are active moderators of our own knowledge. In order to achieve this, we must ask questions, explore, involve in the real or virtual world. VLEs, indeed, foster the construction of knowledge through exploration, interaction, and manipulation of objects. Learners have more control on what and how to learn, feeling more encouraged and stimulated [Hannafin et al., 1994; Hannafin & Land, 1997; Hannafin et al., 1999; Jonassen, 1999].

Another important concept in VLE is the *Collaborative Learning*. This theory is based on the idea that learning is a social activity in which two or more people learn, or attempt to learn, something together [Dillenbourg, 1999]. So Collaborative Learning is a team process where members support each other to achieve an agreed-upon goal. Unlike individual learning, here knowledge can be created and stimulated by the interaction between learners: they engage in a common task where an individual depends on others. This kind of learning is usually based on face-to-face conversations, digital discussions and meetings. Researches claim that Collaborative Learning not only increases interest among participants but also promotes critical thinking. In the field of edutainment, collaborative games allow all players to work together as a team, sharing winnings and outcomes [Zagal et al., 2006].

3.5 VIRTUAL MUSEUMS

Virtual Museum is a general concept, appeared for the first time in 1991 [Tsichritzis & Gibbs,1991], that can be implemented in different ways, according to exhibition design, application and end user requirements. At present, the definitions of Virtual Museum are various and the projects and creation of Virtual Heritage applications have been and continue to be very different. The ICOM itself [ICOM, 2004] suggests three different types of virtual museum - the museum brochure, the content museum and the learning museum. The *brochure* is nothing more than the presentation of the physical museum information through Internet. The *content* museum is instead a website created to divulge information about the available museum collections. Finally, the *learning* museum is a website that provides personalized paths to navigate its contents according to the users' characteristics (age, cultural background, interests, etc...). Typically, this kind of

Virtual Museum has mainly an educational purpose, and is linked with other material in order to motivate the virtual visitor to learn more about a subject of particular interest.

The ICOM definition well describes the categories of Virtual Museums available online, but does not mention the full gamut of possibilities available on-site, where technologies and virtual worlds are reconstructed within the museum itself as an additional tool for routine visit of the physical place.

Therefore, according to several authors [Tsichritzis & Gibbs, 1991; Lepouras & Vassilakis, 2004; Hirose, 2006; Sylaiou et al., 2009; Noh et al. 2009] a more comprehensive classification of Virtual Museums can be introduced, whose brief overview is presented in the following subsections.

3.5.1 Content galleries

Content Galleries are collections of browsable digital objects that visitors can enjoy through different media, discovering an easy way to query and browse the content database through a graphic interface. Content galleries can be presented both online - as a web page/web application - and on-site – as an interactive installation.

Creating compelling multimedia applications, providing an engaging interface to the museum repository, is quite simple, thanks to the wide availability of dedicated software libraries and languages, like Flash and Processing.

An example is *Getty Museum*'s website[6], which let users discover the Art in many different ways: through an alphabetical list of authors, a classification of the different types of Art, a thematic classification and other brief overviews. Web 2.0 practices, like personal galleries that can be used to create personalized visits and share them with friends, are also available.

A different approach is demonstrated in the *Heilbrunn Timeline of Art History*[7] that presents a chronological, geographical, and thematic exploration of the world Art history through the Metropolitan Museum of Art's collection (*Figure 7*). The timeline allows the navigation across locations and periods in order to observe not only the artworks but also their relationship with the historical and geographical context.

[6] http://www.getty.edu/art/ - (Last Accessed February 2014)
[7] http://www.metmuseum.org/toah/ - (Last Accessed February 2014)

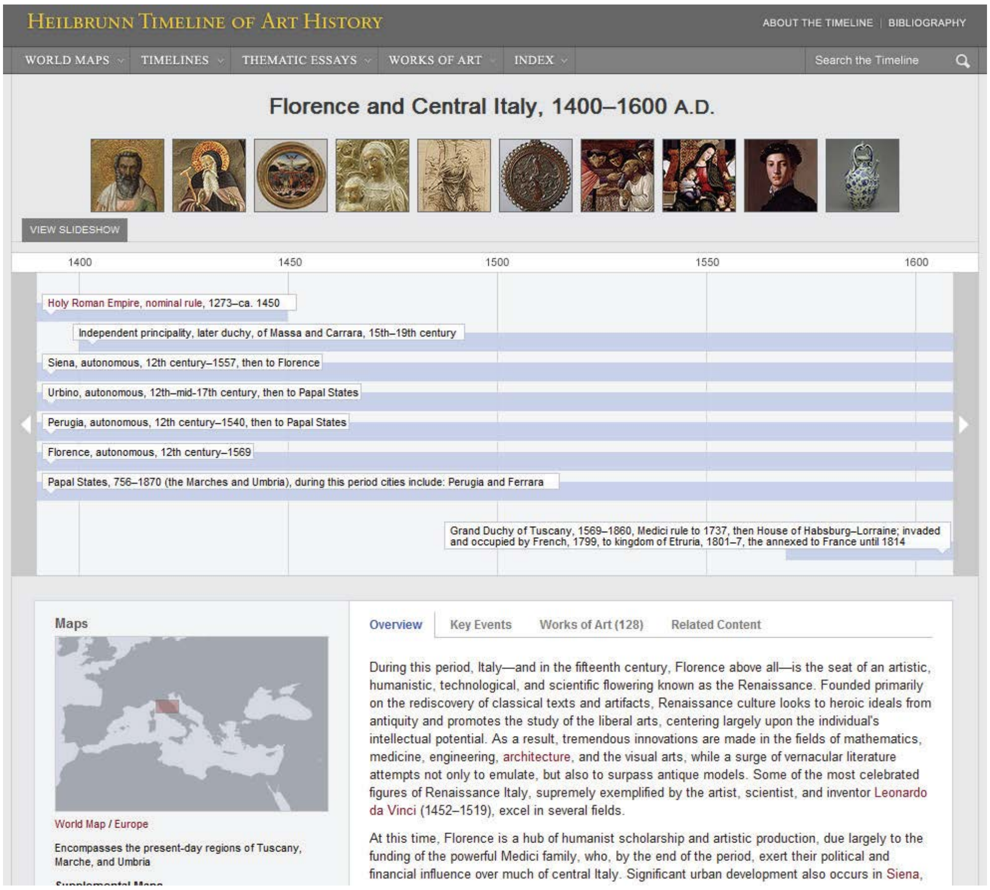

Figure 7. The Heilbrunn Timeline of Art History in the Metropolitan Museum of Art's website.

3.5.2 Enhanced panoramic views

Online galleries allow visualizing cultural contents, but they are often perceived by users as a flat means of communication. What would make visitors more involved it is to immerse them into the exhibit environment and let them have a look around. To this effect, a viewer for 360° panoramic images provides greater interactivity and engages visitors much more than single static images. The viewer allows rotation, tilt and zooming of the surrounding scene. Panoramas can be created using catadioptric cameras, consisting on a single sensor with a 360° field-of-view optic, or synthesizing them from multiple images that are projected from their viewpoints into an imaginary sphere, or cylinder, enclosing the viewer's position, and then blended with specific mosaicing software to create a single seamless image. In addition, panoramas can be made interactive embedding hotspots that allow, when selected, to invoke some actions, for example linking other types of digital media, providing an integrated multimedia experience.

The use of 360° panoramic images has become quite common, and therefore familiar to all users, after the launch on 2007 of *Google Street View*, a technology featured in Google Maps and Google Earth that provides panoramic views from various positions along many streets in the world. An example, applied to museums, is the virtual tour of the *Smithsonian National Postal Museum*[8] (*Figure 8*). The application is meant to show only how the real museum looks like, offering a tour through its rooms, without adding any further information on the museum's collection.

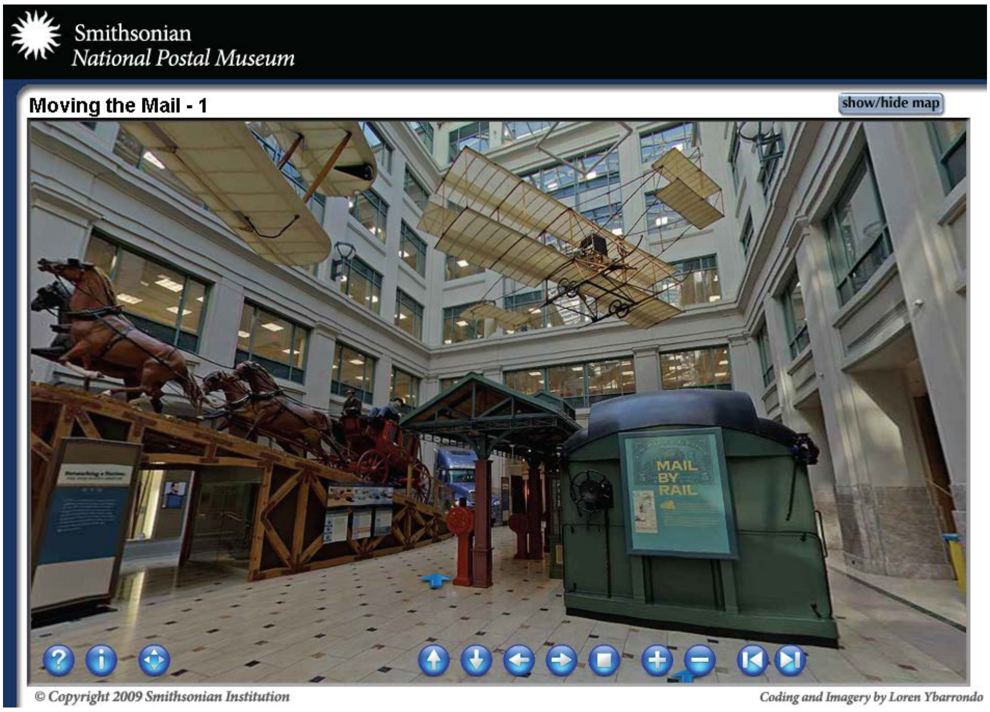

Figure 8. The Smithsonian National Postal Museum online virtual tour.

Visualized contents are not limited to real environments. As a matter of facts, it is easy to obtain photo-realistic panoramic images from high-quality rendering of any virtual environment. An interesting example is *One Day at the Sands*, explained in greater detail in the section *4.2*. The project focuses on the Sands in the 1964, one of the most prestigious and oldest casinos in Las Vegas. The aim of the project is to entertain visitors by giving them the chance Fabulous Las Vegas.

[8] http://www.postalmuseum.si.edu/npm_tour/ - (Last Accessed February 2014)

Pictures and videos have been used to rebuild in 3D the original Sands atmosphere and the panoramic images of the rooms have been augmented with archive material (documents, images and videos), accessible from hotspots in the environment.

3.5.3 Online virtual environments

Online virtual environments (OVE) stems from the Web3D idea, which, initially, aimed at displaying and navigating the Web in 3D. So far, the term refers to all interactive 3D content that can be accessed and visualized through Internet. OVEs have a great pedagogical value, given by their ability to immerse visitors in a navigable content-rich world where they can be involved in learning (and entertaining) activities as well as collaborate in participatory activities [Scali et al., 2002].

Typically, Web3D comes in two forms. In the first, 3D contents are embedded directly into web pages. Since Web3D technology is not currently supported by browsers, they require external plug-ins to handle the 3D contents. Some of them are Java3D, the various VRML viewers, O3D, Unity3D and 3Dvia. The second solution makes use of software clients, capable of handling complex 3D interactive environments, through which the user participate in the virtual simulation. The architecture of the application can foresee a centralized server, as in SecondLife and OpenSimulator, its OS counterpart, or a peer-to-peer network of clients, as in several online 3D games.

Currently, there is still no standard language to distribute 3D contents. The most common formats are VRML, the oldest of all and first presented in 1994, X3D, an XML-based extension of VRML, and Collada, an interchange file format for interactive 3D applications that is widely supported by the most common modeling software.

OVEs are heavily influenced by the available bandwidth, since contents are downloaded as the user utilizes the application. Therefore, on slow connections, the waiting time may become long, annoying the user that will hardly continue his visit. In addition, since web contents can be consumed by potentially any user, the application cannot rely on specific computational resources. Therefore, the developers must reach a good compromise between the complexity of the virtual environment, its visual realism and its usability.

An interesting example of OVE for VH is *Heritage Key*[9], which offers a SecondLife like exploration of historical sites virtual reconstructions from all over the world (*Figure 9*).

Figure 9. The Heritage Key online environment.

The Danish Centre for Urban History has presented for the centenary of the *Danish National Expo in 1909* [10]an interactive 3D model, based on the original architectural drawings, of the international pavilions. The user can wander through the buildings, browsing, through hotspots in the environment, the additional historical documents, like photographs, text, images, videos and oral narratives (*Figure 10*).

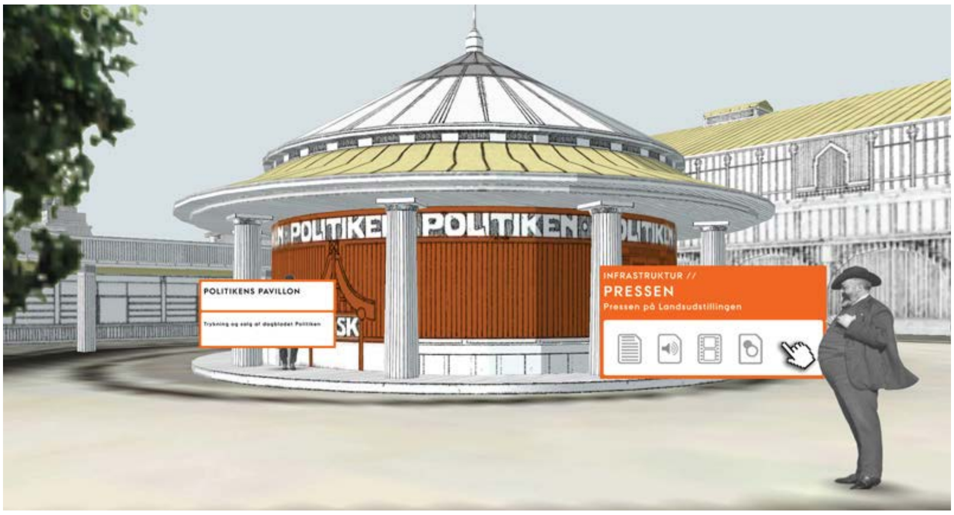

Figure 10. The interactive 3D model of the Danish National Expo 1909.

[9] http://rezzable.com/rezzable-experience/heritage-key - (Last Accessed February 2014)
[10] http://dendigitalebyport.byhistorie.dk/landsudstillingen/ - (Last Accessed February 2014)

3.5.4 Immersive VR environments

A typical immersive VR system consists of VR software, managing the visualization of the virtual environment, a display system, three-dimensional audio support and the input devices that allow users to interact with the environment and the virtual objects it contains. Their essence is the illusion of “presence” inside the computer generated environment they are able to transmit to users [Schuemie et al., 2001].

There are various types of VR systems, which provide different levels of immersion and interaction, ranging from two extremes, the so called “weak VR” and “strong VR”. *Weak VR*, also referred as Desktop VR, is typically a 3D environment displayed on a screen, either mono or stereoscopic, with a single user interacting with the virtual environment. On the other hand, *strong VR* gives users a uniquely and compelling experience of “being there” in the virtual world through a converging stimulation of all human senses and the subsequent suspension of disbelief, involving sight, sound, touch, and sometimes taste and smell. Visualization can involve the use of virtual reality helmets (Helmet Mounted Displays, HMD) or other immersive stereoscopic displays. Users are allowed to move freely in the environment and their position and movements are captured, by means of tracking and sensing technologies, and reproduced in the 3D environment. Sometimes, users are allowed to physically touch the virtual objects using haptic interfaces, like data gloves or force-feedback devices [Burdea & Coiffet, 2003].

Unlike OVEs, here the execution hardware and the software can be tailored according to the specific needs of the application, allowing to build more realistic environments, with higher resolution models and more detailed textures, compelling atmospheric and camera effects, 3D audio support, realistic crowd management and complex user interaction.

An example is *Live History*[11], an on-site installation in the Nationaal Historisch Museum in Holland. Visitors assume an active role in the history of the Netherlands, interacting with objects, documentaries and virtual representation of the main historical events through handheld multimedia devices. Users are physically immersed in a CAVE environment, a room where images of the virtual environment are displayed on walls and floor (*Figure 11*).

[11] http://nhm.id.tue.nl/ - (Last Accessed February 2014)

Figure 11. Visitors inside the CAVE of Live History installation.

The *Virtual Museum of the Ancient via Flaminia*, at the Museo Nazionale delle Terme di Diocleziano in Rome, now no longer visible, offered a virtual tour of the via Flaminia during the Roman Empire through a combination of a virtual storytelling, in the form of audiovisual reconstructions and narrative sheets, and a free navigation, allowed only in specific points of the path. Four interactive stations allowed users to explore the environment through avatars, while the rest of the audience could follow their actions on a central screen, which displays also complementary visual and informative contents (*Figure 12*).

Figure 12. A view of the Virtual Museum of the Ancient via Flaminia.

3.5.5 Mixed Reality environments

Mixed Reality (MR) creates environments that combine at the same time both real and virtual objects. It is possible to visualize MR/AR environments through a desktop display, see-through HMD, PDA or mobile devices. Interaction is generally managed through the device interface, for PDA/mobile devices and touch screen displays, or through tactile manipulation of visual markers/fiducials, whose images are captured with a video camera, or of other sensible objects located in the real world.

An interesting example is the *Jurascope* installation at Berlin's Museum of Natural History (*Figure 13*), where people, looking a dinosaur's skeleton through a telescope can see an animation that overlap the bones with organs, muscles and skin. Then, the virtual dinosaur starts moving and eating inside the room. The installation is certainly impressive, but the only interaction provided to users is to activate the application pointing the telescope at the skeletons in the room.

Figure 13. The Jurascope experience.

Another interesting application is *Streetmuseum*, released by the Museum of London. Users, installing Streetmuseum on their own smartphone, transform London into a huge open-air historical museum (*Figure 14*). Hundreds of images of the city from four centuries of history have been georeferenced and can be seen in the location they were taken through the mobile phone, which acts as a window through time. Historical information connected to the images can be accessed tapping on the device screen.

Figure 14. The Streetmuseum application.

3.6 EDUTAINMENT & GAMIFICATION

Edutainment can be easily explained as Education + Entertainment. This concept refers to a form of education where the learning process happens in an entertainment way, in order to keep people interested and engaged, stimulating their curiosity. Many educators claim that when educational material is presented in a basic learning way, people usually not absorb the lesson or only a minimal part of it. On the other hand engaging representations, multimedia content and collaborative laboratories usually result in a more interesting and affective learning process.

The noun *edutainment* was introduced for the first time by Robert Heyman in 1973, while he was realizing documentaries for the National Geographic Society. But the concept is quite old. Czech educator J. A. Komenský (1592 – 1670) already stated the motto: "school as play". His pedagogical system was based on the creation on games with roles, properly tailored on the students' age. He referred to "play" with two different meanings: play theatre performances to recreate historical events and play games as didactic method to educate body and mind [Němec & Trna, 2007]. During the 19th century many children's books utilized an edutainment approach with colorful pages and funny stories to teach the alphabet. Now, thanks to the advances of technologies, almost all the field of studies benefits of this kind of learning process. Culture and Arts make extensive use of it especially with virtual reality technologies, capable of recreating historical events and artistic restorations.

According to the transformation of the objectives of cultural institutions, as already illustrated, museums now aim at involve visitors in an engaging experience: an edutainment experience. Children and science museums are maybe the principals with games and adventures that teach through practice and discoveries. Also zoos and botanical parks propose direct contact with animals feeding them or treating plants.

A close concept is *Gamification*. It is a relatively new paradigm that comes from the edutainment concept, but concerns a wider reference environment. Depending of the area of study there are many definitions about gamification, but we can use the one expressed by Sebastian Deterding et al. [2011]: *"Gamification is the use of game design elements in non-game contexts"*. As edutainment, also gamification relies on constructivism theories where learning is based on a first-hand experience, encouraging user participation and maintaining user contribution.

There are many famous examples of gamification, especially involving social networks, like *FourSquare*[12], a location-based social networks where users "check in" in all venues they visit collecting points and winning virtual awards, *Nike+*[13] a social running game-like platform where runners can compete with each other, encouraging to improve their fitness program, and *Waze*[14], a navigation application where each user provide real-time traffic information to all the others earning points and goodies.

Kate Haley Goldman [2013], during the 2013 American Alliance of Museums (AAM) Annual Meeting and MuseumExpo, specified the main objectives for an educational gamification approach in the museum area:

- increase attendance (especially new audiences);
- foster innovation;

[12] http://www.foursquare.com/ - (Last Accessed February 2014)
[13] http://nikeplus.com/ - (Last Accessed February 2014)
[14] http://www.waze.com/ - (Last Accessed February 2014)

- increase awareness and associate the institution with community needs;
- content-based goals;
- social interaction goals;
- “Unarticulated institutional goals” (merely copy other museums that have their own app).

As later showed, all these aims represent a strong incentive for cultural institutions to create gamification experiences. The *goSmithsonian Trek,* for example, is a mobile game in which gamers have to solve clues and challenges through nine Smithsonian museums. To win the game, people have to explore some of the Smithsonian's most popular exhibitions and discover facts about its most treasured art pieces. Tate Gallery in London in 2011 proposed *Race Against Time* a platform mobile game designed to expose players to art history. Player has to help a colored chameleon travelling through the history of modern art in order to defeat evil Dr. Greyscale’s plan to remove all the colors from the world. Metropolitan Museum of Art, in New York City proposed the "*Murder at the Met: An American Art Mystery*", an interactive mobile detective game. Transported back in time to 1899, visitors are attending an evening gala while Virginie Gautreau was killed. Through their smartphones, visitors have to explore the museum, collect objects and interviews in order to know the killer, the weapon, the place of the murder, and the killer’s motive.

In all these examples, game design elements are used to involve visitors into the museum's life, discovering artworks and treasures. A list of game mechanics generally adopted for gamification approaches can be found in the appendix of [Xu, 2012].

3.7 HERITAGE INTERPRETATION

As we have already seen, Virtual Heritage is based on edutainment, gamification and constructivist theories, concepts that are based on the common idea that users are the main actors in their cultural experience, creating their own learning process. But this process is based on the heritage interpretation that Tilden [1977] describes as *"an educational activity which aims to reveal meanings and relationships"* and that must be related *"to something within the personality or experience of visitors"*. Interpretation is a linear process, a viewpoint about the past [Thornton, 2007] based not only on what we see, but also on our previously experiences. Therefore, interpretation of a cultural objects or a heritage site depends on visitor's culture, society and subjectiveness. *Table 1* present a list of definitions of *"heritage interpretation"* that Rahaman and Tan [2010] taken from several authors.

Affiliation		Definition of Interpretation
Heritage Scholars	Uzzell	Interpretation is that it opens a window on the past.
	Harrison	The art of presenting the story of a site to an identified audience in a stimulating, *informative* and *entertaining* way to highlight the importance and provoke a sense of place
	Beck and Cable	Interpretation is an educational activity that aims to *reveal meanings* about our cultural and natural resources.
	Moscardo	Interpretation is a special kind of communication
	Howard	Interpretation is deciding what to say about heritage and how and to whom.
	Goodchild	Interpretation is, in fact, only one aspect of the broader topics of *Presentation*, *Supplementary Education* and *Visitor Satisfaction*.
Interpretation Associations/Authorities	Interpretation Association, Australia	Heritage interpretation is a means of communicating ideas and feelings which help people *understand* more about themselves and their environment.
	The National Association for Interpretation, USA	Interpretation is a mission-based *communication process* that forges emotional and intellectual connections between the interests of the audience and the meanings inherent in the resource.
	The Association for Heritage Interpretation, UK	Interpretation is primarily a *communication process* that helps people *make sense* of, and *understand* more about, your site, collection or event.
	ICOMOS Ename Charter	Interpretation refers to the full range of potential activities intended to heighten *public awareness* and enhance understanding of cultural heritage site.
	ICOMOS Charleston declaration	Interpretation denotes the totality of activity, reflection, research and creativity stimulated by a cultural heritage site.

Table 1. Definition of heritage interpretation.

The main aim of the interpretation is surely to accomplish *mindful* visitors [Moscardo, 1996]: active, interested, curious and questioning visitors. To this end, cultural institutions have to find ways to change users into *mindful* users. As illustrated in the *Figure 15*, proposed by Moscardo [1996] there are two different factors that influence the visitor's cognitive state: *setting* and *visitor* factors. The former refers to all those elements which are specific of the institutions, as maps, signs, tours, exhibits, while the latter refers to the users' personal characteristics. The combination of the two produces the kind of visitor. Consequently this means that a non-interested visitor can become mindful if the institution provide interesting and involving setting factors. Guides – paper, electronic and mobile guides - represent one of the most strong and useful setting factor for museums. They indeed provide navigation and orientation through the museum's halls, historical material and answer to questions, elements that complete the visitor's experience.

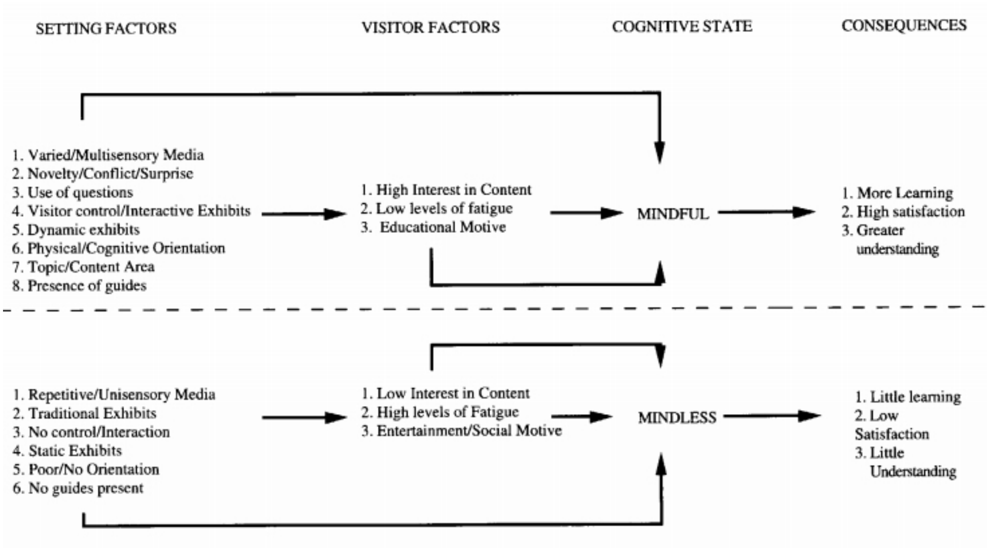

Figure 15. Mindfulness model of visitor behaviour and cognition at built heritage sites.

Rahaman and Tan [2009] propose some approaches to enhance heritage interpretation through new technologies:

- hermeneutic environment though game-style interaction, using gamification modalities;
- embodied interaction through haptic devices, including Natural and Tangible User Interfaces;
- multiple user virtual environment (MUVEs) with artificial agent and dynamic contents;
- greater immersion through augmented stereographic panoramas or immersive displays.

These characteristics, as later explained, represent some of the key features implemented in the following projects.

To summarize the needs that cultural institutions have to achieve to produce a useful heritage interpretation, Moscardo [1996] proposes 4 key principles. First, museums have to provide to visitors a variety of experiences. Second, visitants have to fully control their own experience. Third, interpretation has to propose connections between heritage and visitors' personal experiences. Fourth, institutions have to challenge visitors, question them and encourage their curiosity.

CHAPTER 4 – OUR PROJECTS

This chapter briefly describes the projects carried out during my research period. In the following chapters, instead, we will explore the research topics across all the projects. For an easier and more fluent reading, we thought to shortly present all the researches here and later to only recall them, focusing on the aspect under study.

4.1 VILLA DELLA REGINA

The project focused on *Villa della Regina*, a royal residence of the Savoy Family located on the hills of Turin, Italy. The goal of the project was to create an application that would present a faithful historical reconstruction of the interiors and gardens of the residence. At the time of completion of the project (2010), the entire building was still under restoration and closed to the public. Moreover, due to various historical vicissitudes, the residence has never been open to visitors, so no one could know the historical and artistic value of the villa. The project aimed to present the residence to the public, in order to allow people to see, at least digitally, an important location declared World Heritage Site by UNESCO in 1997.

Villa della Regina was built on the hill of the capital of the Duchy of Savoy by Prince Cardinal Maurizio of Savoy. On the model of the Roman villas, the first version, dating back to 1615, was composed by the Villa, the Italian-style Gardens, the Water Theater and forests and agricultural areas. Over the hills and just beyond the Po river, on the border of the city of Turin, the position appears to be certainly one of the best, both in terms of landscape and climate. From the second half of the seventeenth century to 1975, when the property was closed, several renewals and drastic transformations modified the residence. Unfortunately deterioration and abandonment caused numerous thefts until 1994 when Superintendence for the

Historical, Artistic and Anthropological Heritage of Piedmont began a major restoration lasted more than 20 years.

Because of the tormented history of the Villa and all its renovations, we decided to focus only on the nineteenth-century version of the villa, which is very similar to the current state. After collecting historical sources, including the original blueprints, the modeling process led to the creation of buildings and all the gardens surrounding them. The modeling was carried out at high quality and with a high level of details. Particularly difficult was the modeling of the Palazzo Chiablese building: because it was finally demolished in 1962, the original projects were not found. As a consequence, a careful process of comparison between the written and photographic sources had been followed. Some textures were created ad-hoc photographing the materials of the villa on-site, while others where properly designed according to pictorials and written sources. Finally, a careful process of lighting allowed rendering photorealistic images (*Figure 16*).

Figure 16. Photorealistic rendering of Villa della Regina.

Once created the high quality version, it was also realized the lower resolution variant for the real-time VLE implementation. The reducing number of the total faces process needed a careful manual approach, in order to better preserve the aesthetic quality while decreasing the complexity of the geometry. Even the textures have been suitably scaled and lightened.

Figure 17. The real-time version of the 3D reconstruction of Villa della Regina.

The simpler version has been imported into the Unity3D Game Engine[15]. Users can visit the indoor ambiences as well as the gardens of the Villa as it was back in the 19^{th} century. The interactions are limited and they are only focalized on the freedom of movement within the areas.

The application can be enjoyed online, allowing people from all over the world to take a personalized tour of the ancient residence of the House of Savoy. Although this project did not address particular innovations from the interaction point of view, it was of paramount importance to tackle with problems and first approaches with VLEs, especially those related to the study and research of historical sources, the validation of documents and the creation of a historical environment.

[15] http://unity3d.com/ - (Last Accessed, February 2014)

4.2 ONE DAY AT THE SANDS

One Day at The Sands project exploits the communicative potential of digital technologies, Virtual Reality in particular, to present a perspective on the history of Las Vegas in the 1960s. It is a real-time application aimed at communicating and making perceivable the atmosphere of one of the most famous casinos in Las Vegas through a virtual environment in which users could immerse themselves to relive the sights and sounds of the past, experiencing a part of the history of Las Vegas in an entertaining manner.

The city of Las Vegas is generally regarded and remembered as the most spectacular and extravagant city for entertainment while its history is generally not considered, being hidden by the lights and glitter of the modern town. This history, although brief, is nevertheless remarkable, with a variety of social and cultural aspects that arose from that place and expanded into the rest of the country. We thus deemed important to describe in detail and with scientific rigor the history and the events of such a controversial city, in order to increase people's historical awareness about the place. In particular, our project aims to rekindle the magical atmosphere of the Sands Hotel, one of the most prestigious and oldest resort casinos in Las Vegas, which well represents both the city development over the years and the social transformations occurred in the past. The Sands Hotel was '*the place to be*' in Vegas from 1952 to its implosion in 1996. It was the seventh resort style casino to open on the Las Vegas Boulevard ('The Strip') and one of the most famous entertainment hotspots through most of its years of existence. Its theater was graced by some of the greatest names in show business, like Frank Sinatra, Dean Martin and Sammy Davis Jr. The history of the Sands deserves particular attention not only for the popularity of the hotel, but also for the actions taken on a variety of social issues. The resort received public admiration and approval by declaring its dislike and opposition to nude exhibitions on stage. Moreover the Sands was also the first casino that broke the rigid race segregation on the Strip.

The main objective was to enhance the visitor's knowledge and understanding of the atmosphere, characters, and stories behind this period in the history of Las Vegas, in order to bring new awareness to historical material that hitherto has not been considered as an essential treasure of the past. To this end, we developed a hypermedial, interactive and multiplatform application that combines the recreational aspects of computer graphics and multimedia with the educational purposes of historical archives. The application is rooted in a navigable Virtual Environment that immerses users in the 3D reconstruction of the Sands. The building blocks, or 'micro-elements', of the narrative that will guide users through their visit are represented by the collected multimedia historical contents (text, images, video, and audio). This material has been stored in a database and integrated into the virtual environment, where it can be accessed by visitors according to their own interest and curiosity. In this respect, the virtual environment both provides a reconstruction of the original historical and spatial context of the cultural objects and serves as a visual interface with the historical database. Viewers can virtually walk in the Sands' hall, resting in a suite or attend an incredible show in the Coparoom. The narration guides users through the rooms of the casino, following gamification approaches. Furthermore, in order to make accessible the virtual environment to an audience as wide as possible, we developed an application that can be executed on different hardware and software platforms and even accessed through the Internet.

Figure 18. The One day at the Sands online experience.

We also tested the application in order to analyze the visitor's satisfaction and the usability of the application. User tests underlined the ability of the application to raise a positive experience, reinforcing the hypothesis that digital technologies represent valuable tools to engender awareness and explorative attitudes towards heritage. This positive feedback received from users on both the usability of the system and its capability to encourage interest, curiosity and engagement, which are all triggers for learning and further exploration, suggests that other areas of future research could be represented by the evaluation of the degree of knowledge gained during the digital experience. Additionally, it could be interesting to evaluate to what extent such an application can affect people's perceptions about Las Vegas and influence the will of actually visiting the place. Result of this evaluation could be useful to understand the power of virtual reality tools on current tourism [Guttentag, 2010].

This project is part of a wider project "*Re-living Las Vegas*". The goal is the reconstruction of all the historic casinos on the Strip, as they looked in the past, allowing users to relive the sights and atmosphere of Las Vegas during the years of the Golden Age. The project was in collaboration with the UNLV University of Nevada, Las Vegas. Also *The Evolution of the Stardust* (section *4.4*) and the *Visual interfaces for DBs of cultural contents: the Riviera Casino* (section *4.9*) projects belongs to this initiative.

4.3 INTERACTIVE VIRTUAL PAST

The *Interactive Virtual Past* project proposes a virtual interactive journey through the past of the *"Camera del letto del Re verso Ponente"* (The King's bedroom) in Villa Della Regina in Turin (Italy). As explained previously for the project in section *4.1*, Villa della Regina has a history spanning five centuries in which the building has not only changed several times in shape and size, but also in intended use. These transformations have led to a strong evolution over time especially about the interior spaces of the building. In order to present the whole history to visitors, it was decided to implement this application. Through the VLE users can indeed experience the different eras of the history of the abode and access historical contents.

The project was focused only on one room, the *"Camera del letto del Re verso Ponente"* for three reasons. Firstly because that rooms is a good representative of the museum's change through time. It hosted a very important function through the 1700 (the King's bedroom), and still today, continues to be one of the main rooms of the villa. Secondly, it is a highly studied room, which means more archived materials and historic details. Thirdly, due to time-reasons we preferred to totally complete the project on a single room as example for all the other halls.

The *Camera del letto del Re verso Ponente* is located on the main floor of the villa, in the King's apartment, in the north wing. Currently the barrel vault shows a frescoes by Corrado Giaquinto, the "Apollo's Chariot". The four rounded walls of the vault are painted with the representation of the four seasons, framed by white seventeenth century stucco. The walls are covered with "taffetas chiné à la branche" wallpaper, but only in some part of the room it is original, in some other areas it has been restored and integrated with new one. In the room a careful study of light aimed at exalting the place made by the famous architect Juvarra is notable.

The entire evolution of the room – and the Villa – can be divided in five steps, approximately according to the centuries:

- *Seventeenth century*, is the initial stage. Information about this period are few, we only know some details about the general composition of the room.

- *Eighteenth century*, this was the period when the room was transformed into a bedroom, the King's bedroom.
- *Nineteenth century*. At that time the room was resembled in a similar way at how looks today.
- *Twentieth century*, this is the state before restoration work began in the room. Damages and thefts caused cracks and corruptions.
- *Today*, this state shows the actual state after the restoration.

These 5 stages were modelled and textured according with the historical and artistic sources available, and then imported in the Unity3D game engine (*Figure 19*). Each version of the room was created as a separate level of the application. A time slider was added to allow users to freely move among these levels. Virtual visitors start from the most ancient state of the room and then they can decide to follow the time progression or to jump to any different time period. In each epoch users can walk within the room, observe the furnishing and confront elements with the other periods. Moreover hotspots were added into the scene to allow people to access to multimedia information. The application is available for an online fruition.

Figure 19. The evolution of the room through the centuries.

4.4 THE EVOLUTION OF THE STARDUST

The goal of this project was to present the complex evolution of the Stardust Casino primarily focusing on the architectural elements and also presenting a general history of the resort. Casinos in Las Vegas are subjected to frequent renovations in order to continuously meet the wishes and needs of the public. In fact, over time they changed rooms, swimming pools, theatres, added cinemas, restaurants and spa, everything to entice people to spend time at the resort. And the architectural changes reflect the social transformation of the city. Through the study of the renovations of the casinos it is possible to analyze a slant of the history of Las Vegas. For this reason in this project we decided to dwell mostly, but not exclusively, on the architectural appearance of the resort.

The Stardust resort was conceived and built by Tony Cornero, who died in 1955 before the construction was completed. When the hotel opened, it had the largest casino and swimming pool in Nevada and the vastest hotel in the Las Vegas area. The design was composed by a basic combination of wooden roofs and concrete walls. One of the key elements of all the casinos in Las Vegas was the sign, and that of the Stardust was considered one of the most important one. Representing a solar system that overstepped the edges of the building, at night more than 11,000 bulbs lighted the sign, making it visible 60 miles away. Over the years a nine-story tower and a 32-story West Tower were added, as well as two swimming pools, a golf course and athletic facilities. On November 1, 2006 the Stardust was closed forever and was imploded on March 13, 2007 at 2:33am.

From the sources were modelled 11 different historical versions of the resort relating to its expansions or changes. The modelling and texturing process was based on photographs and archival footages in order to recreate the exact appearance and atmosphere of the past.

For the application a gamification approach has been implemented. Instead of having to face a classic timeline, the user navigates through time "playing" cards. On a gambling table, in fact, there are 11 different cards with the indication of the reference year and some chips. Putting some chips on the chosen card allow to access to the narration of the relative year. In addition to displaying the resort, a set of information appear on the screen. If the user decides to click on an item, the related multimedia content are shown. Photographs, texts, videos, menus, objects with detailed explanations are available to users.

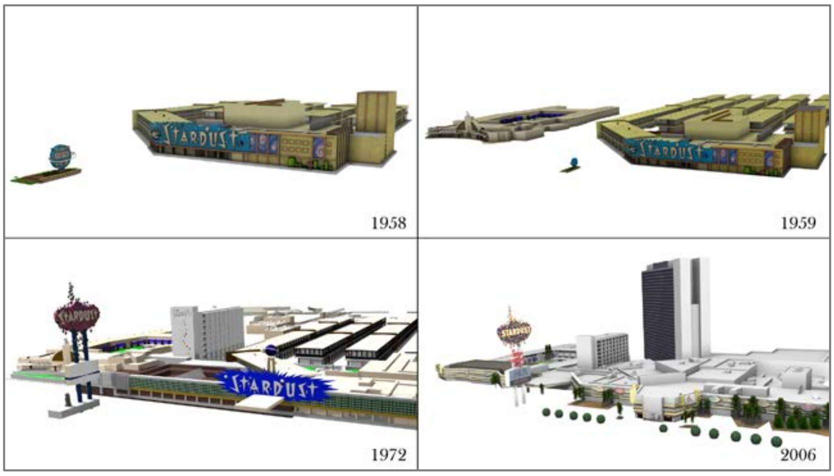

Figure 20. The virtual reconstruction of the Stardust in the 1958 (top-left), in 1959 (top-right), in 1972 (bottom-left) and in 2006 (bottom-right).

The online application was implemented in Flash. This choice was made because the goal of the project was an online application. Although there were obviously other tools available, the choice fell on Flash due to its widespread use. The idea was to be able to embed the application in other web pages already on the web, using a technology that would give the least number of problems for end users. Flash appeared to be integrated in all browsers. Only later some mobile devices no longer supported that format. One possible solution that will be addressed is to replace the Flash platform with an HTML5 viewer.

Figure 21. A view of the application.

4.5 EXPERIENCE THE SOUNDSCAPE OF SAN SALVARIO DISTRICT

In the *Experience the soundscape of San Salvario district* project we studied how the audio can help to recreate a past environment and, secondly, how a VLE can be used as a tool for sound urban planning. This project was in collaboration with the Department of Energy (DENERG) of the Polytechnic of Turin and it focused on the San Salvario district in Torino. South-East of the city center, close to Corso Vittorio Emanuele II, San Salvario district is bordered on the north by the Porta Nuova rail station (the main station of the city) and to the south by the Valentino Park and the River Po. The Church at the intersection of the current Via Nizza and Corso Marconi, built in 1646 and named "Church of San Salvario" gave the name to the whole district. Until the mid-nineteenth century the area was almost empty, with only a few houses, the convent of San Salvario and the Valentino Castle. In 1815 as a result of Peace of Vienna, Turin became the capital of the Kingdom of Sardinia resulting in an increase in population which forced an urban sprawl. The first intentions of extending the city in the San Salvario area came from Carlo Beccaria in 1836. But it is only with the Enlargement Plan of the Capital in 1851 that the San Salvario district really born. Towards the end of the nineteenth century the area was strongly built and a road system was properly designed. Even the new area followed the orthogonal grid, which is the main peculiarity of Turin, thus maintaining continuity with the rest of the city. But the proximity to the railway transformed the district in an area of migrants and merchants characterizing the area as multiethnic. After 1940 San Salvario was further expanded (over the Corso Marconi) following the new expansion plan of the city. Currently, the district is located in the heart of the city of Turin and it has preserved its character of multi ethnicity. The Waldensian Church (built in 1853) and the Jewish Synagogue (built in 1884) are located inside the district, two religious buildings built after the Albertine Statute of 1848, which ensured, among other individual rights, freedom of worship. In the last decade, thanks to a major requalification, the neighborhood has changed its face. Maintained the multi-ethnic character, now there are numerous workshops and small boutiques and in the evening the area is filled by people in bars and restaurants.

The project focused more on one of the most characteristic streets of the district: Via Berthollet. During the day time this street has many commercial activities and the local market, while during the night many nightclubs and diners completely transform the area.

The choice of this district for our project was made based on several considerations:

- the area borders the city center maintaining the same nineteenth-century style buildings;
- during the last decade it has been modernized and improved, marking a significant changes in its shape;
- the strong multi-ethnicity character will surely lead to further changes into urban and social aspects;
- it is subjected to continuous urban studies.

The project consists of two parts: (i) the virtual reconstruction of the current state of the area and (ii) the historical reconstruction of the area in the nineteenth century. For the first objective the research of the sources was not a problem. On site photographs, video, blueprints have allowed to achieve a high level of fidelity with the current situation of the area. For the reconstruction of the nineteenth century version, however, architectural projects, historical photographs and cartographic maps were found at the Historical Archive of the City of Turin. Based on the historical documents found, the two environments were modeled. A high quality model (high poly) was firstly produced and then a simplified one (low poly) for real-time viewing. The high-poly model was made with a strong attention to detail. The texturing process started from materials currently present on buildings. According to photographs, paintings and written documents they were modified, and in some cases replaced.

Once obtained the final two models of the two epochs, photorealistic renderings have been made for the presentation of the project. The low-poly version has been imported into the GE Unity3D allowing the creation of a virtual environment. The project is then advanced to the audio component, the main goal of this project. As we already said the sound is an excellent aid for user’s involvement in VLE, reinforcing the feeling of presence. But the sound needs to be properly designed. In circumstances such as those of our project the audio must wrap users making them feeling as a part of the neighborhood, just as if they were actually walking along the streets. The sum of all the sounds and noises present in a specific place is referred to as soundscape. It helps us to better understand a new location. Moreover the study of the soundscape produces many benefits, including the possibility of improving the living and social conditions of people as well as promote a careful preservation of intangible heritage elements.

The aim of this project was to recreate a real-time navigation of the area, paying particular attention to the soundscape of the street. It was therefore necessary perform measurement campaigns to identify and locate sources, fundamental for the audio reconstruction. Through sound-walks we recorded the principal audio sources in the real environment, also calculating the reverberation times. Then we used the software ODEON in order to scientifically calculate the audio response of the environment. The result of the software calculation is named "*auralization*".

Due to the long times for the calculation process, a real-time audio stream is impossible to produce. Instead we inserted in the real-time environment the 42 different auralizations that we calculated in different position of the street. Users can walk into the street and listen to the reconstructed soundscape of the environment entering in the auralization areas.

Additional details of the project can be found in section *6.2*.

4.6 VIRTUAL TENOCHTITLÁN

With the *Virtual Tenochtitlán* project we reached a high complexity of VH dissemination. This work presents an interactive application for educational and informative purposes concerning the ancient town that dominated Mexico before the Spanish invasion: the city of Tenochtitlán. The subject of the application is the Recinto Sagrado (sacred ceremonial precinct), the heart of the city, which was the center of the political, religious and economic pre-Columbian Mexico. Its maximum dimensions reached approximately 400x400m with at least 78 buildings. From there the Mexica governed peoples of the Valley of Mexico and the whole Central America, between the fourteenth and sixteenth centuries.

The city was founded in 1325 and quickly grew to become the most important town in Central America. Tenochtitlán was connected to the mainland by bridges and embankments (*the calzadas*) and the urban design included a network of roads and canals, so that each area could be reached either on foot or by canoe. It was also equipped with a functional aqueduct. The Spanish conquistador Hernán Cortés arrived in Tenochtitlán in November 1519 and wrote in his diary that he saw the largest and most efficient city in the world. In Europe, only Naples, Paris and Constantinople were so extended. In the Recinto Sagrado the most important building was the Templo Mayor with at its top two different shrines dedicated to two gods, *Huitzilopochtli*, god of war, and *Tlaloc*, god of rain and agriculture resided. Two separate staircases led people from the square to the temples for sacred ceremonies.

During its two centuries of existence, the city deeply changed due to the 12 Kings (*Huey tlatoani*) that heavily modified the layout of the buildings in the Recinto Sagrado. In 1519 Spanish attacked the city and after 2 years of battles conquered and destroyed all the buildings in the precinct. On its remains the Metropolitan Cathedral was built, the largest Roman Catholic cathedral in Latin America.

The aim of our application is to show the ancient city of Tenochtitlán exactly as it was during the Mexica era, presenting the history, culture and mythology through games, activities and interactive multimedia contents. In the absence of the possibility for visitors to walk through the real buildings, it is offered the chance to move in the virtual space that reproduces the ancient Tenochtitlán. In addition it is possible to interact with the environment, discovering history, culture, customs and religion of the Aztec people.

The choice of this site was based on the following considerations:

- It is one of the most important archaeological sites in all of Mexico because it was the center of political and economic life of Central America between the fourteenth and sixteenth centuries. In contrast to many Mexican archaeological sites where the buildings are still intact and can be visited, the buildings of Tenochtitlán were completely destroyed during the Spanish invasion and never rebuilt.
- Today the archeological site is inaccessible because it was flooded by buildings of modern Mexico City. The few visible areas can be seen from suspended platforms. This allows no more than a superficial visit, distant from the experiences that visitors can live in other sites in Mexico.
- Projects already implemented to show public the real conformation of the city are limited to plastics in museums (*Figure 22*). There is no reconstruction of the entire Recinto Sagrado, nor of its elements.
- The ruins of the Templo Mayor were discovered in the early 20th century, but the excavations did not take place until 1978–1982. Now the process of excavation and study is still active.

From several different sources we obtained useful information for 3D modeling process. But this reconstruction must be viewed as a hypothesis reconstructive of the city. In fact, all the data about Tenochtitlán are not unique, because several researchers have formulated diverse conjectures. For our reconstruction we choose to follow the hypothesis of Eduardo Matos Moctezuma, director of the researches at the Templo Mayor, and therefore the most suitable person.

The subject of the reconstruction is just the Recinto Sagrado for two reasons: (i) all the main buildings of the city were located inside it, (ii) the rest of the city was constituted by little houses, less interesting elements for a historical reconstruction. The main buildings underwent several changes during the two centuries of the Mexica domain, with particular reference to the Templo Mayor: almost every king heavily expanded it to prove his greatness and to appease the gods. We can identify seven different stages from 1325 to 1521, during which almost all the buildings in the precinct were moved in different positions depending on the will of the king. The only building that is never moved is the Templo Mayor, because of its symbolic value. The difficulty of representation is particularly focused on this temple because each king rebuilt a new temple over the previous one. As the Russian doll, the last temple embraced all the 6 previous.

Figure 22. The plastic model of the Recinto Sagrado.

The application had some objectives:

- To give users the opportunity to explore an environment that no longer exists. Unlike many adjacent archaeological sites that can be visited today, Tenochtitlán was completely destroyed. A virtual reconstruction can help visitors to an immediate understanding of the structures of the city, creating a sense of immersion and presence. In addition, through a timeline, it is possible to highlight the seven construction phases that characterized the whole Recinto Sagrado.
- To show users the culture, society and history of the Mexica people in comparison to that of the rest of the world.
- To allow comparison of Mexican architecture and the rest of the world.
- To present the particular architecture of the Templo Mayor.

Through the GE Unity3D all 3D models of the buildings have been incorporated into a real-time virtual environment. The user starts his journey located in the Sacred Precinct of the city of Tenochtitlán in the early fourteenth century. Based on his preferences he can move across the seven different time slots available, observing the changes of the environment. During their exploration, visitors can access multimedia materials, compare historical pictures or photographs with the reconstructed ambience and take part in mini games. Moreover, in order to better explain users the architectural particularity of the Templo Mayor, visitors can manipulate and dissect it. This makes clearer to users the complex construction of the building.

Figure 23. A view of the final application.

Virtual Tenochtitlán is an online VR application that can be enjoyed with a computer, mouse and keyboard. However, it can be simply adapted to more immersive contexts, such as within a CAVE (cave automatic virtual environment). The user's feeling of immersion and presence would certainly be enhanced, making the experience even more complete. In addition, the application is multilingual: now the Spanish, English and Italian language is available. In any case, the application allows rapid introduction of new languages: the contents are managed by simple xml file.

4.7 VIRTUAL ME

In order to recreate a more realistic VLE a careful modelling of the environment is not enough. Users are used to live, work and move in ambiences with other people. Creators of virtual environment have to face with the problem of properly populating the empty virtual model. Different approaches are available but only a few can really enhance the visitor’s sense of presence. The creation of autonomous intelligent agents can strongly help in that direction. Artificial intelligence (AI), indeed, has received increasing attention over the last thirty years. It has been used successfully in many fields such as finance, medicine, games, robotics and the web. In particular, in recent years, a quite complex area of research has emerged: the simulation of the autonomous behaviour of characters in computer graphics. Emulating human behaviour, indeed, is a very desirable characteristic for virtual agents, so as to make them act in ways similar those of the real people. There is plenty of literature that focuses on a single specific aspect of human behaviour emulation, but it is quite rare to find a collection of implementations encompassing several aspects of the problem. VIRTUAL-ME (VIRTUal Agent Library for Multiple Environment) is a library that provides programmers with a complete set of classes that assembles various human characteristics and makes it possible to build smart agents. In the library, the virtual human management is implemented by a Behaviour Tree (BT). This structure is employed to drive the AI character's behaviour while the accomplishment of the chosen actions is dictated by a combination of both needs and emotion emulation techniques.

The VIRTUAL-ME library was created after an in-depth analysis of the state of the art of various fields. In particular, the library proposes solutions to deal with the following key issues:

- agent behaviour mechanisms;
- affective computing;
- the emulation of human needs mechanism;
- the environment perception problem, especially the vision;
- the problem of navigating a virtual environment;
- memory models;
- event management.

All these elements concur to compose a reproduction as accurate as possible of human intelligence.

Affective Computing

An emotion is defined as a complex, subjective experience coupled with biological and behavioural changes. Emotions are capable of altering attention, or the likelihood of a certain behavioural response, activating associative memories, influencing the learning process and aiding social behaviour [Levenson, 1994]. Defining emotional states appropriately can determine a more accurate representation of human behaviour.

While most models are tailored to a specific scenario, the solution implemented in our work offers a generic emotion model designed to be a good compromise between simplicity and granularity (in terms of emotion description).

The model conceived in this project was inspired by the work of Han et al. [2010] and Russell [2010]. It is controlled by two dimensions: *Activity* and *Mood* (see *Figure 24*). Low values of the *Activity* parameter represent a more phlegmatic attitude, whereas high values identify a hyperactive disposition. For example, in some people, a negative event can induce a despairing reaction, with a sense of paralysis, while in other people it can rouse a furious reaction. The *Mood* parameter, on the other hand, identifies a negative valence with low values, while a positive value identifies a pleasant demeanor. As an example, in an emergency situation some people's reaction is negative, driving them to despair and other people might remain serene and in control.

To create a more varied and heterogeneous (i.e. a more believable) collection of agents, each of them was generated with a particular attitude or character disposition. In other words, every agent possesses a "basic" personal emotion that is chosen randomly. Then, as in everyday life, interactions with other people or with the environment can alter the current agent emotion, inducing a change in its behaviour. Once a change has occurred, the agent will return to his primal emotion after a period of time. This idea stems, again, from the observation of human nature. Even if some events can modify the actual emotions of individuals, in many cases, this change is just temporary and, as time passes, they return to their own proper attitude and temper.

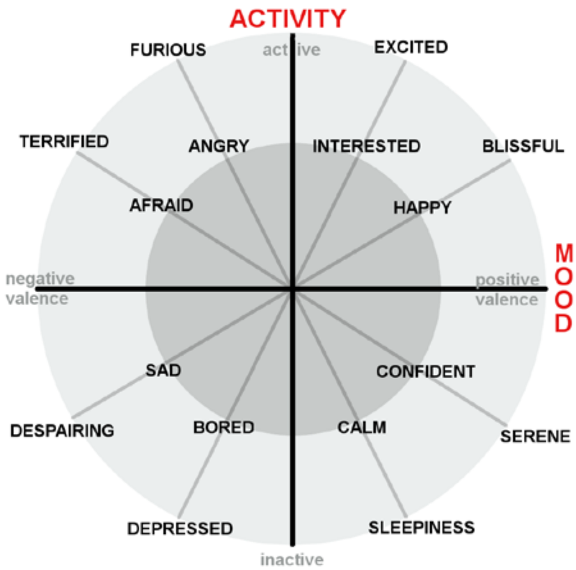

Figure 24. Emotion representation

Emulation of Human Needs

The implementation of needs is one of the most common techniques used in video games to drive autonomous agents. In this frame, an agent has a set of ever-changing needs that demand to be satisfied. To this end, the agent figures out what can be done on the basis of what is available in the surrounding environments. Inside the library, the application designer can define, for each type of agents, a specific set of needs, their domains and how they would evolve.

As an example, in our test cases, human needs reflecting the work of the humanist psychologist Abraham Maslow were implemented (1943). He elaborated a hierarchy, depicted as a pyramid, which suggests that people are motivated to first fulfil basic needs before moving on to other, more advanced, needs. Therefore, according to the characteristics of the specific simulation, we considered most of the basic needs (like hunger, thirst or physiological needs) and some of the higher level needs (such as friendship and self-preservation) described in the Maslow's pyramid (*Figure 25*).

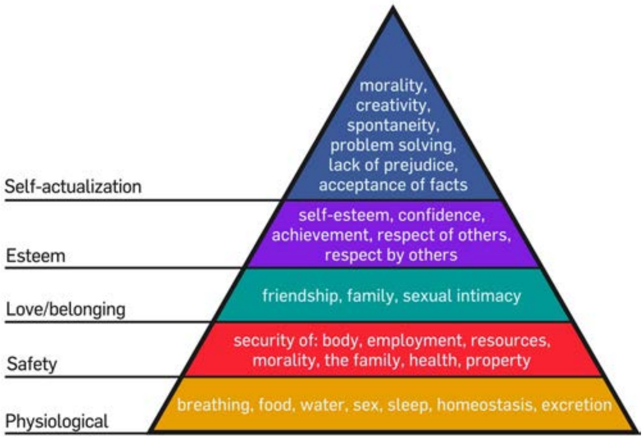

Figure 25. Maslow needs hierarchy pyramid.

Navigation

The VIRTUAL-ME Library implements a "decentralized" navigation system that allows the agents to be autonomous in their choices. A two levels navigation model was designed. The first level manages the global navigation problem relying on the A* algorithm [Granberg, 2013]. A* requires to map the walkable area with a graph, which can be done only when obstacles are known a priori. Thus, the second level is responsible of handling dynamic obstacles, such as moving objects, agents or new hurdles created during the simulation. Agents have been equipped with a visual system that provides the ability to perceive the environment: an object is "seen" if at least one of its vertices falls into the agent's field of view and its vertices are not occluded by another object. Therefore, while A* determines the main path as a sequence of nodes, vision allows agents to walk from one node to another avoiding unexpected obstacles.

In order to preserve the agent autonomy, i.e. to avoid a centralized management, a force-based collision avoidance mechanism has been implemented. In brief, if a potential collision is detected by the vision system, a force is applied to the agent to change the direction and speed of its motion. The design of our local navigation system was inspired by many techniques like [Reynolds, 1987], [Fiorini & Shillert, 1998] and [Berg et al., 2008] and improved in order to correct some of the difficulties affecting them, proving, for instance, to be able to properly avoid obstacles getting rid at the same time of reciprocal dances and virtual agent deadlocks. As an example, in *Figure 26* we show the results of a test conducted to verify the ability of the agents to avoid deadlocks. In the experiment, 120 agents were arranged around a circle and instructed to reach their antipodal position. The congestion formed in the middle was quickly resolved as the agents reached their goals.

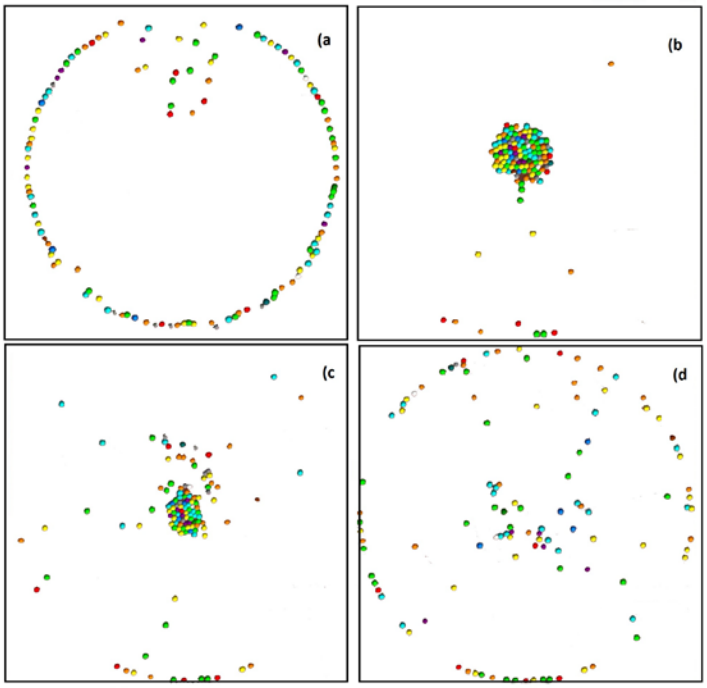

Figure 26. Example of deadlock avoidance: (a) 120 agents on a circle are instructed to reach their antipodal position; (b) a congestion forms in the middle of the circle but (c-d) it is quickly resolved.

The choice of a two levels navigation model was driven by efficiency purposes. In fact, while a navigation system merely based on vision is indeed able to drive the characters to their destinations, its performance drop with respect to the proposed solution is severe (see *Figure 27*).

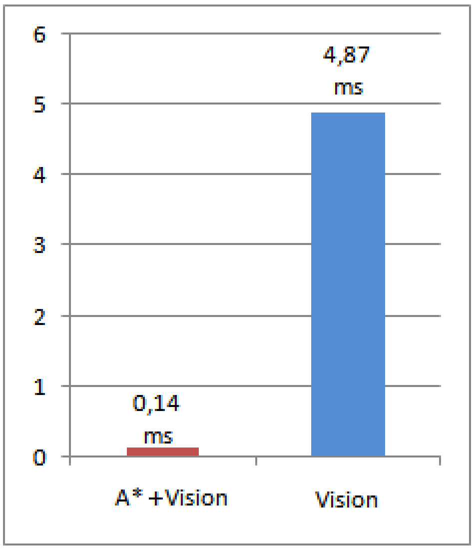

Figure 27. Comparison of the average per frame computational times of the two levels and of the vision-based only navigation systems in a reference environment

Memory Model

The most important purpose of a memory model is to allow agents to remember past information. The lack of a storage mechanism could lead to mistakes or damaging repeated behaviours which would make agents appear less believable.

The memory model has been implemented in a very simple way. It consists of two structures: 1) a FIFO list keeping track of all seen objects and of all seen agents and 2) a FIFO list of the objects the agent interacted with and, for each object, a piece of information summarizing the changes in the character emotion, i.e. the emotional impact of the interaction itself. The processing of this information can contribute to drive the character behaviour, since it allows agents to learn from past experiences.

In order to simulate the agent process of forgetting information, the lists have a constant length and items are removed after a certain time.

Events

An event is an occurrence that takes place in a virtual world. It is caused by environmental factors or agents' actions.

In VIRTUAL-ME, an event generator starts and ends the events and eventually makes them evolve in time. Each agent can be associated with an event responder, which contains all possible actions that the agent can do, according to his personality and to the event urgency (or priority), when a specific event is notified.

The event managing mechanism will be further discussed in the next paragraph due to its interconnection with the agent behaviour.

Interactions with the surrounding world

The agent behaviour is influenced as well by its interaction with the surrounding environment. To model these interactions, the environment and the objects it contains (including other agents) can expose different attributes. Those attributes are defined in an XML file associated to each object (or to each category of objects) and an agent can query them. The retrieved information can then be used to make decisions or to control the agent actions. For example if an agent is willing to gamble, it will look for an available gamble table by querying the ones in its surrounding to find one that is active and has free seats. Each table returns these pieces of information and the possible locations of the free seat. Then, when a table has been found, the agent walks towards the location of a free seat.

Agent Behaviour

As described in the previous sections, the demeanor of our virtual humans is determined by their emotions, needs and memory (i.e., their internal state) and by the state of the environment (i.e., their external state). Furthermore, agents have the ability to navigate through the environment, interact with it and with the objects it includes and to respond to events.

In order to manage all these elements, the agents' behaviour has been implemented using Behaviour Trees (BT). A BT defines and manages agents' tasks, which are related to the fulfilment of their needs and to their reaction to events.

In the BT, an agent task is represented by a sub-tree defining a sequence of child nodes, which are leaves of the BT. When a task is activated, the leaves are executed one by one (in order from left to right). The first child of the task sub-tree is always a *Condition node* that tests the agent's internal state (e.g. being hungry, willing to socialize) and the external state (e.g. having enough money to buy food, availability of other agents to whom he can talk) to check if the agent wants to or can realize the specific task. If the condition succeeds, the task execution is broken down into a set of sub-tasks managed by *action nodes* (e.g. search a seat in a restaurant, walk to the seat, seat, call the waiter, and so on). An active action node has one of the following three states: *Success* (the leaf has been completed correctly); *Running* (the action will continue during the next simulation step); *Failed* (the leaf has ended incorrectly). A task is successful only if all of its children succeed, otherwise, it reflects the state of the current active child (i.e. Failed or Running).

All agent tasks are children of the BT root, which acts as a selector, sequencing the different tasks on a priority order based on the child position (from left to right). The agent behaviour is managed as follows: the tree root calls tasks in order of priority. If the task condition is not verified or one of task's actions fails, the next task is started. If all tasks fail, the default task (which is the only one not starting with a condition) is executed. When a task is completed, the BT restarts task scheduling from the one at highest priority. An example of an agent's BT with five tasks is shown in *Figure 28*.

This control flow can be modified by events. After receiving an event notification, the event response is immediately served if it has a priority higher than that of the current task being executed which will consequently terminate. Otherwise, the event will be possibly served when the BT activates the corresponding task.

With this structure, the BT manages the agent's behaviour at two different levels: a higher level that includes needs, emotions and memory; and a lower level formed by the agent's motion ability and perception system. The high level plans the agent's future actions, while the low level manages the way the agent reach physically its goal (path finding and object avoidance).

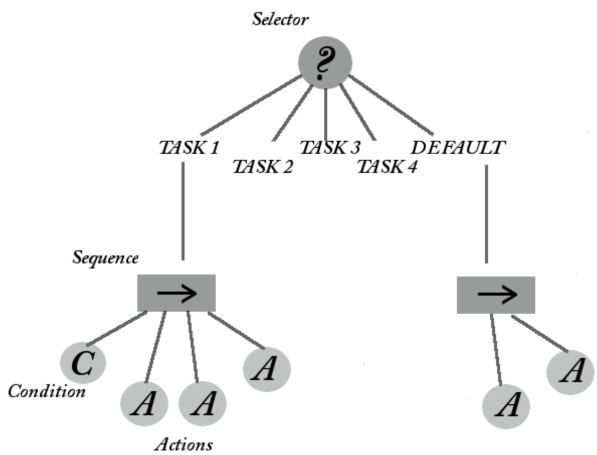

Figure 28. An example of Behaviour Tree.

The library has been integrated into the Unity3D game engine and tested in different scenarios characterized by different complexity of the environment, the agents' behavioral patterns, the total number of agents and agents' classes. The results are explained later in section *6.3.4*.

4.8 THE EVOLUTION OF THE ITALIAN RADIO AND TELEVISION: VIRTUAL MUSEUM

The subject of this project was the creation of a system to present and facilitate access to contents of the Museum of Radio and Television in Turin. This little museum is located in the city center, inside the building of the RAI (Italy's national public broadcasting company) and collects instruments, objects, scenery and historical relics of the Italian radio and television. Most of the items are equipment used for radio and television, such as microphones and cameras, but also many other items that relate to the era before the radio, as the decoder of Marconi, are present. The antiques are visible in very large display cases divided by historical periods. In the same glass case too many items are located, often overlapping each other. The explanations about the objects are minimal and limited to just the object name and the year of use. The interaction with users is then next to nothing and the information poor, although the technological devices represent a huge source of technical information.

On these considerations, we decided to offer users an interactive experience that presents the items in the museum through an approach of "discovering of knowledge". All contents of the museum have been cataloged by historical period, obtaining a timeline that starts from the late nineteenth century and reaches almost the present days. Information and multimedia materials about the historical artifacts were collected. By studying the sources we have chosen to focus only on three decades of the long history of the Italian radio and television. This is for two reasons, the greater abundance of information about those historical moments and the difficulty in terms of time and resources for the development of the entire timeline. The three decades chosen were:

- *30s*: it was the period in which the first amateur radio operators start to transmit and radios spread in Italian houses. Moreover during the war the radio, particularly the BBC (Radio Londra), was the main source of news.
- *50s*: the radio was replaced by television, RAI (Italy's national public broadcasting company) and main television programs born.

- *80s*: television was in every apartment and it represented the main element. Commercial television channels started, greatly expanding the television show offer.

For each decade a different 3D environment was created. The idea was to show users how, with the flowing of time, the radio and television had greatly changed the habits and customs of the people. It was therefore decided to set the whole project in a typical Italian living room. Passing through the three different mentioned stages, the furnishing, the disposition of objects and the appearance of the room strongly denotes the reference years. Research carried out on decor magazines dating back to the previous century has evidenced that some particular elements distinguished the ages. In the first room ('30) it is possible to identify a marble column, typical decorative element of that period. In the next room ('50) the key element is the big wooden television, in the center of the room. Finally the last room presents a big closet with a smaller plastic television. All these elements combined to the study of the entire interior (upholstery, furniture, curtains, paintings, etc.) allow users to easily identify the era in which they are located and to better contextualize the experience.

Figure 29. The room in the ‘30s.

The three rooms were modeled and textured and later imported into the GE Unity3D, creating three different interactive environments. The user can freely move around the room, look at the elements that characterize the historical period and teleport through the decades, simply by moving a timeline. While navigating each of these scenes, user can interact with multiple objects. These active objects, identified by a special lighting, provide access to the information contained in the database. Once clicked on an active object, user can see a window that contains content related to the selected object, with an interface divided into two parts:

- In the left part there is the name of the argument to which the element refers. If the user has clicked on a specific radio of the past, in this section he/she can find the history of radio during the years in which he/she is located. In this way the selected element is better contextualized. In addition, other elements of the database that have a relationship with the one selected are proposed.
- In the right page instead a multimedia content gallery - with pictures, video, audio, text - related to the object selected is presented. For all those multimedia content a brief description is provided. At the bottom of the page a timeline presents the whole period of the evolution of Italian radio and television. On that two elements are marked, the exact year in which the active element refers to and the entire historical period in which it is lived.

Moreover the 3D models of the radio and television also act as real devices. In fact they can be switched on and users can watch or listen to old shows.

Figure 30. The interactive television in the application.

The main objective of this project was to help users to create meaningful connections with the digital contents. Once entered into the database through an active object, the user can freely move among other contents by following historical/social/cultural links based on *concept maps*. Through this process people can easily acquire new knowledge following their curiosity and interests.

4.9 VISUAL INTERFACES FOR DBS OF CULTURAL CONTENTS: THE RIVIERA CASINO

This project [Martina & Bottino, 2012] aimed to improve the accessibility, for the general public, to the contents of cultural databases through the development of novel visual interfaces that are compelling, intuitive and easy to use. It also allows an easier understanding of the historical and cultural context related to items in the database, helping to increase knowledge and create links and relationships around them. Furthermore, as confirmed by modern neuroscience studies [Yates, 1966; Baddeley, 1998], the interaction with a 3D environment represents the most intuitive paradigm for a majority of humans, since it is rooted on common everyday experience. Therefore, using this paradigm to access information can be fruitful in several domains, increasing comprehension of learning contents, and for different target users, especially the not trained ones.

The main goal of this project was to developing novel interfaces for accessing and managing a cultural database by integrating its contents within a VE, which is used to (virtually) re-create the original spatial and historical context of records, where visualization and sounds can be used to improve the users' sense of immersion and presence. The re-created context can then be explored virtually to gain new insights on specific elements, and to improve the awareness of relationships between objects in the database. The proposed interface is divided in two parts, closely related and synchronized: (i) a 3D graphic view of an interactive VE showing the reconstructed environments, where database items have been inserted as "sensible" objects that, when clicked, send a query to the database to access the information related to a specific object; (ii) a text-based form, where objects can be searched by keywords, tags and/or metadata, their related (multimedia) information can be accessed and, at the same time, their context can be visualized into the VE.

The strengths of this project are the possibilities to navigate the VE as if you were browsing among the records of the database, to always re-contextualize the search item within its historic ambience and to perform searches of different types using the possibilities offered by both textual and visual methods, which are complementary and strongly integrated for more targeted queries.

To test our interfaces, we built, as case study, a prototypal application aimed at presenting the collection of historical documents related to the Riviera casino-resort, in Las Vegas. The Riviera, opened in 1955 on the Las Vegas Boulevard ("the Strip"), was the first skyscraper in Las Vegas and became one of the most important and luxurious resort in the city. Several famous singers and artists of the period, including the showman Liberace, the highest paid artist in the world in the '50s, performed in its theater. The primary source of documentation was UNLV's Special

Collections archive. The section dedicated to the Riviera includes project documents, images of the resort, photographs and documents of the leading characters and of the most important events related to the resort. Other information was found in books, newspapers and magazines of the period. The research data were digitized and stored in a database, with accompanying metadata concerning the collection and management thereof. This information was also used to create the 3D models of the original premises for the Riviera virtual reconstruction and of all the objects, furniture, and elements included therein (*Figure 31*).

Figure 31. Some digitized historical sources - photos, videos, postcards - and a view of the virtual reconstruction of the Riviera casino.

Two different representation layers were implemented, in order to test advantages and disadvantage of both approaches: an interactive real-time virtual environment and an image-based virtual environment. User tests underlined the effectiveness of both interfaces in improving the accessibility to cultural databases contents.

Figure 32. The RTVE interface.

4.10 GAINE

This project, *GAINE* (tanGible Augmented INteraction for Edutainment), is an open framework for the implementation and management of interactive AR applications for edutainment purposes. The idea is a system able to manage tabletop games, as well as interactive applications, using tangible objects with which users can interact with the game and get an immediate visual feedback. Our framework is able to handle tangible elements, 2D and 3D graphics, AR visualization and a system of rules to manage the game logic. If necessary, a video output is available for an external monitor or projector. The platform can also be used for presentations, such as an interactive whiteboard or for interactive storytelling applications. The combined use of AR and tangible interfaces (TUI) allow proposing a framework with innovative features specifically designed for children. Everything has been thought to be completely configurable in a simple and intuitive way, just using the XML language.

In our project, TUI is composed by two elements: (i) an interactive table and (ii) some marked tiles. Similar to Reactable [Jordà et al., 2005] our interactive table is composed by a big table with a semi-transparent plexiglas top. Inside the table there are:

- an infrared illuminator, illuminating the semi-transparent surface of the table;
- a webcam, which records everything happen on the top of the table;
- a projector, which projects the output on the semi-transparent surface;
- a computer, with the reacTIVision [2013] software.

Moreover it is also possible to add an additional external monitor for a second channel video output.

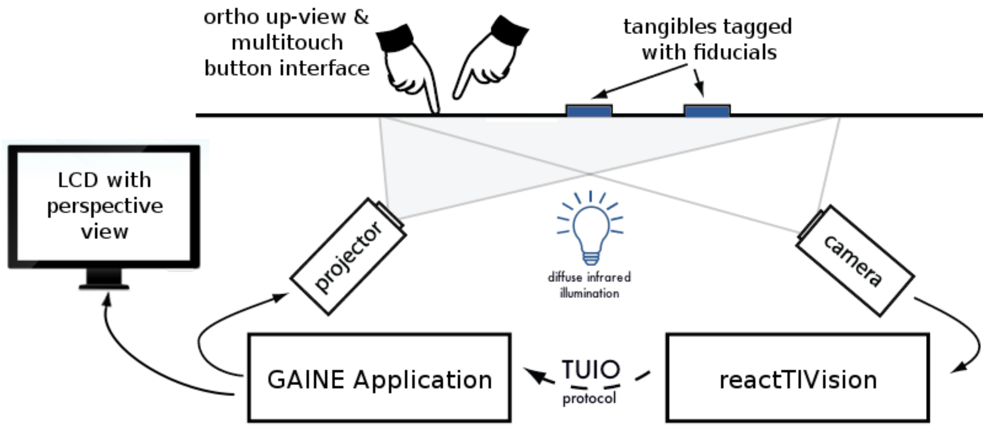

Figure 33. Our interactive table.

The user can interact with the system in two ways, using the semi-transparent surface of the table as a touch-screen or placing tiles (marker) on the surface. Once identified a marker the system track all its transformations, sending data to the software. The communication between the elements occurs through a client-server system, where the reacTIVision server through the camera detects all markers placed on the table surface and sends position, angle, and number of fiducials to the client program. Communication takes place via the TUIO protocol.

As a case study we implemented a tabletop game in which users have to build and manage their own nineteenth century city. The goal of this AR strategic management game is to reach the highest level of "welfare" for citizens of the new town. To build the city, players can add or remove markers on the interactive table.

Each new added element changes the game parameters and, obviously, the level of welfare.

Figure 34. The GAINE project.

Furthermore players can also decide the level of taxes and trigger events, as earthquakes. For the game in order to not overload the AR visualization, we realized 3D models of the main buildings of the town at a low level of detail. Starting from archival materials, houses, factories, hospitals, churches, transportation, were all reconstructed based on real historical buildings in Turin. The photorealistic reconstruction of the buildings was chosen in order to increase the realism of the application and meet the preferences of the public. The environment is also animated thanks to the implementation of an AI system. People are generated from the houses and walk in the game board, avoiding obstacles, while public transportation follow the streets system. It is also possible to dive into the reconstructed environment, walking as if you were a citizen, just enabling the "*first person*" mode.

Figure 35. The first person view.

The *GAINE* structure consists of some functional blocks that deal to perform different tasks and are able to communicate among them, the *GameManager*, *ObjectManager*, *EventManager*, *RuleManager* and *WidgetManager*, later explained in section *8.1*.

A peculiarity of the project is its ease of customization, as well as the ease of configuration without modifying the program. There is a set of XML configuration files, very intuitive and easily editable, in which users can define any information regarding the models associated with the tags, their behavior and the rules of the game, besides the graphical interface.

4.11 BEYOND THE PICTURE

This project [Bottino & Martina, 2011] presents an interactive application developed for enjoying paintings by immersing visitors into them and exploiting natural interaction to navigate their contents. The visitor is provided with the capability to modify the viewpoint on the painting by changing its observation position. Visitor's head movement are captured with a computer vision system and used to render a novel view of a realistic 3D reconstruction of the painting. The screen becomes a window on the picture, from which the user can navigate and inspect the rebuilt environment, focusing on specific details or discovering part of the painting that are hidden in the original view. Visitors can discover the environment represented in the painting and at the same time to play with the picture itself, without ever losing the scientific accuracy and rigor of the reconstruction. We also underline the fact that the same technique can also be applied to other cultural images like postcards, photographs and sketches providing a novel and interesting approach for enjoying historical artifacts.

In order to test these techniques we chose “Piazza Castello”, a tempera painting of Carlo Bossoli dated to 1852, which depicts the homonym square in Turin, also famous as the “Medal Plaza” of the Turin 2006 winter Olympic Games (see *Figure 36*).

Figure 36. The “Piazza Castello” painting of Carlo Bossoli, 1852.

Our objective is to provide the best user experience for this application. Therefore, since the image of the painting is presented on a high resolution large display, it is of paramount importance to achieve a 3D reconstruction which is both accurate (that is, as close as possible to the representation in the painting), and visually, or aesthetically, pleasing (that is, “looking how it should”). Therefore we are not interested in how the 3D model to show is obtained, as soon as it has the characteristics previously described.

In the literature, several techniques to infer the 3D scene structure from a single view have been reported. Tour Into Picture (TIP, [Horry et al., 1997]) is a very simple Image Based Rendering (IBR) technique that allows creating novel different views from a single image. In short, the approach deals only with images with a single vanishing point, which are transformed into a texture mapped box. Foreground objects, segmented manually by the user, are represented with simple planar polygons. Several variations of TIP have been proposed [Li & Huang, 2001; Boulanger et al., 2006; Zhang et al., 2006]. The main drawback of this and similar methods, like [Lourakis, 2007], is that they are limited to produce 3D models composed of planes or other simple planar primitives. Approaches taking into account curvilinear surfaces as well, more complex but more realistic, have also been presented [El-hakim, 2001; Ting et al., 2005; Saxena et al., 2009]. Most of them require a more or less complex user interaction for producing the final models.

While some of these techniques appear promising for our case, for “Piazza Castello” we could exploit an already available 3D model of the environment in the 1851, accurately reconstructed from historical documents, including maps, drawings, paintings and historical chronicles. This model has been developed for an interactive virtual tour of the city of Turin during that period, in the scope of the 150th anniversary of Italy’s unification that was celebrated in 2011. The initial model is very complex, since it includes all the small details of the buildings, which were not necessary for our application. Therefore, it has been simplified in order to keep its main distinctive elements.

In order to interact with the model we developed a face detection and tracking module. When the system detects a user in front of the “painting”, it tracks the head movements transferring them to the virtual camera. This method is a very intuitive and natural approach to discover and play with ancient paintings. More details can be found in section *8.2*.

4.12 USABILITY ANALYSIS OF GESTURAL INTERFACES

People naturally communicate through gestures, expressions and movements [Valli, 2006]. Natural Interaction stems from the desire to ensure that persons interact with technology in the same way they are accustomed to interact with the real world in everyday life. Thanks to the ease of Natural Interfaces the quality of human-computer interactions is improving, breaking down the barriers for disabled and elderly people. Obviously, in order to be efficient tools, these interfaces must be properly designed for the type of people to who they are addressed to [Donald, 2010]. Valli [2006] argues that one of the positive effects of NI is to reduce the cognitive load (working memory). This memory corresponds to the amount of elements in the short-term memory in any instant of time and it is extremely limited (studies reported that in an adult it can contain an average of 7 elements [Card et al., 1983]. Because of its limited nature, the working memory tends to simplify high-level information with schema as simple as possible, in order to not overload the brain. Natural Interaction aims to facilitate this function by providing mental patterns that already belong to the everyday life. Hutchins et al. [1985] point out that the structures that are frequently used by humans do not need to be rebuilt every time that we need them: they are recorded in memory. This can be achieved with constant practice or with the use of interfaces that use a language closest to that of humans, as gestures. Currently, the gestural interfaces can be divided into *touch-screen* and *free-form*. The *touch-screen* gestural interfaces - or touch user interfaces - require that the user touches the device. This necessity poses constraints on the types of gestures that can be performed. Instead, the *free-form* gestural interfaces do not require user to directly touch or handle any object. It is sometimes used a controller or a glove as input device, but more often the body is the only input device - in this case we have a *Full Body Interaction* [Saffer, 2009].

The freedom of movements along with the naturalness of interaction with the digital world deeply accentuates the people's sense of presence and involvement. Although natural interactions are available for the last years the research on gesture is still extremely poor. Several NUI devices have been recently developed, but all of those are not yet fully exploiting the possibilities offered, especially in the context of the Virtual Environments. Most VLE with natural interactions, in fact, are based only on few gestures, generally limited to movement or rotation of the whole human body. To this end, we conducted a thorough user survey to develop a vocabulary of gestures that can be used to interact with a virtual environment to navigate, select and manipulate objects and interact with the system that are natural, effective and easy to remember. The objective is to find the gesture more natural for users through a Usability Engineering approach in order to maximize the User Experience and to reach high levels of usability. The building of the gesture vocabulary follows the principles of the Usability Design, according to which the user has the major role in the design process. Moreover, the development process is iterative and at each cycle the usability of the design choices is validated through sessions of user testing.

In this work, the Microsoft Kinect was used to capture the body movement. The Kinect is an RGBD camera and its data stream is processed by the OpenNI libraries[16] to extract the body posture. FAAST[17] and Beckon Motion[18] libraries are then used to transform gestures into commands and to control a virtual environment managed by Unity3D, a game engine which is commonly used to develop VR applications (*Figure 37*).

[16] http://www.openni.org/ - (Last Accessed, February 2014)

[17] http://projects.ict.usc.edu/mxr/faast/ - (Last Accessed, February 2014)

[18] http://www.omekinteractive.com/tag/beckon-motion-toolkit/ - (Last Accessed, February 2014)

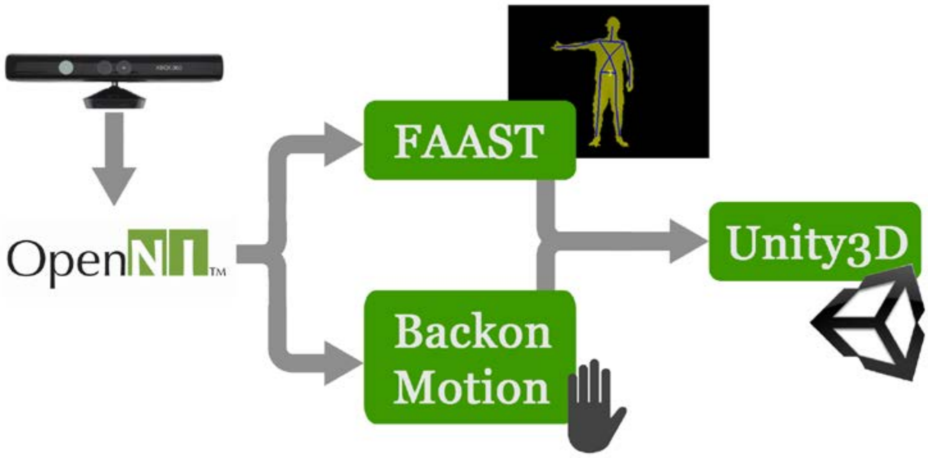

Figure 37. The system used for the usability analysis.

The process can be identified in 4 steps:

1. Recognition of actions normally used in a virtual environment.
2. Through the *Wizard of Oz* approach and the *Think Aloud* protocol we identified the most natural gestures for the majority of participants.
3. Definition of the initial gestures vocabulary.
4. Final user experience evaluation.

Identification of actions

The taxonomy identifies the different types of gesture and their interpretation. Within the literature, we find that researchers have proposed different categorization in the field of HCI. According to Kortum [2008] gestures can be divided on the perspective from which are analyzed, as *semantic* classifications (the meaning of the gesture), *functional* (its specific function in an interface) and *descriptive* (the explicit action).

Quek [2004] distinguishes gestures based on the user's intent:

- *Semaphoric*: any gesturing system that employs a stylized dictionary of static or dynamic hand or arm gestures;
- *Manipulative*: those in which the movements directly control the elements;

- *Conversational* (gesticulation): movements made during an interpersonal communication. These are the most liable to undergo changes according to culture, personal style or social context.

With regard to AR and VR the most used are the manipulative gesture and semaphoric [Karam & Schraefel, 2005], while rarely gesticulation.

Karam and Schraefel [2005] added to the three categories of Quek, the *deictic* gestures and *sign languages*. The first are those that refer to something easy, generally referred to the child - pointing, showing an object, or reaching for something - while the second is a real language with a grammatical structure.

In addition, other researchers added:

- *Patic gestures*: movements that represent a path or direction;
- *Mimic gestures*: actions that copy other real life movements;
- *Ergotic gestures*: movements of object manipulation (rotate, move, open, etc ...).

Pavlovic et al. [1997] separate intentional movements from non-intentional. These involuntary movements do not carry any kind of useful information to interaction, so often they are not even classified as a gesture [Pavlovic et al., 1997; Hoven & Mazalek, 2011].

Bowman and Hodges [Bowman & Hodges, 1999] summarize the possible gesture in a virtual environment in three basic categories of interactions:

- *Navigation*. The methods of locomotion combined with those on the control of gaze and the direction of movement to control the user's perspective (e.g. walking, running, turning, gaze orientation);
- *Selection*. It is one of the most common functions in a VE and can be performed on objects in the environment or on interface elements (or 2D elements in general) in order to activate or manipulate them (e.g. "click", "hover");
- *Manipulation*. It concerns the way in which an object is managed based on the user's actions (e.g. drag'n'drop, zoom, pan).

To these three categories, we added another one, *System Control*, which represents those actions that relates to the interaction with the system and not with the virtual environment (e.g. activation menu, item selection, parameter setting).

Identification of the most natural gestures

In order to identify the most natural gestures for each above-mentioned action we used a combination of a Wizard of Oz approach and a Thinking Aloud protocol.

Wizard Of Oz approach is based on the concept that the experimenter interprets and simulates the response of the system (usually still a prototype) to the actions of unaware users. Participants then believe that they are actually interacting with the system and controlling a fully functional application. During an experiment the "wizard" (technical) sits hidden from the gaze of the user who held the test. Useful in the design and planning phase, this technique allows to quickly identifying user behavior. The designer can then make decisions based on the results of the test.

The *Thinking Aloud* protocol is one of the most reliable techniques for both the design and evaluation phase thanks to its high flexibility, robustness, low cost, ease of implementation and credibility [Nielsen, 1993]. While participants use the system they also have to constantly think aloud, verbalizing their thoughts and moods. Knowing what is going on in the users' minds and what they are observing in real-time, researchers can get interesting data.

Combining these two techniques, we investigated what were the most natural gestures for the actions previously analyzed. The focus was not on how a user makes a movement but what he/she was performing and why. Through these tests quantitative and qualitative data were collected (*Table 2*).

Qualitative	**Quantitative**
Types of gesture used for the required actions.	Number of times in which a gesture is used.
Types of gesture used for multiple actions.	Number of times in which a gesture is used for different actions or number of gesture used for the same action.
Verbal comments (Thinking Aloud or others).	Comparative data on the gesture used by categories.
Observations on users' behavior and their attitude towards the environment (physical or mental difficulties, stress factors, interventions of the moderator).	

Table 2. Qualitative and quantitative data collected.

Figure 38. An example of people interacting with the system.

Our group of participants was composed by 18 people, 11 men and 7 women, from different backgrounds and with mixed technological skills. Users had to complete some tasks within a virtual environment. The 3D scene was created in Unity3D and it was properly designed to make try all the identified actions. Results are in *Table 3*.

Definition of the initial gestures vocabulary

Once identified the most natural actions we proceeded to the definition of the vocabulary of gesture and then to their implementation. The vocabulary has been defined by listing the most common gestures resulting by the Exploratory Test with the addition of some gesture indicated by the literature (e.g. the *Hover* gesture). In Unity3D three new environments were specially created for the Assessment Test and all the gestures were enforced. Most of the Gesture Recognition algorithms were implemented through the FAAST library, while the hand gesture through the Beckon Motion Toolkit. Although FAAST also gives the possibility to control the cursor with hand, its resources are limited compared to those of Beckon Motion toolkit: FAAST can recognize only one hand at a time and the pointer is only associated to the one of the operating system. We wanted to give users the possibility to choose which hand to use, so we preferred to work with the Beckon Motion toolkit.

Action	Preferences
LOCOMOTION	Walk-in-place with 15 preferences, a person flexed torso forward while no one has used arms.
STEERING	The most common gesture was twisting of the torso or the entire body, 3 participants raised their arm pointing the desired direction.
MOVEMENT IN SPACE	The totality of the participants used gestures that mimic movements in real life for actions such as jump, crouch, climb over objects and climb ladders.
POINTING	All users have used deictic gesture for pointing out objects or elements of the interface (using arms)
SELECTION and CLICK	All of the respondents made a push gesture to the item they wanted to select.
SLIDE	The majority of users considered as more appropriate flap gesture (similar to how we turn a page) or scroll, less interesting the push (6 people) or hover gesture (1 person).
ZOOM IN / OUT	Zooming in and out on images the dominant gesture was the pinch-to-zoom (44%), followed by the push/pull.
EXIT MENU OR GALLERY	Exit from a menu was realized with a step back (50%) or with a back inclination of the torso (17%). 28% of users have also used the push gesture (clicking the arrow in the interface).
PLAY / STOP VIDEO	Nearly 90% of people executed commands play / stop with one click. 2 users have instead used gestures belonging to real life as the use of a remote control or the turning a control knob.

Table 3. For each action the most natural gestures preferred by the majority of users.

Final user experience evaluation

The aim of the Assessment Test was to evaluate the usability of the implemented functions. Users had to move within three different 3D environments with diverse tasks. For each environment the complexity increased as also the number of gesture to use.

Figure 39. The virtual environment used for the assessment test.

Participants were 22 people (11 males, 11 females) aged between 17 and 59 years old with a medium-high level of education. Among the participants were also three lefties. Most users (59%) were used to experience virtual environments (e.g. video games), and 68% have already used gestural interfaces. Each participant experienced the three environments using the gesture that was more natural for them. Before starting each environment a mini tutorial outlined the available gestures. At the end participants had to answer to a questionnaire to assess the usability of the gestures. Due to the many parameters we wanted to investigate, a single questionnaire would be reductive. Then the final questionnaire was created ad hoc and it was composed by some parts:

- *Screening questionnaire*: This section is devoted to assessing the level of previous experience with gestural interfaces, as well as collecting data (age, sex, level of education, height, dominant hand) to classify users and to better interpret their responses.
- *Satisfaction questionnaire*: using the model proposed by Kevin Arthur [Usoh et al., 1999] with minor changes (some questions were adapted to our situation). This section evaluated for each gesture performed, the degree of ease of use, naturalness in execution, learnability, usefulness of the information provided and degree of appreciation.
- *Perceived Exertion Questionnaire*: this part wanted to evaluate the perceived exertion of each gesture. People were asked to evaluate the effort proved, without overestimating or underestimating it. The Borg scale CR10 [Borg, 1982] was used to estimate this parameter in a simple and immediate way.

- *VRUSE Questionnaire* [Kalawsky, 1999]: its structure in sections allowed us to eliminate unnecessary parts related to different usability factors, maintaining the two sections about the input system.

The results are reported in the table below.

Action	**Results**
LOCOMOTION	Preferred gesture: *Gate System* (the extension of the right foot forward). Physical exertion: 0.18
STEERING	Preferred gesture: *Rising of one of the two arms.* Physical exertion: 0.2
SELECTION AND MANIPULATION	Preferred gesture: *Hover* movement. Physical exertion: 0.5
SLIDE IMAGES	Preferred gesture: *Hover* movement.
ZOOM	Preferred gesture: *Pinch-to-zoom*. Physical exertion: 0.0
PAN	Preferred gesture: *Open hand* movement. Physical exertion: 0.4
EXIT FORM THE GALLERY	Preferred gesture: *Right foot back.* Physical exertion: 0.0

Table 4. The final results.

The last section of the questionnaire investigated the usability aspects of user input (the gestures) and usability in general. The overall evaluation of the input system was rated 4.14 (SD: 0,62; MIN:1; MAX:5), while the general usability 4,31 (SD: 0,47; MIN: 1; MAX: 5). In addition, participants indicated that the input system was simple to use (4.00) and satisfying (4.10). Moreover the negative correlation value (r = -0.85, p <0.005) between the question *"The input system is ideal for interacting with a virtual environment"* and *"I would have preferred another input system"* showed the strong appreciation of the vocabulary of gesture. The most negative feedback regarded the excessive sensitivity of the system which required, at times, a good precision in the execution of the gesture.

Furthermore, the system reached high level of intuitiveness (3.97) and ease of use (4.00). Lower ratings were assigned to the repetition of errors. In some cases the users' behaviour was ambiguous and sometimes the system detected a wrong gesture. This problem, although it happened few times and particularly during the early user tests, it was still annoying. We believe it is not of particular importance because it represents a normal stage of the learning process.

4.13 SKYLINEDROID

SkyLineDroid [Armanno et al., 2012] is an application of Virtual Heritage where Augmented Reality is used on mobile phones to support visitors of outdoor cultural heritage sites. Virtual and real world are overlaid on the device screen, according to device position and orientation, in order to immerse users in the 3D historical reconstruction of ancient buildings. Furthermore, a wealth of available multimedia information, related to each virtual element, is available and can be accessed by visitors according to their own interest and curiosity. Therefore, users are provided with a complete multimedia cultural guide which allows them to assume an active role in their journey through history.

Figure 40. An example of SkylineDroid view.

The system is designed to handle multiple 2D and 3D content, in order to provide visitors a true timeline of the evolution of the site. Virtual models of ancient constructions and monuments of the selected period are shown on the device display on their original location. Therefore, *SkyLineDroid* allows users to customize their visit by choosing what to see, from which point of view and to interact with history, observing the architectural and social evolution of the site through a straightforward comparison with its actual state.

The structure of *SkyLineDroid* is the following. When the application starts, it shows a welcome message that explains its functionalities, followed by a short introduction with some general information about the heritage site the user is going to visit. Touching the display, the application switches to the navigation mode, where the user can select the historical period he/she is interested in. Then, when the device is pointed at the surrounding world, the application renders, according to their location w.r.t. the observer, the 3D models of nearby ancient buildings on top of the live video frame, creating the augmented view. Tourist can click on the preferred building and the application will display a range of additional multimedia contents related to that building in that particular historical period. Each virtual building is associated with a visibility region, that is the area from which its 3D representation can be viewed by the user without being occluded by other buildings or without being too far for appreciating the model details. When no virtual buildings are visible, they are treated as Point Of Interest (POI) and their location is shown in AR as balloons. Navigation in the augmented world is facilitated by a radar displayed on the monitor, showing the locations, with respect to user's position, of the virtual elements surrounding him. In addition, displacing the device parallel to the ground plane, a full screen 2D map of the area, which is interactively rotated according to user's orientation, appears on screen. Icons highlight on the map user's position and locations where augmented views are available. Hence, the application performs a dual role: a virtual driver through the past and a guide for visiting the actual places.

A prototypal version of *SkyLineDroid* has been implemented on the Android platform. As a test case, it has been designed to immerse visitors of Las Vegas in the historical evolution of "the Strip", the main city boulevard, focusing in particular on three of its most prestigious and oldest casinos, the Stardust, the Sands and the Riviera. The timeline goes from 1952 to 2006. During this period, these casinos underwent several renewals and expansions, which have been all virtually rebuilt. In total, there are 16 time-slots through which visitors can appreciate the temporal changes of (a part of) the Strip skyline. For each building and each period, a wealth of historical original documents is available, like pictures, advertising billboards and restaurant menus, video footage and radio shows, maps and postcards (*Figure 41*). This original archive material, which has been also used to model the different versions of the casinos, has been granted by several institutions and private persons: UNLV, holder of the UNLV Special Collections, the Liberace Foundation's music archive and Tom Askew's Private Collection.

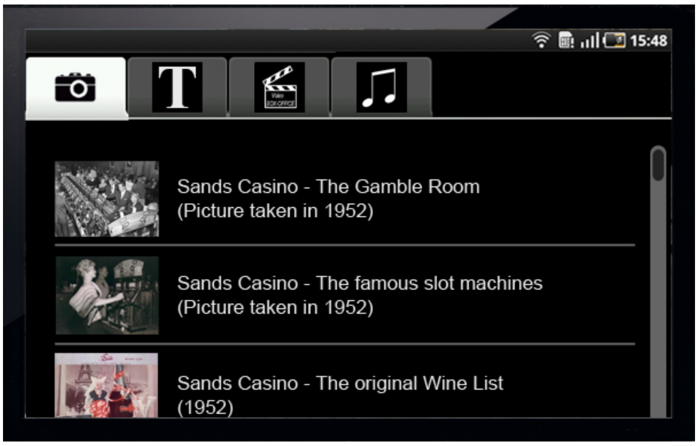

Figure 41. The content gallery related to the 1952 model of the Sands.

A block diagram, outlining the operations required for handling AR contents, is shown in *Figure 42*.

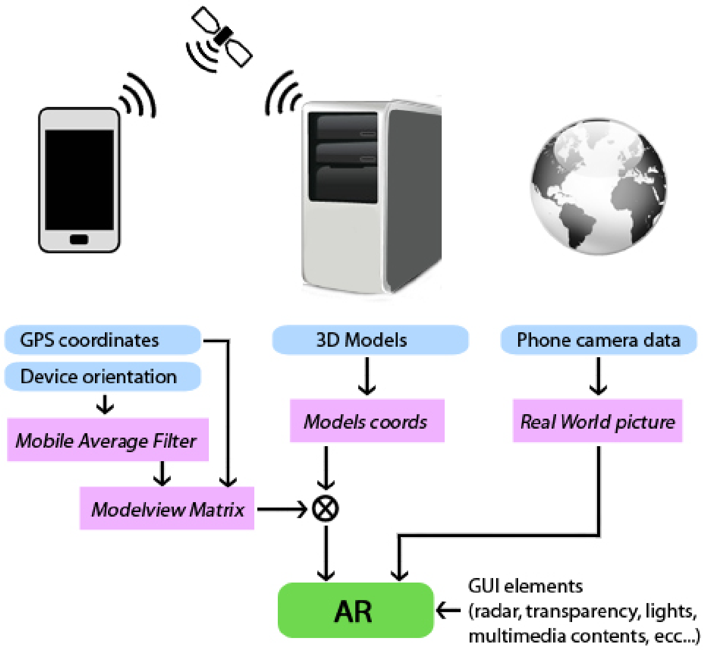

Figure 42. Management of AR contents.

SkyLineDroid is based on a client-server architecture. The server handles requests from the client (the user's mobile phone) and stores in a database all the 3D models and multimedia information used during the augmented tour. Anytime the user chooses an historical period to visit, a request is sent to the server for obtaining the POI list and for downloading only the models corresponding to that exact period. The models are cached on the device so that a further request of the same model does not require its download from the server. Models are time stamped in order to invalidate cache entries that become stale after a model update on the server.

Models descriptions, including their geometry and associated textures, are stored in XML format using an optimized subset of COLLADA features [2014], in order to reduce size of the transferred data and their decoding time on the client. The description of the multimedia content related to each model is included in a separate XML file. Along with the list of available material and their thumbnail sketches, the way it will be presented to the user (in terms of its organization in tabs or folders) is defined as well. This file is downloaded only when the user taps on a model (on the 3D view) or on an icon (on the map view). Finally if the user taps on a thumbnail, the referred content (e.g. a high resolution image, a video or an audio file) is downloaded from the server and activated.

The client/server architecture is necessary for handling the large amount of multimedia data that can be used to support visitors during their journey. Another advantage of this structure is that contents, in terms of both available POIs and their related data, can be added or modified at any time on the server without requiring users to download an update of the application.

We underline the fact that *SkyLineDroid* is an open platform that can be easily adapted to any other cultural heritage site by simply changing the collection of 3D models and digital contents handled by the application.

4.14 MUSA

When developing an application to be deployed in a museum context, a set of preliminary questions involving both the curators and the developers needs to be answered: what is the objective of the application? How information can be effectively communicated to the target users? How to cope with users' different cultural background, interests and age? When the mobile indoor dimension of such an application is taken into account, additional issues arise, such as: how to deliver visitors contextual information related to the artworks or locations in their surrounding? How to help them following the physical path of the exhibit and finding their way through complex museum halls that they are probably visiting for the first time?

In order to answer these and other research questions, we developed *MusA* (Musem Assistant) [Rubino et al., 2013], a general framework offering a set of predefined tools and functionalities that can be used to develop flexible and compelling multimedia interactive guides for mobile devices. These guides are aimed at helping a meaningful exploration of exhibits and cultural venues according to the personal interest and curiosity of visitors, supporting them with contextualized information while, at the same time, providing personalized ways of managing their visiting path and access to cultural contents.

MusA focuses mainly on two issues that curators and exhibit designers have to face: (i) supporting mobile users with information of interest related to the works of art on display or the surrounding environment and (ii) helping them to follow their visit path inside the venue.

Both these problems are addressed in our solution through the delivery of location based services, which rely on the accurate identification of the indoor location of the visitor by means of a vision-based positioning system. The key feature of *MusA*, indeed, is the capability to accurately identify the position of the visitor within the museum. In a museum it is easy to get lost, especially if its floor plan is complex, and the relevant literature has frequently underlined that orientation and way-finding represent an issue for both museum curators and visitors [Rounds, 2004]. Considering that patterns of circulation and attention ultimately influence visitors' cultural and leisure experience [Bitgood, 2006], providing solutions that help visitors orientating themselves both physically and cognitively seems particularly important for cultural institutions that aim at fulfilling their educational mission. According to these considerations we developed a vision-based approach to indoor positioning. The system can identify the user's position simply by scanning a visual marker, depicting specifically designed two-dimensional patterns. Alphanumeric information are encoded into the marker and they are used as key to obtain the fiducial position and orientation from a database.

Given the possible application scenario of a *MusA* based mobile guide and the fact that it can be potentially run on any off-the-shelf mobile phone, we took into consideration the following points in the development of our pose estimation approach:

- the positioning algorithm should be as light as possible in order to be executed in real-time, even on devices offering limited computational power; hence, for these devices, approaches requiring the optimization of non-linear objective functions with complex and iterative algorithms [e.g., Sturm & Maybank, 1999; Schweighofer & Pinz, 2006] are not the best-suited;

- a lightweight algorithm, requiring a low amount of energy for its execution, helps reduce the device battery consumption, which is a vital parameter for any application aimed at supporting the visitor for a medium to long time span;
- any approach requiring one to know in advance the intrinsic camera parameters [e.g., Sturm & Maybank, 1999; Schweighofer & Pinz, 2006; Chen et al., 2010] is again unsuitable, since these parameters vary from camera to camera, thus requiring a database of camera parameter sets, periodically updated to consider new devices;
- in indoor positioning and navigation, the environment is usually represented by 2D maps and, thus, the localization data can be reasonably expressed with only three degrees of freedom [Mulloni et al., 2009]; another thing to consider is that, in most scenarios, a reliable indication of the user orientation inside a building is required to provide useful navigation information, while we can be satisfied with a less precise estimate of the device position, or even considered it as co-located with the detected marker.

With this in mind, we designed a novel visual marker easy to identify and analyze (*Figure 43*).

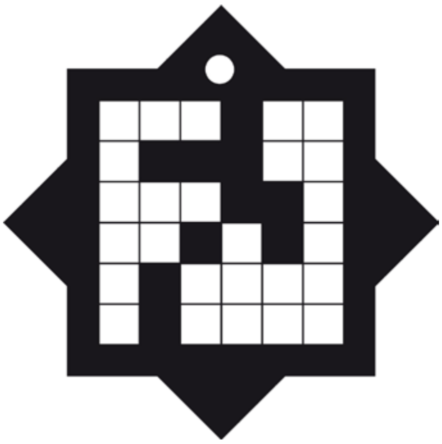

Figure 43. Our marker.

Our libraries can compute the full 3D position and orientation of the camera relative to the marker, and consequently obtaining the visitor's position and orientation. A detailed explanation of the approach can be found in [Rubino et al., 2013].

Another relevant feature of *MusA* is the possibility to deliver visitors additional rich multimedia contents that can provide insights about their surrounding environment and the works of art they are seeing through textual commentaries, high-resolution images, videos and audio contributions that can be accessed and browsed through the device display. Different thematic exhibits can be designed by the curators and managed by *MusA*. Thus, users are provided with the possibility to choose at any time their visiting path according to their interests and curiosity. A thematic path can help to reduce barriers between the museum and the visitors, otherwise overwhelmed by a quantity and a variety of contents that are hard to be processed in a short visit time, improving the learning process and the recall of information from the exhibit. Furthermore, such a structure allows to include a cultural object in different thematic paths, and thus, to communicate its information in different ways and styles, according to the specific perspective of the narrative designed by the curators or to the specific audiences targeted by the themes. As a further option, visitors can create their own tour, by selecting the works of their interest and then being guided to selected destinations. Finally, the knowledge of the user's position inside the building allows to exploit location based games in the educational process.

The implementation and use of *MusA* in a museum context has been tested at Palazzo Madama—Museo Civico d'Arte Antica, a historic building and UNESCO World Heritage Site located in the city center of Turin, Italy. The museum's collections are organized in four categories over the four floors of the building: medieval stoneworks (moat level), Gothic and Renaissance masterpieces (ground floor), Baroque art (first floor) and decorative art objects, such as ceramics, textiles, glassware and ivories (last floor). This heterogeneity, combined with the extension of the venue over 4,000 m2, makes Palazzo Madama a particularly multilayered and complex cultural context: as a result, visitors have frequently reported difficulties orientating themselves inside the building. Additionally, previous studies have pointed out that only a minority of visitors actually follows the thematic and chronological paths designed by curators, showing critical issues with both physical and cognitive orientation [Hausmann & Poellmann, 2013].

Based on these observations, we deemed Palazzo Madama as being particularly suited for experimenting with the functionalities of *MusA* in a real and challenging scenario. To this end, two different applications were developed: "Step by Step", a mobile museum guide addressed to an adult audience, and "Intrigue at the museum" a location-based game specifically designed for children. The two applications were deployed and thoroughly experimented in order to analyze the user experience and the visitors' appreciation of the applications.

Step by step is a mobile guide aimed at guiding visitors through the museum collection. Relying on *MusA* functionalities, three thematic paths were developed by exhibit designers:

- “*Great Treasures*”, devised for helping visitors with tight time constraints to discover the museum masterpieces;
- “*Discover the unusual*”, a selection of the museum’s works of art that present uncommon and usually unnoticed characteristics;
- “*Decorative techniques*”, focused on the materials and the techniques mastered by artists over several centuries.

These paths were developed in order to cater to visitors’ interests and visiting agendas. Additionally, considering that visitors have different visiting styles and may prefer not to be guided in the museum, users are also able to build their own personalized visiting path through the “*Wander and learn*” tool, which let them freely select the rooms and works of art to be explored. To provide maximal flexibility, users are allowed to switch the current visit theme at their will. The users can then be guided at any moment to their next destination (*Figure 44*a) activating the navigation function and pointing with the tablet at a *MusA* marker in their surroundings (*Figure 44*b). When the tag is recognized by the system, the navigation data are presented to the user on the tablet display. To make this information as clear and readily understandable as possible, route communication integrates different elements: a 3D map, rotated according to the user orientation, and an arrow showing in AR on the camera image the current walking direction. The whole path is described on the map and the user can control an interactive animation showing the detailed instructions to reach the destination (*Figure 44*c,d).

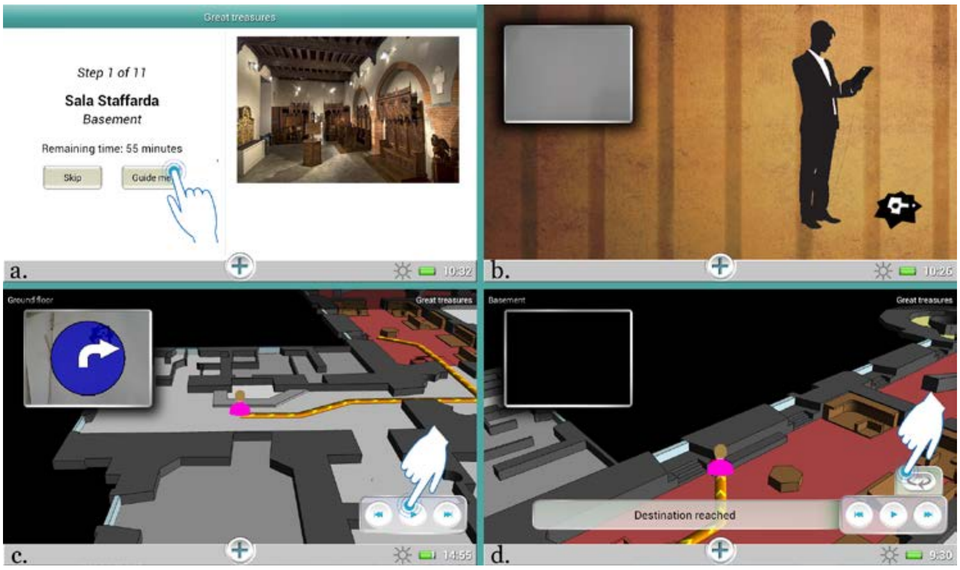

Figure 44. Screenshots of the application interface showing a step of the tour (a), the marker aiming menu (b), the 3D map and the path animation (c, d).

When the desired destination is reached, the user can activate the related contents by pointing the tablet to the marker associated to that item or, alternatively, clicking a button in the user interface. The layered contents are then fetched from the DB and displayed on screen according to their structure.

Visitors can access contents related to the environment and works of art on display also through hotspots embedded in interactive 360° panoramic images (*Figure 45* a, c). The rationale of integrating this feature into the guide is that the panoramic images allow a seamless shift between the image displayed and the surrounding environment, facilitating the interaction with the elements it contains [Bruno & Pollichino, 2011]. Panoramic images also allow a reduction of the number of tags installed in the museum rooms. Furthermore, they offer visitors the possibility to display, and eventually access, other items present in the same room but not included in the thematic path chosen (*Figure 45* b, d), which can possibly foster visitors' interest into alternative paths in the museum collection.

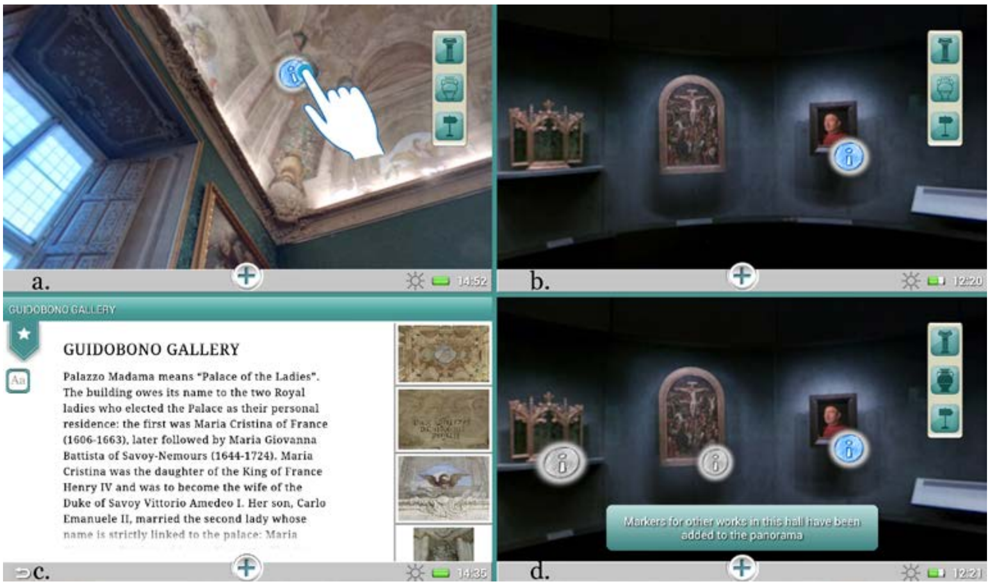

Figure 45. An interactive hotspot (a) and its related content (c); a panoramic image showing the path hotspots, in blue (b), as well as those included into alternative paths, in gray (d).

The whole application can be customized by users, selecting the display language, requesting accessible routes or modifying the interface setup, e.g., to display contents designed for dyslexic users (*Figure 46*).

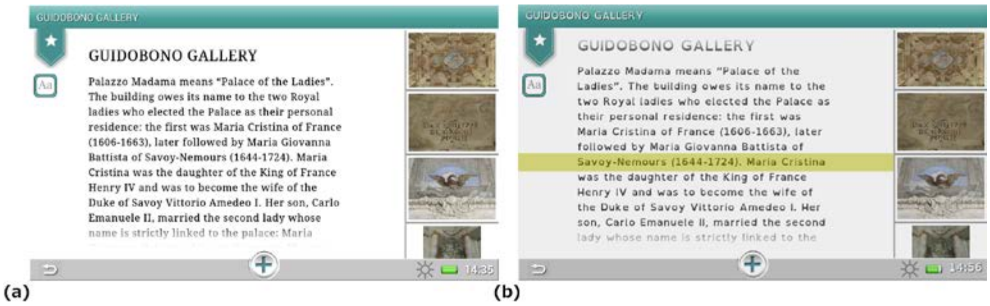

Figure 46. A screenshot of the interface for dyslexic users (b), which, compared to the version for non-dyslexic users (a), shows the usage of the OpenDyslexic font, a lowered contrast in the interface and the possibility to highlight the current reading line, helping users to focus on the text.

Intrigue at the museum is a location-based mobile game targeting a young audience, i.e., 7–13 years old children. Its goal is to identify a virtual thief in a set of suspects, with the help of different clues obtained by the player as he/she explores the environment solving puzzles and mini-games activated by the markers deployed in the building. These mini-games are related to the artworks or the museum venues. In order to progress in a mini-game, different pieces of cultural information received by players at the game start and a careful observation of the artworks and their surrounding environment are necessary, thus encouraging children to pay attention to details that could be easily unnoticed.

Both Step by Step and Intrigue at the Museum were thoroughly tested after their deployment to analyze several elements of the user experience and to investigate the degree of appreciation of the applications and of their functionalities. Among the different methods used in current mobile usability research [Bellotti et al., 2011], we opted for a field study entailing the involvement and participation of actual visitors of the museum. Such approach allows to conduct the evaluation in a realistic environment, taking into account, among the factors usually reported as affecting the mobile experience [Kenteris et al., 2011; Nayebi et al., 2012; Baharuddin et al., 2013], not only users' characteristics (mobile user factor), but also the environmental and social context of use (mobile environment factor). Overall, the analysis followed a mixed-method approach combining quantitative and qualitative research. Given the peculiar characteristics of the user categories targeted by the two applications, different protocols were applied in their evaluation process.

Evaluation of Step by Step

Volunteers were recruited at the museum ticket office, asking visitors to freely use the application and participate in the test. Each user was then provided with a 7 inch tablet to run Step by Step.

Pre- and post-visit questionnaires were collected, followed by semi-structured interviews addressed to a subset of users. The panel was composed of 171 volunteers, 57% males and 43% females. The majority of participants were first-time visitors (75%). Visitors spanned different age groups: 36–50 (28%), 27–35 (26%), 18–26 (22%) and 51–65 (15%); participants younger than 18 years were only 5%, since they were invited to use *Intrigue at the museum*.

The pre-visit questionnaire mainly aimed at investigating the mobile user factor by collecting socio-demographic data, visitors' expectations and information about their level of confidence with mobile devices. As for the approach to technology, most of respondents (70%) declared to own a tablet or a smartphone, 25% of them perceived her/his level of confidence with these devices as "excellent", 40% as "good", 23% as "average" and only 5% as "low". Other results pointed out that most users decided to use the application attracted by new ways of exploring cultural heritage sites, desiring to get a better understanding of the museum exhibits.

Post-visit questionnaires aimed at investigating the usability of the application, with specific regard to the ease of use, usefulness and satisfaction dimensions mentioned by the literature (Nayebi et al., 2012). The questionnaire stimulated volunteers to express their level of agreement with a set of statements, using a 10-point Likert scale, or to make choices between options. Results are summarized in *Figure 47* which report the most relevant questions related to the three dimensions of our usability framework, their average ratings and a vertical line indicating their standard deviation. Most of the answers were found to be consistent (standard deviation in the range [1.55, 2.17]).

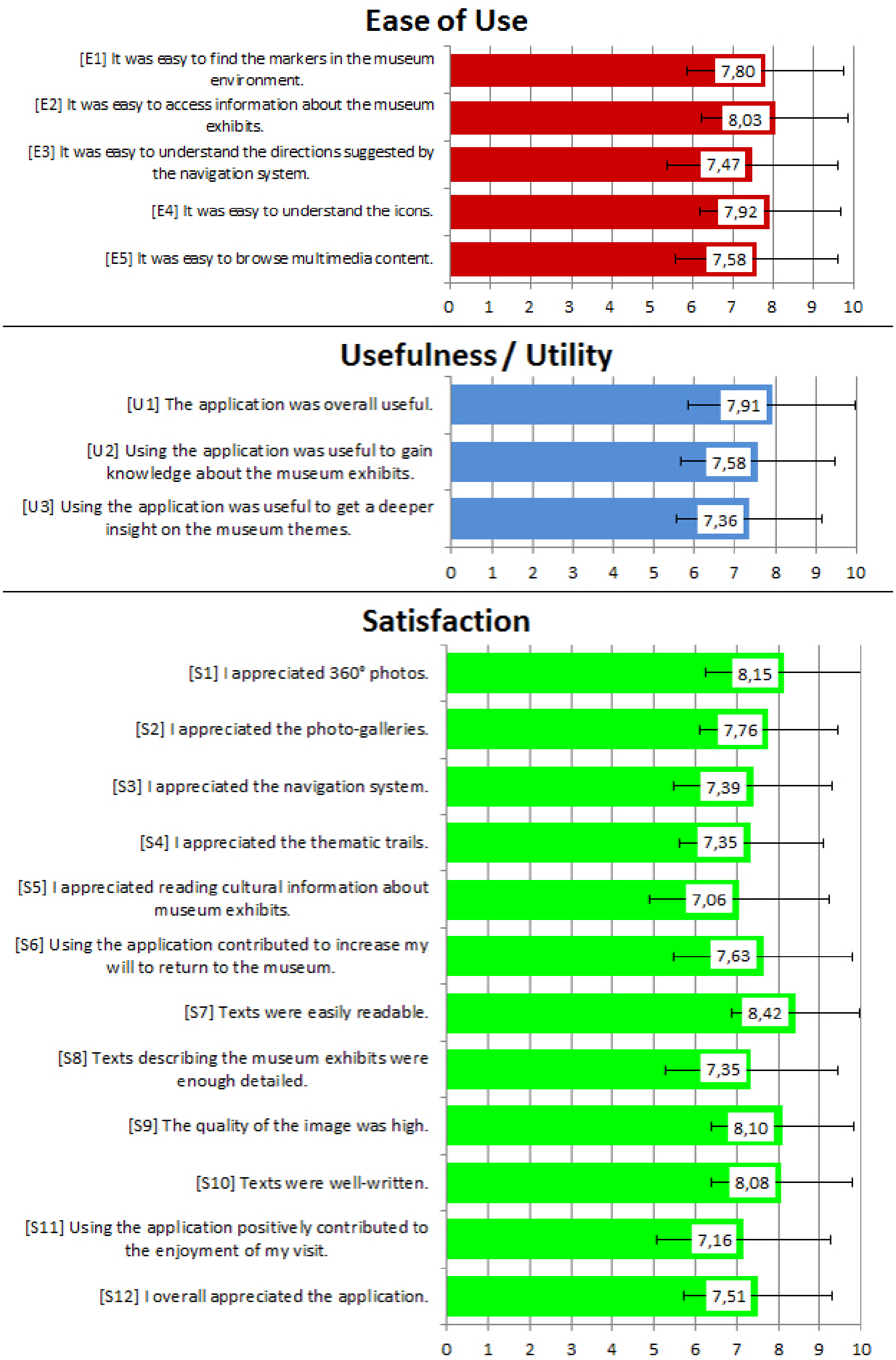

Figure 47. Post-visit questionnaires.

The overall degree of satisfaction manifested by volunteers towards Step by Step was positive, with an average rating of 7.51 (S12). Among the functionalities enabling visitors to access and interpret information, 360° photos were the most appreciated feature (8.15, S1), most likely for their intuitive nature. Other multimedia features such as photo-galleries (S2) and texts (S5) were rated 7.76 and 7.06, respectively, with texts acknowledged as easily readable (8.42, S7).

As for the usefulness dimension, users agreed that the application was useful overall (U1, 7.91), facilitating to a certain degree the acquisition of a better knowledge (U2, 7.58) and a deeper insight (U3, 7.36) on the history of the palace and the works of art on display.

Indoor positioning and navigation (S3) were overall appreciated, receiving an average score of 7.39. Additionally, the analysis of the ease of use dimension pointed out that participants found the navigation process quite easy to follow (E3, 7.47) and the markers easily recognizable inside the environment (E1, 7.80). While indoor positioning and navigation still represent for visitors unexpected features for a museum context, as shown by the pre-visit questionnaires, our findings suggest that people generally appreciate these services once exposed to them.

A subset of 35 visitors was invited to participate to a semi-structured interview after the use of Step by Step to further investigate the usability dimensions, and to gain better insights into other aspects of the application use (*Table 5*).

Ease of use
IE1) Was it easy to understand your position on the digital map?
IE2) Was it easy to understand the direction to be taken to reach your next destination?
Usefulness
IU1) *Was using the navigation system useful to reach your desired destinations?*
IU2) *Was using the mobile guide useful to get a deeper knowledge and understanding of the history of the palace and the works of art on display?*
IU3) *Was using the mobile guide useful to better manage the time allocated to your visit?*
Satisfaction
IS1) *Was it pleasant to use the mobile guide?*
IS2) *Would you recommend the use of Step by Step to your friends?*
IS3) *How did you feel when using the mobile guide?*
Additional questions
IA1) *Did you read the texts describing the works of art on display and the rooms of the palace?*
IA2) *Did you use the photo-galleries, when available?*

IA3) *Did you use the navigation system?*
IA4) *To what extent have you used the mobile guide during your visit?*
IA5) *Did you refer to informative tools such as panels, labels and touch screens during your visit?*
IA6) *Had you already used a mobile guide in a museum context before today?*

Table 5. Outline of the semi-structured interviews.

Overall, the majority of respondents (31) actively used the guide throughout the visit. However, (question IA5) 25 out of 35 people regularly combined the use of the tablet with the traditional habit of relying on informative tools such as panels, labels and touch screens. Considering that only four people had previous experiences with mobile museum guides (question IA6), it can be inferred that the mobile guide was perceived as a novelty and that people had to adapt to this new visiting approach.

As for the contents, 26 people stated that using the mobile guide was useful to get a deeper knowledge of the palace and of the museum collections (IU2). However, only 29 users regularly read the texts about the works of art on display (IA1), and only 18 visitors regularly explored the photo-galleries or the other additional contents. Interviews made evident that the interface was not clearly pointing out the availability of such materials, thus highlighting an element to be improved.

Twenty-two visitors used (IA3) and found useful (IU1) the indoor navigation system. Other participants preferred to wander throughout the museum by themselves, asking for directions to museum assistants or looking at maps in paper format, if needed. Again, this behavior was mostly explained mentioning traditional visiting habits. Some users found difficult to understand their position on the digital map (IE1) or the directions to be taken (IE2). These problems are related, as previously commented, to the issue of map readability and route communication, which should still be improved.

Concerning the satisfaction dimension, 30 participants found the application pleasant to use (IS1) and would recommend it to a friend (IS2), describing themselves when using the app as “interested”, “focused” and “curious” (IS3). People who did not enjoy the use of Step by Step defined themselves as being “distracted”, since recalling the operating principles of the system was difficult and reading long texts was negatively affecting enjoyment.

Finally, answers about the usefulness of the guide for the management of the visiting time (IU3) highlighted two different patterns: people who followed the guided tours used the guide effectively as a time manager, while, on the other hand, people who selected the free tour generally pointed out that accessing rich multimedia content induced them to explore in more depth the collection, satisfying their interests and curiosity, thus staying in the museum longer than expected.

Evaluation of Intrigue at the Museum

Unobtrusive observations involved 30 young visitors and were aimed at understanding how the use of the mobile game was integrated into children's exploration of the museum, if the application was perceived as an enjoyable tool and if it actually facilitated a mind-on encounter with the museum environment. We specially investigated the degree of engagement and enjoyment facilitated by the game since, besides being desirable outcomes in themselves, they are also precursors of learning [Csikszentmihalyi & Hermanson, 1995].

Additionally, observations were useful to check if the gaming experience was fluid and if children actually followed the game mechanics (e.g., scanning tags, activating mini-games, progressively excluding characters from the list of the suspects and so on), thus conducting an implicit evaluation of the ease of use of the interface and of the application as a whole.

In order to code players' behaviors, verbal and non-verbal key-indicators of engagement were previously identified among the ones presented by the relevant literature [Bitgood, 2010; Fui-Hoom et al., 2012] and then adapted to the context. Results pointed out that 83% of young players revealed one or more signals of engagement, the most frequent being hunting markers, walking faster, and pointing at markers while saying aloud sentences such as: "Look! There's another one [i.e., marker] over there!".

Concerning the ease of use dimension, most of the participants successfully used the application after familiarizing themselves with it at the beginning of the visit. Usage problems were reported only for two children who did not immediately understand how to operate the system and asked museum staff for help. We think this result highlights the intuitiveness of the user interface.

In order to investigate how adult companions perceived children's enjoyment, engagement and social interaction, 81 questionnaires were collected. The effectiveness of the game in facilitating an enjoyable visit is demonstrated by the adjectives used to describe the feelings manifested by children, which had almost exclusively a positive connotation (*Figure 48*). Answers also revealed that the application components more appreciated by players were, in order of relevance, solving the mini-games, hunting for the tags in the museum environment, finding the suspect and, finally, reading contents. This suggests that the application was successful in capitalizing on the physical exploration of the museum venue to foster attention and mind-on activities. The lower degree of appreciation manifested towards the contents was mainly related to the way they were communicated (i.e., as texts), suggesting that better ways of integrating those contents into the game mechanics should be experimented.

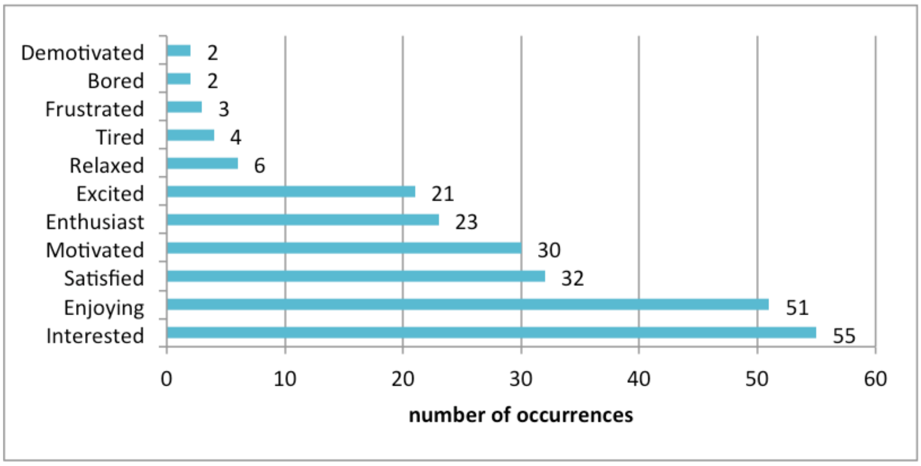

Figure 48. Adjectives describing players' feeling.

The complete evaluation data can be found in [Rubino et al., 2013].

CHAPTER 5 – RECREATION OF CONTEXT

Heritage contents were generally disclosed through simple presentations. Since before the advent of the Internet and the development of digital software, historical contents were showed to the public through books, pictures and video footages. But today those means needs to be flanked by other more adequate tools, able to better engage the new audiences. As already mentioned the definition of museum states that the communication to users has to happen through the most appropriate tools available, in order to meet the people's preferences and needs. Virtual Reality approaches through accurate 3D reconstructions and interactive environments, fosters users' immersion and emotional engagement. This is particularly significant when the aim of the interpretative process is to recreate a specific context [Forte & Pescarin, 2012]. The main concept of the VLE, indeed, is the possibility to carefully reconstruct any environments in order to recreate the original historical and artistic context of any cultural object or historical characters. By recreating the historical and artistic context, users can appreciate with greater simplicity and effectiveness historical elements, identifying not only the characteristics of the object itself, but being able to better understand the relationship between the object and the sociological and historical environment in which it 'lived '. In this way, the features are easily identified, enhancing their significance.

Through virtual environments, the various documentary resources that have been used to build that context acquire a new and full meaning from their reciprocal relationships. Furthermore, the fact that different pieces of information (3D models, images, sounds and other multimedia contents) can be experienced simultaneously is an effective way not only to convey factual information but also to suggest a certain atmosphere, adding an emotional value to the exploration. VLEs, in our opinion, represents the current best way to engage users in a fully edutainment experience. According to the specifications of VLEs, we have many diverse kind of them that produces different experiences. Each characteristic needs to be properly studied and combined with each other in order to accomplish the predetermined goals. In the VLE users are free to navigate and interact with the objects it contains and with the multimedia cultural contents related to the elements in the environments. This navigation is not limited to a spatial navigation, but we can also explore the temporal dimension experiencing the changes that affected a location during its different epochs. In fact, one of the main features that divide VLE in two big sets is the focus of the environment: on a single historical time period or on an historical evolution in time. In the first case it has presented to users an instant of time, or an event of very short duration, generally also placed in a precise location. This choice aims to encourage people to focus more on what is a specific historical period, analyzing the social and cultural aspects, and inviting the viewer to pay more attention to crucial aspects of that time. E.g. faced with a historic building, user has thus able to analyze more closely the architectural details and the social uses of that past time. The second case, however, propose a timeline allowing users to take a virtual journey through time. Visitor is encouraged to pay attention more on the comparison of details, rather than on the particulars themselves. Freely moving among eras, the visitor has the opportunity to independently interpret the historical, artistic and social differences occurred in the same place through time. Although more complex than the first, this method is more effective because the self-comparison of details produces greater users' curiosity and involvement.

5.1 VLE ON A SINGLE HISTORICAL TIME PERIOD

In most cases, the historical and artistic events can be identified in a very small span of time and in well-defined places. The historical reconstructions can focus on a single historical period, allowing users to 'live' a day in the past. Most of the VH literature and researches have almost always focused on this goal. In these cases, the reconstruction of the environment should be carried out with particular attention to details because they represent the main characteristic, attracting the users' attention.

Through the development of 2 different projects we have analyzed the characteristic features of the recreation of a single context. In the first case, Villa della Regina is a very typical historical ambience and the recreation of context required the realization of the entire residence with gardens. In the second case, in *One Day at The Sands*, the entire complex of buildings of the resort and casino in Las Vegas was recreated.

Villa della Regina, better explained in section *4.1*, had a tormented history during its five centuries of life, and the building underwent several renewals, dramatically changing all the interiors. The goal of this project was to present to people the royal residence during the last period of its restoration. According to this objective we decided to identify a precise historical period in order to reconstruct the environment and recreate the context. We choose the nineteenth-century version of the villa, a variant very similar to the current state. Only some furniture and wallpapers were different, but we decided to implement the older version and not the current one because the restoration works had as objective the recreation of that particular version.

As the methodological approach (*Chapter 2*) said, an important step is the identification of the historical sources available. The photograph archive of the Superintendence for the Historical, Artistic and Anthropological Heritage of Piedmont (Archivio Fotografico della Soprintendenza per i Beni Storici, Artistici ed Etnoantropologici del Piemonte) has represented the main place where to find pictorial sources. It contains a photographic catalog of approximately 600 pictures taken during various photography campaigns conducted in the twentieth century. Moreover books and pictures were found in other historic archives of the city of Turin and over the Internet. Therefore excellent sources of intangible heritage were the oral interviews recorded with the people who lived in the residence, when the building was an orphanage.

After collecting sources, including the original blueprints of the villa, the modeling process led to the creation of buildings and all the gardens surrounding the villa. Although contrary to the rules of the methodological approach described above that suggests the use of open source programs, for some modeler's needs the modeling has taken place with the software 3Dstudio Max. This, however, was the only case. The modeling was carried out at high quality and with a high level of details. Particularly difficult was the modeling of the Palazzo Chiablese building: because it was finally demolished in 1962, the projects were not found. So, a careful process of comparison between the written and photographic sources had been followed. Some textures were created ad-hoc photographing the materials of the villa on-site, while others where properly designed according to pictorials and written sources. Finally, a careful process of lighting allowed rendering of photorealistic images (*Figure 49*).

Figure 49. A photo-realistic rendering of one room of Villa della Regina.

Once created the high quality version, it was also realized the lower resolution variant for the real-time VLE implementation. The reducing number of the total faces process needed a careful manual approach, in order to better preserve the aesthetic quality, decreasing the complexity of the geometry. Even the textures have been suitably scaled and lightened. The simpler version has been imported into the Unity3D Game Engine. The real-time version presents, indeed, a VLE where users can visit the indoor ambiences as well as the gardens of the Villa as it was during the 19th century. The interactions are limited and they are only focalized on the freedom of movement within the areas. Some environments of Villa della Regina have been used for another application with greater interactivity (section *4.3*).

Finally the real-time environment has been brought online. People from all over the world can take a personalized tour of the ancient residence of the House of Savoy.

A step forward from the basic condition of the VLE just presented above is to propose a virtual environment where users can not only observe buildings, objects and furniture, but first of all have a complete experience of a bygone era. In the *One Day at The Sands* project (section *4.2*) we wanted to communicate and make perceivable the atmosphere of one of the most famous casinos in Las Vegas through a virtual environment in which users could immerse themselves to relive the sights and sounds of the past, experiencing a part of the history of Las Vegas in an entertaining manner.

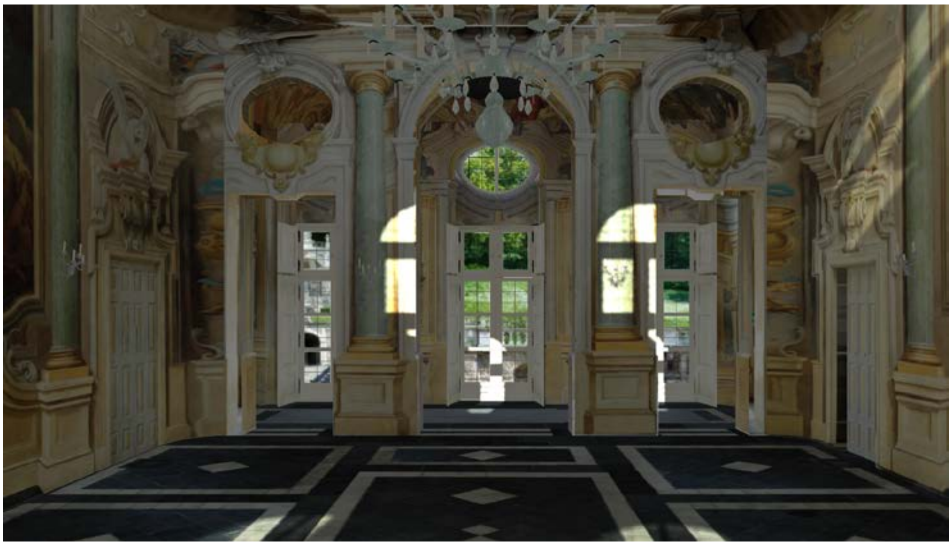

Figure 50. A view of the indoor environment of Villa della Regina in the real-time reconstruction.

In our work we integrated the visual exploration of the historical archives with a virtual reconstruction of the cultural sites and of their original atmosphere. Moreover we wanted to provide an effective learning environment. While the exploration of the virtual environment and of the related contents can be a learning activity in itself, since the user is exposed to a variety of information, other elements should be taken into account to achieve the planned pedagogical goals at their best. The effectiveness of a Virtual Heritage application is related to the concept of presence, and cultural presence. To this end, the environment and the context become tools capable of transferring the cultural significance of a historic place [Howell & Chilcott, 2013].

According to that, we entirely recreated the Sands Resort and Casino in Las Vegas. Firstly we needed to find historical sources. The primary fount of documentation was the Special Collections archive of the University of Nevada, Las Vegas (UNLV), which was established at the end of the 1960s with the purpose of documenting the history, culture and events that contributed to the development of the city of Las Vegas. It contains a variety of original documents, including newspapers, posters, manuscripts, maps, architectural drawings, photographs, and video and audio tapes. In particular, the section dedicated to the Sands is the richest of the archive and includes:

- images taken inside and outside the resort;

- photographs and documents related to leading figures in the Sands' history, including artists that performed in the casino, distinguished guests, resort workers and the famous Copa Girls, the Sands' showgirls;
- letters of thanks, appreciation and presentation and documents related to the organization of events;
- original menus, advertising and promotional brochures;
- backstage footage of television series and movies shot at the Sands;

These resources are enriched by two specific sub-collections:

- the 'Martin Stern Collection', dedicated to the projects of the architect who designed and defined a significant portion of the Las Vegas skyline, including more than 200 original drawings of the Sands;
- the Oral History Collection, containing audio or video interviews with people that worked or lived in Las Vegas during that period.

This significant amount of documents, accumulated over more than 40 years, was carefully selected and catalogued in order to establish accurate cross references between sources and to maintain their timeline coherence. Other valuable information was found in books [such as Ferrari & Ives, 2005; Burbank, 2007], newspapers and magazines of the period and on the Internet. The inclusion of the records of the Oral History Collections was deemed particularly important for the project: memories and life stories are now recognized as valuable historical resources that can add multiple perspectives to the narrative process [Solanilla, 2008], and they are useful both to create new insights into the past and to interrogate previous histories [Kean, 2008].

The research data were digitized and stored in a database, with accompanying metadata concerning their collection and management. The collected information was then used as a reference to create the 3D models of the original premises for the Sands' virtual reconstruction, as well as all the objects, furniture, and elements included therein. Since the Sands Hotel underwent several renewals and expansions during its life, we chose 1967 as the reference year since life at the Sands was particular vibrant at that time, and the documentary resources found for that specific year were particularly abundant.

Several authors, such as Debevec et al. [1998] and Furukawa et al. [2009], proposed photogrammetric approaches for the 3D reconstruction of architectural environments. However, due to the lack of a sufficient number of images depicting the elements to be reconstructed, or those with a suitable quality, these approaches could not be applied during this project. Therefore, the process of creating the 3D digital models was divided into the following steps.

First, the main volumes (walls, rooms, streets, gardens, pools, theaters) were defined on the basis of the available project documents, blueprints, plans and sections. Then, furnishing elements and objects included in the real environments were reconstructed using the available iconographic material as reference. A detailed work of virtual restoration, i.e. the reconstruction of the original appearance of the artifacts and the choice of the materials and textures to be applied to their 3D models, was carried out. As an example, *Figure 51* shows the mural behind the old Sands bar in the Gambling Room, whose digitally restored version was created by combining different chunks of information, obtained by partial views, often in black and white images, filling in the holes where necessary, and re-coloring the image according to the most convincing interpretation. As we will show in the following, the visitors are able to observe the restoration work in a critical way, since they can directly access in the virtual environment the documents used for these reconstructions.

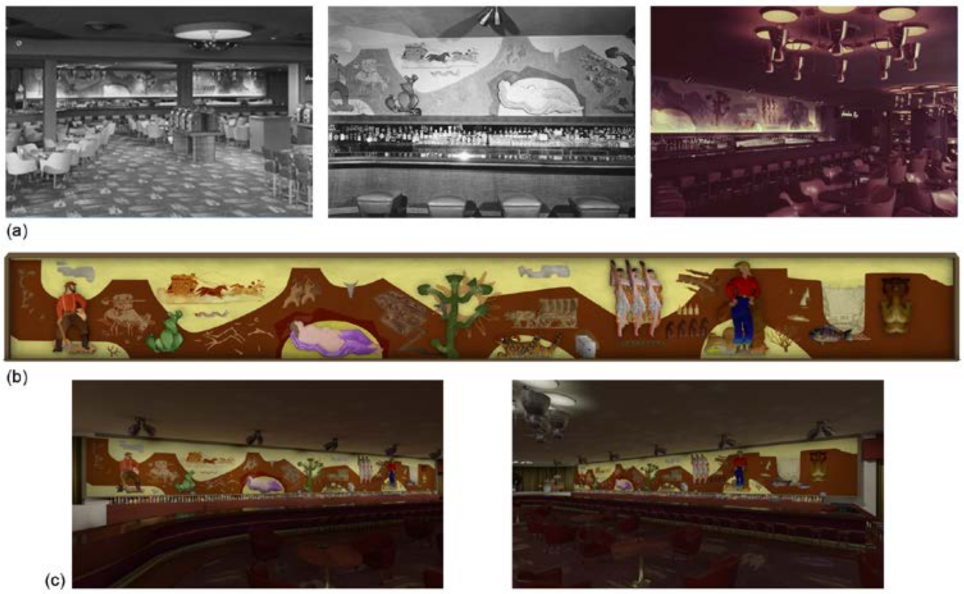

Figure 51. (a) Images depicting the Gambling Room bar mural, (b) the digitally restored version, and (c) two renderings of the bar.

The Sands main 'spaces', were entirely reconstructed in 3D. These include:

- the exterior, with the famous 36 ft tall Sands sign, the big arches and the pool area;
- the lobby-gambling room with original slot machines, the gambling tables and the bar lounge;

- the Copa Room with the stage where the Sands stars performed every night;
- the suites of the Aqueduct, a three-story building opened in 1963;
- the Emerald conference and ceremony room;
- the office of Jack Entratter, initially Entertainment Director and later President of the Sands, who made the hotel the most famous casino on the entire Strip.

Finally, the lighting design of each space was aimed at reproducing the original atmosphere depicted in the iconographic material through an accurate qualitative comparison between available images and photo-realistic renderings of the environments (*Figure 52*).

Figure 52. (a) A historical photo of one of the Aqueduct suites, which can be compared with its 3D reconstructed version (b). The accuracy thereof can be appreciated from the superimposition of its wireframe model on the original image (c). Finally, a daytime pho to-realistic rendering of the virtual suite is shown in (d).

5.2 VLE ON AN HISTORICAL EVOLUTION

Different approach is instead the study and representation of an entire historical evolution of a place or an item. Often historical buildings, characters and objects imperatively require an explication that cannot be reduced to a single moment in history, but that evolves over a period. This evolution represents the main element because emphasizes the comparison between objects and eras. And it is precisely the comparison that generates historical significance, and deeply helps users to simply and effectively understand features and details, acquiring new information. Through the comparison the constructivist learning process is accentuate. In the literature, this approach is less analized than the previous one, because more complicated and it requires more resources for the realization and especially for the search of historical sources.

In this case, we analyzed this approach through the implementation of three different projects, each with slightly different characteristics and objectives.

The *Interactive Virtual Past* project (section *4.3*) proposes a virtual interactive journey through the past of the *"Camera del letto del Re verso Ponente"* (The King's bedroom) in Villa Della Regina in Turin (Italy). Villa della Regina has a long history spanning five centuries and the building underwent several modifications over the time. From the Cardinal's home to the summer residence of the Queen, later an orphanage and finally restored as a museum. These changes have led to a strong evolution over time especially about the interior spaces of the building. In order to present the whole history to visitors we realized a VLE representing the residence in different eras.

The key moments are well represented by the five centuries:

- *Seventeenth century*, is the initial stage. This period virtually corresponds to the years after the enlargement of the villa, in the second half of the '600. Few details about the room’s initial state are available, we only know that the vault was built in the 18th century, so the room had a flat wooden ceiling. The walls were painted in a light colored “cocciopesto”, excluding the highest part where there was a fresco, now partly visible on the upper floor of the villa.

- *Eighteenth century*, near to 1755, this was the period when the room was transformed into a bedroom. The vault was made lowering the high of the room. Chinese textile was added to the walls totally changing the appearance of the whole bedroom, giving it a green look. The pavement was renovated with wooden tiles and curtains were added to each windows and doors. The big king's four-poster bed was in the center of the room.

- *Nineteenth century*, around the year 1845. At that time the room was resembled in a similar way at how looks today. The wallpapers are totally renewed and curtains removed from doors and windows. The furniture of the room has drastically decreased. We also chose to remove the bed for 2 reasons: there was no precise information about the bed's state in 1800, and often the governess' diary did not report it.
- *Twentieth century*, it resembles a date close to 1994 which is the state before restoration work began in the room. During the Second World War the room was damaged because of the bombarding. Moreover the state of abandonment of the second half of the century and numerously thefts ruined the room with cracks and corruptions.
- *Today*, this state shows the actual state after the restoration, and near the year 2010.

The modelling process started with the construction of the walls, pavement and ceiling, starting from plans and blueprints. Then the furniture was carefully modelled with all the details. For the four-poster bed we had no references, so historians help us suggesting some pictures of similar beds which we have used as references. For the texturing process most of the textures were created by photographing current objects or recoloring historical pictures. For the pavement textures, for example, a photo of the ground was taken from a normal point of view (*Figure 53*a). Thanks to editing software a single tile was individualized, and cut out from the image (*Figure 53*b). Then it was straightened into a square shape, and the color was corrected if needed (*Figure 53*c). The single tile was then repeated to fill the required dimensions, creating the required texture (*Figure 53*d).

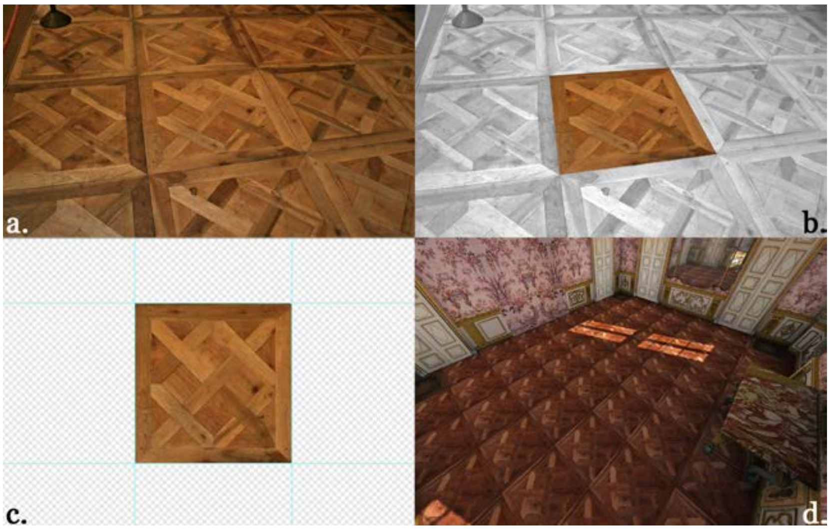

Figure 53. The process for the creation of the pavement texture.

Unlike the project just described, *The evolution of the Stardust* (section *4.4*) is based on the transformation in time of a compound of buildings. The difference lies not only on the complexity of the volume of buildings to manage, but also on the presentation of content and on the kind of information that we wanted to convey through the application. Also the interaction mode is different. The goal of this project was to present the complex evolution of the Stardust Casino primarily focusing on the architectural elements and also presenting a general history of the resort.

Most of the archival materials relating to the Stardust are stored within the UNLV (University of Nevada, Las Vegas) LIED Library, in the Special Collection archive. This library contains all the documents about the history, culture and events that contributed to the development of the city of Las Vegas. Digital collection project proposes to digitize all the historical material in the UNLV library and make it freely accessible[19]. Several documents were found, among which the original plans for construction and renovations of the resort, with many photographs inside and outside the buildings. Postcards, cards and letters of thanks completed the set of sources. In addition to the Special Collection, the search for materials was also performed at the Clark County Government, in which were deposited the official maps of the casino, and the Neon Museum, a non-profit organization dedicated to collecting, preserving, studying and exhibiting iconic Las Vegas signs. The found documents have been scanned and digitized.

From the sources were modelled 11 different historical versions of the resort relating to its expansions or changes. The modelling and texturing process was based on photographs and archival footages in order to recreate the exact places and atmosphere of the past. Textures were generally taken from photographs. In many cases we had to recolor the images taking as reference current materials. Once the modeling, texturing and lighting processes were finished, high resolution renderings have been created. For each period numerous images and video about architectural details and new construction have been realized.

With the *Virtual Tenochtitlán* project we reached a high complexity of VH presentation. This work presents an interactive application for educational and informative purposes concerning the city of Tenochtitlán. The heart of the application is the Recinto Sagrado (sacred ceremonial precinct) where all the political, religious and economic buildings were located. The aim of our application is to show the ancient city of Tenochtitlán exactly as it was during the Mexica era, presenting the history, society and mythology through games, activities and interactive multimedia contents.

[19] http://digital.library.unlv.edu/ - (Last Accessed, February 2014)

Due to the impossibility for visitors to walk through the real historical buildings, it is offered to them, the chance to move in the virtual space that reproduces the ancient Tenochtitlán. In order to recreate the context we firstly need to carefully identify documentation. The sources came from:

- Archaeological books and magazines with maps, photographs and reconstructive hypotheses made by archaeologists under the direction of Eduardo Matos Moctezuma, the archaeologist director of the studies of the Templo Mayor;
- Documents drafted by the Spanish invaders, including Hernán Cortés and Bernal Díaz del Castillo, and the friars, as Bernardino de Sahagún;
- Photographic material available on the archaeological remains of the Templo Mayor, useful both for documentation and for the realization of 3D models;
- Photographic material documenting objects, sacred offerings and other artifacts preserved in the Museum of the Templo Mayor and Museo Nacional de Antropología;
- Plastics in the Museum of the Templo Mayor and Museo Nacional de Antropología;
- DVD and informational documents provided by the museums.

From these sources we obtained useful information for 3D modeling process. But this reconstruction must be viewed as a hypothesis reconstructive of the city. In fact, all the data about Tenochtitlán are not unique, several researchers have formulated diverse conjectures. For our reconstruction we choose to follow the hypothesis of Eduardo Matos Moctezuma, director of the researches at the Templo Mayor, and therefore the most suitable person.

The subject of the reconstruction is the Recinto Sagrado for two reasons: (i) all the main buildings of the city were located inside it, (ii) the rest of the city was constituted by little houses, less interesting elements for a historical reconstruction.

The difficulty of representation is particularly focused on the Templo Mayor because each king rebuilt a new temple over the previous one. As the Russian doll, the last temple embraced all 6 previous.

The 3D modeling process was performed in two ways: for findings that still exist today it was possible to create reality-based models, while for all the others it was used the reconstructive mode. In the first case using two or more images of a subject the system automatically reconstruct the 3D model. The second case is the classical one, where modelers create volumes according to references images.

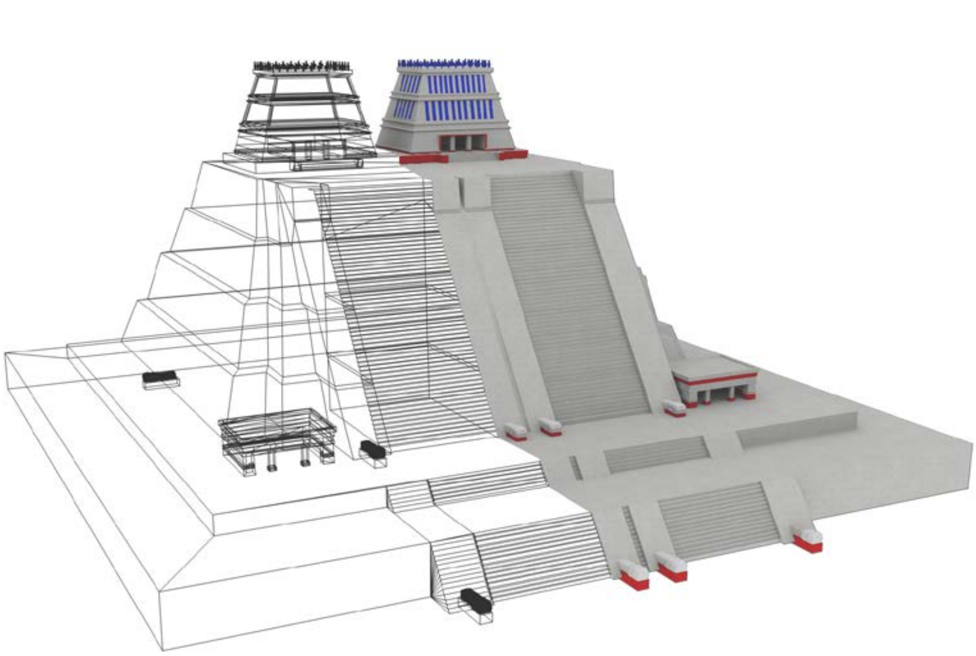

Figure 54. The modelling of the Templo Mayor.

CHAPTER 6 – ENHANCING PRESENCE

A VLE in order to provide an effective learning approach has to involve users under many different point of view. The general concept that encompasses these aspects is the presence, better explained in section *3.4*. To recall the concept we can say that it is the subjective belief of users that they are in a certain place, even if they know that the experience is mediated by the computer. The greater the sense of presence of the user, the greater the involvement, that result in a maximization of the experience. The explication of presence has been often related to the number of senses involved by the VE and to the quality of the sensorial stimuli. In fact, the characteristics that contribute to the completion of the concept of presence are many, some even almost absent in the literature, such as the involvement of the sense of taste. But the involvement must not only be based on sensorial stimuli, but other features of the context would help to complete it, and these must be specially designed according to the environment that has to be rebuilt.

Based on the objectives of the research and of individual projects, we focused on enhancing the sense of presence along three main lines:

1. maximizing the quality of the visual feedback;
2. introducing and maximizing the quality of the audio components of the simulation;
3. creating environments that are not empty and static, but populated by different types of characters.

6.1 MAXIMIZING THE QUALITY OF THE VISUAL FEEDBACK

In VH the goal of the VLE is to present a reconstruction of an environment with historical objects and characters to inform and educate people about cultures different from the current one in terms of time or space. The aim of the reconstruction is therefore to create environments that Roussou and Drettakis [2003] referred as '*believable environment*': historical reconstructions accurate under a historical and scientific profile regarded as truthful by the public. To achieve this feeling of truthfulness the high visual quality and photorealism are needed. Although photorealism is not a critical component for the truthfulness of the representation, it has become due to the characteristics of popular entertainment products now on all digital platforms. Darley [2000] and Gillings [2000] argued for an immersive visual representation photorealism is required.

The concept of photorealism and more generally of the high aesthetic quality of visualizations, are at the service of two other important concepts, *authenticity* and *accuracy*. The first identifies validity of information while the second the accuracy in the representation of this information. In a VH representation the importance is that it is both accurate and authentic. In other words we need to present users a high-quality simulation that is as close to the real-world context as possible. It is for this reason that in our projects we always aimed at maximize the aesthetic quality to demonstrate users the strong authenticity and accuracy of the reconstruction.

We should also point out that when we need to show visitors faithful reconstructions of the past photorealism is advisable, but instead when structural elements, construction methods and mechanic elements should be explained, photorealism does not help understanding, but rather complicates the explanation. Only in these respects, very rare in the VH but really common in other areas (as in the training industry) non-photorealistic visualizations are more explanatory.

In *One Day ate The Sands* project (section *4.2*) we aimed at maximizing the quality of the visualization to improve the sense of presence. Traditional techniques for real-time rendering of 3D models require to increase the complexity of model geometry and lighting to improve the photorealism of renderings. This has a dramatic effect on the computational resources required and developers must reach an acceptable compromise between the visual realism of the virtual environment and the complexity of its description.

We followed an alternative approach known as Image-Based Virtual Reality (IBVR) [Chen, 1995; Bourque & Dudek, 1997]. With this technique, the virtual world is represented as a set of initial images, which are used to synthesize the user's view at new and arbitrary viewpoints. In our work, reference images have been obtained from offline photorealistic renderings of the virtual environments, computed using high-resolution 3D models and textures, complex shaders, volumetric effects, and advanced rendering techniques. These images are then stitched together, using automatic mosaicing software, to create 360° panoramic images (*Figure 55*), which are finally displayed on an interactive viewer that allows rotation, tilt and zoom of the surrounding scene. The final high-resolution panoramas (8000 × 4000 pixels) allow to preserve the quality of the images during zoom operations.

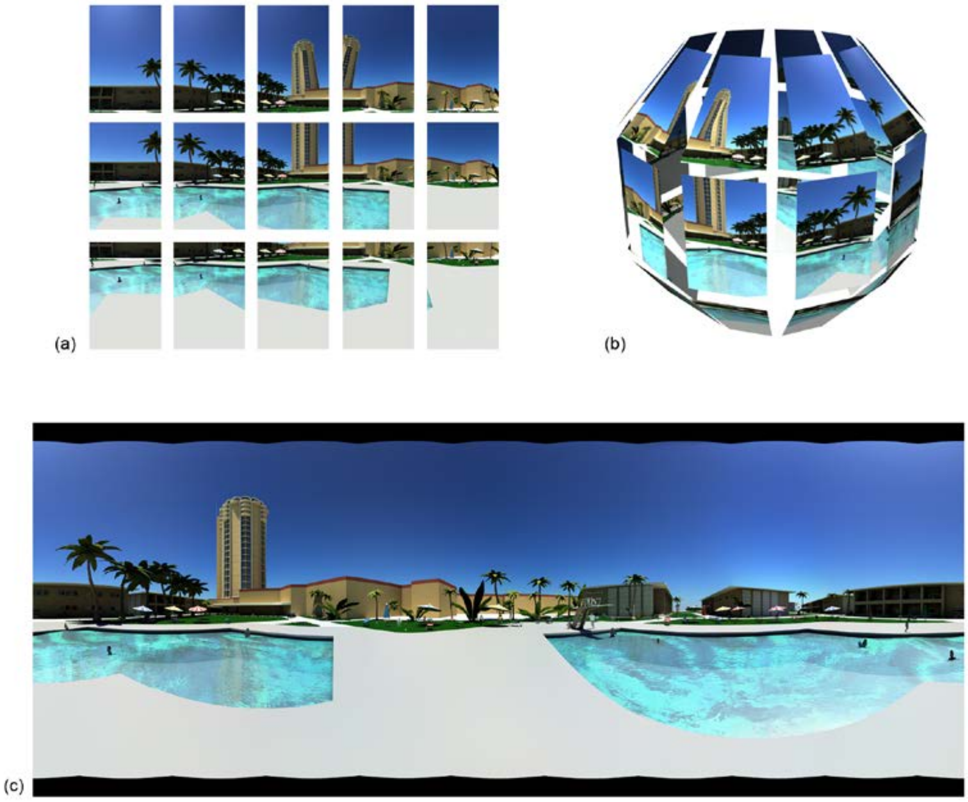

Figure 55. The panoramas are created by taking images with a virtual camera rotated by 360° in 10 steps to create three image strips taken at different elevations (a). The renderings are then projected from their viewpoints onto an imaginary sphere enclosing the viewer's position (b) and stitched together to obtain the final panorama (c).

To navigate the virtual environment, the user can move between predefined viewing locations, which are linked together to create various paths. In addition, panoramas are enhanced by embedded hotspots that, when selected, allow to access different types of digital media (e.g. commentary, textual documents, photos, audio and video), providing an integrated multimedia experience.

In spite of the limited freedom of movements within the environment, IBVR offers several advantages over the traditional 3D geometric approach:

- high-quality photorealistic views of the environment can be displayed in real-time and manipulated interactively with simple algorithms;
- the requested computational resources and rendering times are independent of the complexity of the virtual environment;
- even with the lack of geometric information, users are provided with a 3D illusion; therefore, the sense of presence in the virtual environment is preserved and even enhanced by a photo-quality realism that resembles that of the real world.

As a further advantage, the viewer for panoramic images is easily portable, being based on a technology (Flash) that is widely supported on different platforms, and it can be embedded into HTML pages, allowing the project to be disseminated through the Internet, thereby reaching a wider audience.

We also tested the application with a group of final users in order to identify the appreciation of the characteristics of the project. Each volunteer was asked to fill in a questionnaire, specifying his/her level of agreement with a set of statements, using a 5-point Likert scale, making choices between options and answering a short oral interview.

The results showed that the visual quality of the virtual environment was quite high (4.14), and also the sense of immersion into the reconstruction of the casino was positively rated (3.38). When we confronted the IBVR approach with a reproduction of the same context in a GE, the IBVR was strongly preferred for its visual quality (76.2%), while the GE version for its higher freedom of navigation (66.7%). So the high-quality representation of the IBVR approach proposes an experience more exciting and closer to the users' preferences that the GE one, in terms of aesthetic value. As we will see later the interaction component is fundamental and predominant on the aesthetic one. For this reason, subsequent projects have been developed with GE, sometimes with the supplement of IBVR views.

In the *Virtual Tenochtitlán* project (section *4.6*) we also used a non-photorealistic representation. Alongside the photorealistic visualization we associated the non-photorealistic one for a better explanation of the architecture of the Templo Mayor. This temple, insde the Recinto Sagrado, is the main building, 36m high with at its top two different shrines dedicated to two gods. During the two centuries of existence, the 12 Kings heavily modified the Recinto Sagrado and the temple itself. Each king rebuilt a new temple over the previous one. As the Russian doll, each version of the building contains within it the previous ones. This particularity is really important to explain to visitors but very hard to represent it. We decided to extrapolate the temple from the photorealistic reconstruction of the Recinto Sagrado, showing it isolated in a neutral environment. There users have all the tools to manipulate the building. They can rotate, zoom in on it, and also dissect it along the three axes X, Y and Z. This representation helps users to clearly understand the complex construction of the building. In this case we opted for a non-photorealistic visualization in order to focus the visitors' attention on the dynamics of building and not on the aesthetic end.

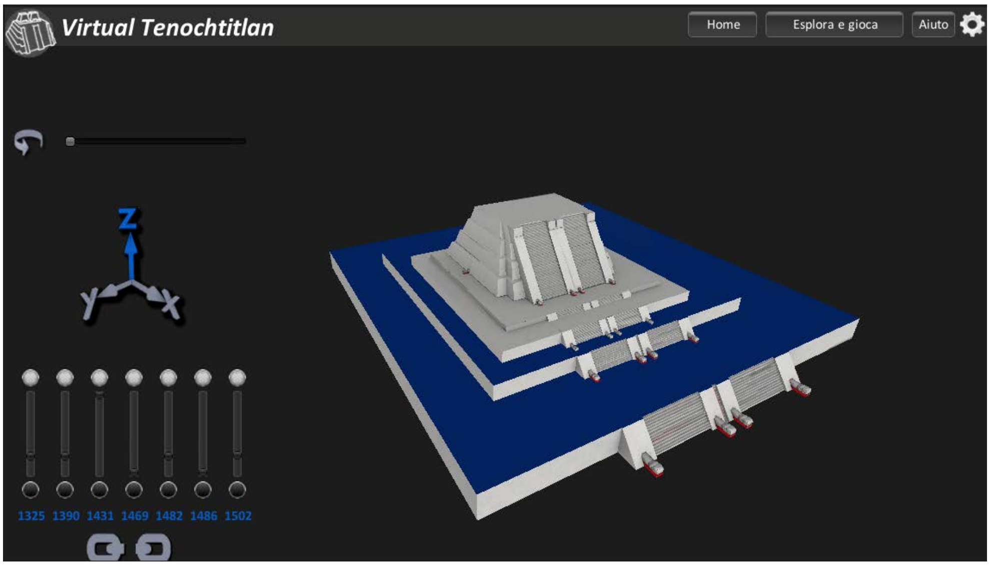

Figure 56. The “Dissect the Temple” part of the application.

6.2 MAXIMIZING THE QUALITY OF THE AUDIO COMPONENTS

User's sense of presence and immersion in a VLE is a fundamental element that must be properly managed in order to provide visitors a complete learning experience. As we saw in the previously sections, the visual component plays a key role in the users' involvement. High quality renderings, detailed 3D reconstructions, pictures and video presentations contribute to create a stimulating environment. But there is another aspect that evokes a greater level of presence: audio. Rheingold [1991] said: *‘there's nothing like the sound of footsteps behind* *you to help convince you that you are in a dark alley late at night in a bad part of town - sounds have the ability to raise the hairs on the back of our neck*'. He emphasized how audio transport information and, as reported by Laurel [1993], also evoke emotional responses. Many researchers stated that the auditory system represents a supplementary information channel that can enhance the user's experience. Visual and auditory together reinforce information content, providing a greater sense of presence [Hendrix & Barfield, 1996; Dinh et al., 1998]. Jelfs and Whitelock [2000] in their research found that audio feedback increased the students' sense of presence, contributing in a better task performance, besides providing a motivating learning experience. Similar Devis et al. [1999] found that users who experienced virtual environment with audio felt a greater sense of presence than who were in silent spaces. Moreover they also reported that the addition of audio enhance the subjective visual quality of the representation. Participants feel proportions and 3D perspective in VLE more correct, so as the realism of the ambience when they heard sounds rather than the silent. Indeed, audio component enhance the visual quality of the environment and helps to improve and complete the sense of presence in VLE.

The audio within a VLE can be present in many different ways. The feedback sound following an interaction is considered as an element of fundamental importance for a proper interaction with a digital system. But this audio interaction does not add any important information to the historical and artistic context represented. For a correct setting of historic features a sound that surrounds the user is necessary. Generally reconstructed environments offer a spatialized audio that recalls sounds and noises that were probably present in those environments in bygone era. In *One Day at The Sands*, for example, users can always hear typical environment sounds able to charaterize the place in which they are. In the gamble room sounds of people betting and slot machines jingles are present, while in the swimming pool children laughing and as background audio noise of dives. In this way, the audio is used to better contextualize the experience, adding details to the narrative.

Different method is if we want to follow a historically and scientifically rigorous approach not only for the visual reconstruction but also for the sound. In this case it is not possible, as in the previous case, to insert sounds in the environment that are likely to belong to that environment, but through scientific methods must be calculated the correct sound response of the environment.

In the *Experience the soundscape of San Salvario district* project (section *4.5*) we studied how the audio can help to recreate a past environment and, secondly, how a VLE can be used as a tool for sound urban planning. This project was in collaboration with the Department of Energy (DENERG) of the Polytechnic of Turin and it focused on the San Salvario district in Turin and precisely on one of the most characteristic streets of the district: Via Berthollet. During the day time this street has many commercial activities and the local market, while during the night many nightclubs and diners completely transform the area.

As we said in the VLE the audio must wrap users making them feeling as a part of the neighborhood, just as if they were actually walking along the streets. The market, commercial activities, passers, cars, all contribute to the creation of what is identified with the concept of *soundscape*. The idea of being able to "orchestrate" the ambient sounds has been proposed in 1970 by Murray R. Schafer, a Canadian composer who also coined the term. In his opinion the soundscape coincides with the acoustic environment in which we live and it is *"the set of sounds wherever we are"*. According to him, all the sounds of the world incessantly reproduce the largest symphony ever composed, and that will never end. *"We are at the same time the audience, the performers and authors of this composition"*. The places where we live are marked by their sound identity, linked to their morphology, configuration and culture.

To analyze a soundscape is firstly necessary to discover the significant features of all the present sounds, their quantity and their dominant presence. It was therefore necessary perform measurement campaigns to identify and locate sources fundamental for the audio reconstruction. The acoustic surveys were carried out through sound-walks during morning (10am-1pm) and afternoon hours (2pm-6pm), times in which the district is very crowded. To obtain the descriptors indices a sound level meter (SLM) has been used, that is an electronic instrument that reacts to sound in a way similar to that of the human ear. We adopted the impulse response method, using an adequate number of source (6) and receiver (14). For each source (we use the explosion of a balloon) the reverberation time was calculated in the laboratory. These values were then used to appropriately calibrate the further sound model, in order to obtain an average of the reverberation time simulated similar to those measured in the laboratory (with a margin of error of 10%).

Once obtained real reverberation times it was possible to use the software ODEON[20], properly developed for simulating the interior acoustics of buildings. Given the geometry and surface properties, the acoustics can be predicted, illustrated and listened to. The software uses the image-source method combined with ray tracing. Although it is only designed for indoors uses, for our project we tested on an external environment. We needed to incorporate the virtual 3D model of the street within a parallelepiped that represents the atmosphere - with a suitable absorption coefficient (in our case 90% absorbent) –in order to recreate a completely sealed space. With this trick we were able to use a close model, as the software needs, with results of an open space. Then ODEON calculates the sound data with a ray tracing process: omnidirectional sound sources generate rays that

[20] http://www.odeon.dk/ - (Last Accessed, February 2014)

travel in straight lines. Whenever they encounter a surface they change intensity and direction, based on the characteristics of the hit material. In this way it is possible to calculate the soundscape of the environment with a high accuracy. The results of the ray tracing process can be viewed as numerical data or listened to: the points on which the receivers are placed in fact represent the location where the software calculates the acoustic results. By listening to the receivers users can hear the exact sound that they would in real life at that particular place. The name of this kind of result is *auralization*.

It should be noted that these calculations require many hours of processing and cannot be done in real-time. For this reason for our project we identified the most characteristics locations of the street and we calculated the soundscape only in those points. The results have been exported as WAV files and imported into Unity3D. The GE allows to insert in the VLE sound sources (*Audio Source*) and to manage the propagation of sound based on the distance from the listener (*Audio Listener*), following three kind of sound decay:

- *Logarithmic Rolloff*, it is the mode more closer to reality and it follows a logarithmic curve;
- *Linear Rolloff*, the decay is proportional to the distance from the source;
- *Custom Rolloff*, it allows to customize the decay curve.

For our project we choose a Logarithmic rolloff, because more faithful to reality.

Within the application, the user can walk through the streets of the district, look at the buildings and parked cars. Along the street there are 14 points, spaced every 30 meters and identified by an icon. Each of them represents a listening area where users can listen the auralization processed by ODEON. When the user enters within these areas, the interface shows 3 different listening options:

- WEST, the user listens to the soundscape of the street at that point oriented in a westerly direction (facing Via Nizza);
- EAST, the user listens to the soundscape of the street at that point oriented in a easterly direction (facing Via Madama Cristina);
- NORTH, the user listens to the soundscape of the street at that point oriented perpendicular to the street.

Figure 57. The interface of the application.

Because of the impossibility of a precise calculation of the soundscape in real-time and due to long processing times of the software ODEON, we could only offer users 42 different calculated soundscapes on the street. Hopefully in the future, with increasing computational power of computers and the implementation of faster ray tracing algorithms, we will able to generate a real-time audio stream. In any case, while navigating the environment from a point of auralization and the next, the user is not in a silent environment, we decided to let him hear the sounds actually recorded during the data acquisition sound-walks.

Through this process we are then able to enhance the presence in the VLE adding a correct sound response. Not only using ambient sounds able to contextualize the environment in which users are located (as in the case of *One Day at The Sands*), but also by calculating the exact sound in the individual points of the virtual environment. In this second way, having an accurate result scientifically calculated, the VLE can also be used as a technical tool to study and design the urban and environmental planning.

6.3 POPULATING THE ENVIRONMENT

The user's sense of presence, as early explained, represents one of the most important characteristics of an effective VLE. In order to make users feel to being a part of an environment and "really" live in a certain place and time the feeling of immersion has to be emphasized. The visual and interactive parts surely play a fundamental role, as well as the users' freedom of movement. But there is also another characteristic that strongly helps the user in a more accurate contextualization: *social presence* (SP). Any environment that we visit in real life is hardly an empty space. Generally each ambience has people who carry information on the site itself. How people act, dress, move are social and cultural elements that allow humans to immediately identify key characteristics of places. Comparisons between people who we normally meet and know in our provenance with those encountered in the visited place represent a huge source of knowledge. SP can be defined as a sense of feeling togetherness with others [Thie & Wijk, 1998]. A necessary condition is the presence - physical or remote - of other people in the virtual environment. Biocca, Harms and Burgoon, [2003] identify SP as the factor that contributes to the effectiveness of new technologies. Social networks, indeed, have a huge success thanks to the interaction among people. In VLE social presence has been studied because researchers found that it encourages qualitative interactions and user questioning, enhancing the educational process [Garrison, 2007]. Tu and McIssac [2002] reported that SP highly contributes to a positive influence on learning. Leh [2001] demonstrated that students did not feel confident in environments without a sense of SP, and Whiteman [2002] that SP enhances users' skills while they interact with others in VLE.

The highest level of SP is reached with an interaction among people that involves the largest number of human senses. One of the most famous virtual environment that used that kind of SP is Second Life[21], where avatars of people remotely connected could interact and collaborate with each other in various activities. This kind of interaction requires an online multi-user system, a type of structure which in my case would go out from the terms of my research. So we decided to implement SP elements with a different approach: representing the characters of the period with computer-based modes. This is also because in the case of VLE for museums the availability of remote people interactions is almost impossible. For these reasons we thought some ways to create a sense of SP capable of contribute to the creation of warm learning ambience [Rourke et al., 1999] and at the same time to better contextualize the historic environment. From the most basic level to a more complicated, different approaches are here presented.

6.3.1 Historical pictures as characters

In the *One Day at The Sands* project (section *4.2)* we have chosen an IBVR approach where users move in the environment among predefined viewpoints, watching a still panoramic visualization. With that technique the only possible way to populate the environment was to place static figures within the environment. In

[21] http://secondlife.com/ - (Last Accessed February 2014)

the archival material several historical photographs representing persons inside the casino were identified. With a careful cropping work some of the figures were extrapolated and inserted in the corresponding environments. For example, in the swimming pool we can find many people who are diving, in the gamble room croupiers and bartenders are working as well as people play slot machines. All those characters came from historical photographs of the Sands.

Although the introduction of static figures in virtual environments represents the simplest level of SP, we can however observe that these figures help users to better contextualize the environment. People's clothes, their behaviours and activities say a lot about the represented environment and time. Moreover we choose to use only black and white images in order to clearly show users that those characters, although taken from real photographs, represent an addition to the reconstructed environments.

Figure 58. Characters in the *One Day at The Sands* project.

6.3.2 Animated virtual humans

A step forward in SP can be represented by animated characters. In three-dimensional VLE where user can freely move and interact with objects in the environment, photographs of people as in the previous case cannot be used. It must therefore use three-dimensional characters.

First, it is necessary to find sources about the people at the desired time and place that we are representing. The characters must in fact be appropriately dressed and sized to the locals. Photographs, paintings, stories are all sources useful for the realization of three-dimensional models of humans, clothes and textures. In our case virtual humans have been created using Blender[22], the open source 3D modeling software. Starting from images representing humans in T-pose (legs slightly apart and arms outstretched) an accurate modeling process creates human bodies. Obviously in order to realize different kind of people, once modeled the first character, some little changes can generate diverse bodies. A really important aspect in the creation of a crowd of people is the complexity of the geometry: too many polygons can cause delay and malfunctioning in the VLE experience. The final number of 3D faces has to be divided between the geometry of the environment and all the human models. So the complexity of each body strongly depends on the total amount of polygons of which is composed the environment and the number of humans we want in the VLE.

To better contextualize the environment it is advisable to animate the virtual humans. Animations can be simple or complex, but short animations in loop proved to be an effective method. In case of a VLE that represents a market, for example, we can have the greengrocer that arranges the fruits, the butcher that moves the meat and the florist creating a bouquet of flowers. Through these simple animations users who are experiencing the VLE, although they recognize the artificiality of those repeated movements, can feel a better contextualization thanks to the harmony of all of the animations in the scene. It is obvious that greater the complexity of the animation is and greater the sense of user involvement will be. But it is also to consider that an animation of a human is a complex process, which requires much time apart from being very expensive. For this reason short and simple animation loops allow to get an excellent result with an efficient process.

Figure 59. Simple animated characters.

[22] http://www.blender.org/ - (Last Accessed February 2014)

6.3.3 Basic AI system

A greater evolution of the concept of population of the environment is the introduction of autonomy in virtual avatars. A basic level is what we implemented for the project *Experience the soundscape of San Salvario district*. As we have already said, the project represents a system developed in Unity3D that allow users to walk in the San Salvario district in Turin, see the historical restoration of the nineteenth century and listen to the sound reconstruction of the environment. In the reality the district has lot of traffic and in order to recreate a similar situation an asset that automatically and intelligently manage the road system was created. Through a simple system of Artificial Intelligence (AI), cars circulate through the streets of the district, without clashing. The car (agent) travels in straight lines with a constant velocity. When it enters an intersection the system communicate at the agent that it has different available actions. According to the crossing rules, the agent decides whether to go straight or turn in another way. So, we have a number of autonomous cars traveling along the streets, populating the neighborhood and recreating a more real situation.

Since the project *Experience the soundscape of San Salvario district* was limited to a single one-way street, the artificial intelligence system developed did not take into account the possibility of meeting other cars at intersections. In addition, since there are no people that walk in the streets, it has not even been implemented to stop the car when a pedestrian decided to cross the road. These situations are not present in this project, but they are in the next one.

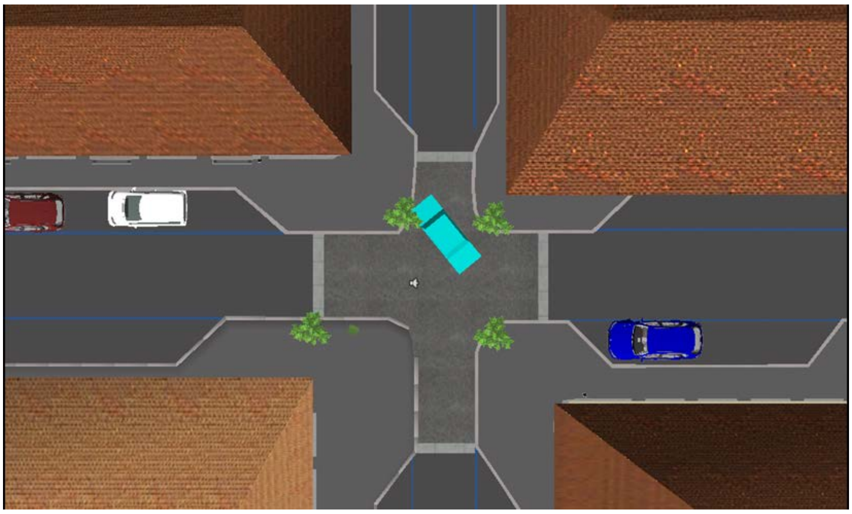

Figure 60. The AI system in the *Experience the soundscape of San Salvario district* project.

6.3.4 Smart Autonomous Agents

The most complex level of environment population that we reached is the one of the autonomous character behaviour simulation. Over the last three decades, scientists have attempted to model all kinds of human behaviour, using simulation and visualization, primarily aimed at creating educational and training systems. The general problem of simulating (or creating) intelligence can be broken down into a number of specific sub-problems [Russell, 1980]. Investigations in the following fields appear to be the most popular: affective computing, the emulation of human needs mechanism, the environment perception, the autonomous navigation of a virtual environment, memory models, event management and the overall agent behaviour mechanisms.

Emotions are a fundamental trait of human personality. How we distinguish one emotion from another is a much debated issue among researchers in human science. The classification of emotions has mainly been considered from two fundamental viewpoints. The first treats emotions as discrete and substantially different constructs (an emotion is completely individual), while the second asserts that emotions can be characterized on a dimensional basis (an emotion is composed of interacting elementary components, [Rumbell et al., 2012]). Emotions can have different roles in driving agent behaviour, for example they can be used to select the next action or to control memory [Sceutz , 2004]. There is plenty of literature about these different roles of emotions in agent behaviour (partly surveyed in Rumbell et al. [2012]). Researchers agree that the choice between basic or dimensional emotions - and which specific emotion within this category - should be based on the primary function of the agent and on the specific purposes of the application. For example social regulation requires a complex emotion mechanism, which can allow social interactions to be fully represented. On the other hand, alarm mechanisms require a basic emotional model, due to the necessity of an instantaneous and drastic effect. In other words, it is not possible to elaborate a model capable of approaching every situation and environment, but it is reasonable to develop a model that can cover as many roles as possible.

Needs-based AI is an alternative way to drive an artificial agent which is simple to understand and implement. The next action picked is based on the agent's internal state and on the environmental inputs. Need fulfilment have been used, for instance, by Terzopoulos to drive virtual pedestrians' behaviour [Terzopoulos, 2008] and one of the most famous implementations of this mechanism is represented by the game The Sims [Wright, 1997]. Another possible mechanism is to define the agent behaviours in terms of responses to events, as discussed in [Stocker et al., 2010].

Other researchers have been focusing on the problem of enabling the AI component to perceive and explore its environment. For example, Tu presented in his work [Tu & Terzopoulos, 1994] a framework to simulate artificial fishes in which the perception relied on a visual sensor spanning a 300-degree angle around the fish head.

In addition to a vision system, a smart agent should be equipped with a navigation system, whose purpose is to provide a path without obstacles from one point to another in the environment. This task is usually broken in two subtasks: *global navigation*, which uses a pre-learned map of the space, and a *local navigation* which, on the other hand, provides the ability to avoid unexpected obstacles along the path and mainly relies on the vision system. The majority of researchers, faced the problem of navigation adopting a central collision avoidance system that controls the agents' movements and positions.

The agent's capability to influence the environment is defined by a set of possible actions that reflects on changes to the state of the environment itself. All actions that humans undertake in an environment are influenced by their emotional and physical state and by their personality. To create believable virtual characters, these factors must be taken into account. This makes the creation of agents emulating the rich complexity of humans a real challenge.

Among the possible behaviour management models, several researchers recommend the use of the Behaviour Trees (BTs). The Behaviour Tree is a "*simple data structure that provides graphical representation and formalisation for complex actions*" [Markowitz et al., 2011]. The first implementation of BTs appeared in 2004 in a one-act interactive drama called *Façade*, and since then, they have been increasingly used by game AI programmers to create more exciting and complex characters. Their effectiveness is witnessed by the fact that important games, like Spore (in 2007), Halo3 (in 2008), and NBA '09, adopted this approach.

The software library VIRTUAL-ME has the capability to deal with different aspects related to the management of autonomous characters behaving like humans. Based on the analysis of the peculiarity of these aspects, this work proposes an organic, all-encompassing and real-time solution that can facilitate programmers and scientists in populating a virtual environment with a crowd of smart agents. This library enables the creation of different worlds populated with several independent agents, incorporating general cases that bring together most human behaviours and that can be easily extended to deal with other peculiar cases. The library deals with some specific problems - agent behaviour mechanisms, affective computing, the emulation of human needs mechanism, the environment perception problem, especially the vision, the problem of navigating a virtual environment, memory models, event management – deeply analyzed in section *4.7*.

VIRTUAL-ME Library has been implemented in C# and integrated into the Unity3D GE. Simulations were carried out to test and explore the potentiality and effectiveness of the library. Two environments have been used.

The first world is a virtual reconstruction of The Sands Hotel in the 60's, one of the most prestigious and oldest resort casinos in Las Vegas, which was entirely reconstructed in 3D for a previous Virtual Heritage project (section *4.2*). Two of its main spaces were used for the simulations: the Gamble room with the gambling tables and the bar lounge, and the Copa Room where shows were performed every night. The Casino is a complex scenario consisting of more than 3.7M vertices.

Different types of agents were populating the environment: customers, barmen, waiters, croupiers and artists. Customers have by far the most complex behaviour. Besides managing events and satisfying basic internal needs (eating, drinking, resting or going to the toilet) they can also enjoy their time at the casino by playing and gambling, attending shows and interacting and speaking with other customers or casino personnel. Barmen and croupiers join their working place when there are customers to be served and interact with them according to customers' requests. Waiters have a slightly more complex behaviour, since they have to manage table occupancies, customers' orders and item delivery.

Two main events were scheduled in the simulation: a show in the Copa Room that agents can freely choose to attend, and an emergency situation, where all the agents have to reach their closer emergency exit from the casino.

Figure 61. An image of the casino simulation.

The second environment depicts a park with a lake and other facilities, such as benches to rest, news-stands, a running path and some street food shops. A one way road and two pedestrian crossings were inserted, enabling agents to cross the road forcing the cars to stop. The agent types in this simulation are only two: drivers and pedestrians. The drivers have only a default task, which is driving across the park and stopping if any pedestrian crosses the road. Pedestrians behaviour include different tasks, such as eating, drinking, resting, running, watching the lake or buy a newspaper and read it. No events were registered for this environment. The number of vertices is 0.24M, far below those of the Casino.

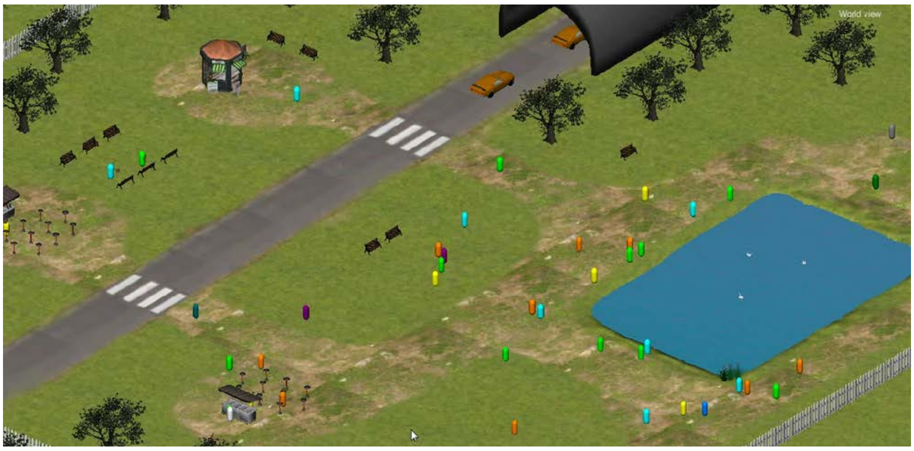

Figure 62. An image of the park simulation.

Although it is difficult to analyze all the details of the simulations, especially when the number of agents populating becomes very large, our observations allow us to state that in all the simulations the agents behaved as expected, acting according to their internal state and reacting properly to events.

Some examples observed in the Casino environment are the followings. When the thirst level is high, agents reach the bar, or call a waiter if seated at a table, to place an order. When an agent is in a good mood, he has money to buy fiches and he is willing to play, he reaches a gambling table. The amount of time he spend playing depends on the game evolution. Wins and losses can change the agent emotional state, affecting his will to stay longer. Effective interactions between agents have been also observed when an agent wants to start a conversation. First, he looks for a potential partner, and if the counterpart agrees to have a chat, the conversation begins. According to the dialogue evolution, which was randomly selected among a set of possible options, the current emotions of the two agents can change.

Agents' response to events was also working as expected. Attending the show was a medium priority task. Thus, agents executing tasks at higher priority (such as having dinner at the tables) did not respond to the event until they completed their actual tasks, while agents involved in tasks with the same priority of the show (e.g. gambling) were equally deciding to attend the show or continuing their activities. When the emergency event was triggered, given that this event has the highest priority among all tasks, all the agents rapidly left the casino through the nearest exit door.

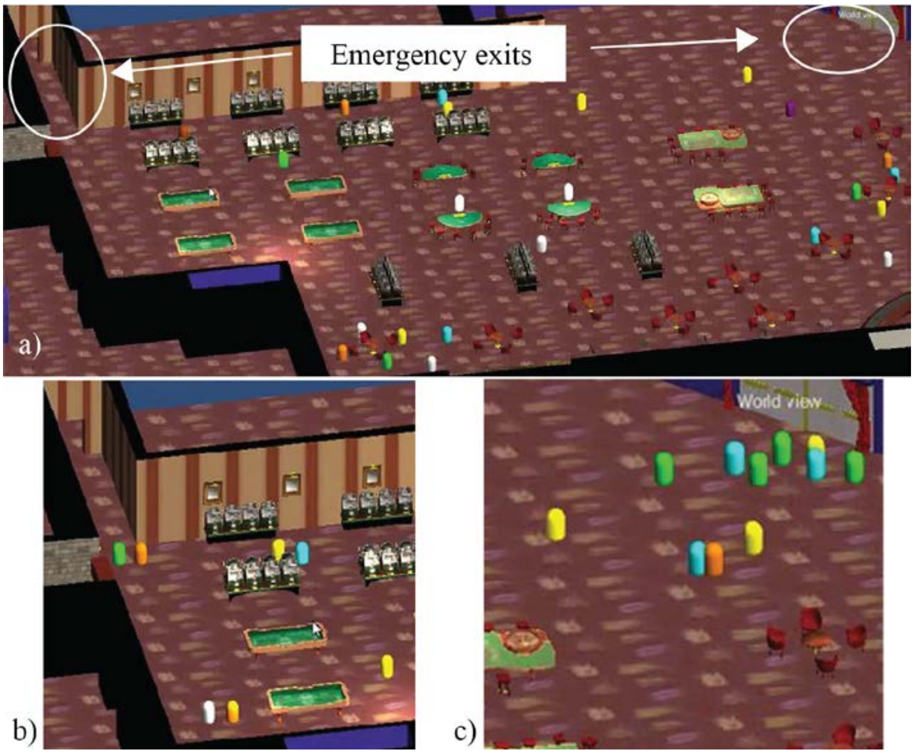

Figure 63. (a) the agents in the casino before the emergency alert, (b-c) the agents evacuating the building through their closest emergency exit.

Two simulations were run in each environment using different representations of the virtual humans. In the first case, referred to as *Humans*, the avatars were represented with a complete mesh, having an average resolution of 3.000 vertices, and avatars were animated with Motion Capture data. In the second case, referred to as *Capsules*, avatars were represented with an inanimate capsule (400 vertices). This choice aimed at separating the complexity of AI management from that of the agent graphical representation.

All simulations were run on a 64-bit intel core i5-2410M 2.3 GHz architecture with 6 GB of RAM and an NVIDIA Ge-Force GT 540M graphics card. The simulation results are summarized in *Table 6*.

The first tests were aimed at understanding how many agents could be managed in different simulation scenarios. To this end, we run the simulation keeping on adding agents, until the frame rate dropped below 10 FPS. The Humans simulations could handle up to 130 agents for the park environment and 70 for the

Casino, which, given the complexity of the environment and of the behaviour of its agents, can be considered as a reasonable result. The Capsules simulations reached up to 95 and 250 avatars for, respectively, the Casino and the park, showing that reducing the level of details of the avatar models results in a major increase of the library performances, especially in the park, where the agents have a less complex behaviour.

Further tests were aimed at collecting values of the resources used by the library. To this end, we run each simulation with 50 agents profiling the application. As it can be seen from the results, both Humans and Capsules simulations run at real-time, with a worst case of 14.86 ms (67.3 FPS) for the Humans Casino. The library functions use a percentage of the CPU time that spans a range between 36% and 48% in different cases. The estimated costs per agent shown in *Table 6*, obtained as the average CPU and library times per agent, provide an indication of the increase of the computational burden related to the population growth. The average memory allocated per agent is 1.38 MB and 0.94 MB in the Humans simulations, and 0.58 MB and 0.43 MB in the Capsules simulations, for, respectively, the Casino and the Park.

		Casino		**Park**	
		Humans	Capsules	Humans	Capsules
Max N. of Agents		70	95	130	250
CPU	[ms]	14.86	11.20	11.26	11.17
	[fps]	67.3	89.3	88.8	89.5
Virtual Me	[ms]	6.19	5.40	4.20	4.00
	[%]	41.7	48.2	37.3	35.8
Time for Agent (ms)	CPU	0.29	0.21	0.18	0.17
	VMe	0.122	0.106	0.071	0.067
Memory/agent	[MB]	1.38	0.58	0.94	0.42

Table 6. Overview of the performance results: maximal agent number (first row); computational resources for 50 agents (second row); computational resources per agent (third row). CPU is the total execution time, while VMe is the amount of time allocated to the VMe functions. The last row shows the average amount of memory allocated per agent.

A thorough comparison with the many approaches to agent's behaviour management is virtually impossible. First, standardized reference benchmarks in this area are still missing or have not been widely acknowledged [Kleiner et al., 2013]. Second, while VIRTUAL-ME provide a compromise between believability, autonomy and performances to manage real-time simulations, several approaches pursue different objectives, such as managing large crowds, usually simplifying the

AI and adopting centralized solutions, or providing more complex behaviour mechanisms, which however often hamper the management of large number of agents.

The two approaches most similar to our research, in terms of agent complexity and number, were the work of Terzopoulos [2008] and the RAIN library[23]. As for the first work, the maximal number of autonomous agents that can be handled in real time is approximately 100. To obtain a measure of merit on the RAIN library, we modeled agents with a simple behaviour (similar to the one implemented for the Park) and kept on adding them to the simulation, founding as 120 their limit number to maintain an interactive frame rate.

Concluding, though more complex tests in more challenging environments are required, our results suggests that VIRTUAL-ME is a valuable solution for the implementation and management of a quite large population of different types of smart agents, each with its own peculiar behaviour.

[23] Rivel Theory. Rain

CHAPTER 7 – FRUITION OF CONTENTS

Cultural collections, managed and maintained by archival institutions, galleries and museums, typically contain a huge amount of up-to-date information related to historic sites, buildings, documents, artistic elements, objects and art works. Such collections are usually composed by a combination of structured data, text, photographs, maps, plans and other similar things. Nowadays, most of their contents have been digitized, and stored with their associated metadata into multimedia databases. These *cultural archives* have been often designed for a professional or specialized target. However, cultural institutions are more and more faced with the problem of providing access to contents to a wide and assorted audience. This is also due to requests from governments or other funding entities, which are often supporting cultural archives having among their goals the development of a shared cultural experience for their citizens, and from specialized agencies like the UNESCO. As written in the Charter on the Preservation of Digital Heritage [UNESCO, 2003], "*The purpose of preserving the digital heritage is to ensure that it remains accessible to the public. Accordingly, access to digital heritage materials [...] should be free of unreasonable restrictions*" and "*Member States may wish to cooperate with relevant organizations and institutions in encouraging a legal and practical environment which will maximize accessibility of the digital heritage*".

Therefore, the immediate goal of finding better access to the knowledge maintained in cultural archives is to provide an appropriate fruition of their contents to the general, non-expert users. On the contrary, as already stated, database structures have been designed with specialists in mind and it often needs an expert to extract and interpret the data. The access methods provided are usually difficult to use by the non-professional users, who often look for information according to their personal curiosity and interest, with poor specific knowledge of the subject. Furthermore, traditional interfaces, mostly relying on text-based forms, are not well suited for searching data whose characteristics are difficult to express through few keywords, as those concerning historical representations, traditions and non-verbal sources. Hence, one step towards opening up access to cultural databases is to find better ways to search contents, using easier interfaces and finding more compelling and exciting ways to present the results. Furthermore, the presentation layer should be effective and, preferably, specifically designed to reach different audiences.

Current database systems provides different ways of accessing contents, either through the direct use of query languages or by means of different kind of form-based interfaces. These methods, however, often require some computer skills and still do not provide users with easy and natural tools for exploring database contents. Many systems, like ubiquitous and recommenders systems [Adomavicius et al., 2005; Wang et al., 2008], have been designed to improve access and navigation through data. These systems suggest, based on previous choices and preferences expressed by users, the navigation between elements. The development of interactive curatorial narratives [Mulholland, 2012], based on user choices and ontologies, allows to create unique narrative paths and to generate meaning and understanding from the relationships between objects. Ontologies are based on the creation of an information flow, related to user preferences, through a process of discovery of logical knowledge, based on closeness of meaning or cause/effect. But this kind of process is not natural for human beings, which generally discover and learn about things coming into direct contact with objects and relating them to the surrounding world. Meanings and knowledge usually come from a comparison of items, from previous knowledge of the person and, especially in the cultural/artistic/historical field, from an analysis of the contextual environment surrounding those items. However, while professionals and specialists are aware of such context information, this is not disclosed to, or is difficult to explain to, the general public. For this reason, it is important to try to recreate, where possible, a condition of "discovery and knowledge", recontextualizing the elements of cultural collections in the places where these objects were in the past or, where this is not possible, in an environment that helps users to better identify the historical period and location.

Especially in the last years, experiments have been done to investigate the integration of VR and 3D environments with databases. The main field of application of the 3D interfaces is undoubtedly that of GIS (Geographic Information System), where data are geolocated and their integration into navigable 3D maps (or VEs) right in the location where they refer to, allows to significantly improve the data representation. A review of the literature on VR and GIS can be found in [Coltekin, 2003].

Concerning the specific field of Virtual Heritage, the reconstruction of 3D environments has been used in several researches to present historical and artistic data included in a database. In [Hynst et al., 2001], the authors present a framework for archeological applications, which allows describing the excavation phases and all the artifacts found. Objects, reconstructed in 3D with laser scanning techniques, are integrated into Digital Terrain Models of the excavation area in different epochs, which can be freely navigated into a VE. However, no interfaces to query the content database are provided, nor it is possible for users to access detail information related to the displayed artifacts. The main goal of the *"Memory and Reality: Monument to the dead soldiers of the Great War"* project [Borgatti et al., 2005] was to simplify the access for the general users to the large amounts of documents available in the *"Archive of the Fallen"* of the Certosa di Bologna, in Italy, since the version of the database for specialists was far too complex. Therefore, a simpler interface for the non-skilled users was created, showing a VR reconstruction of the Certosa where tombs outside and inside the monument are linked to a biography. An interactive digital narrative and real-time visualization of an Italian theatre during the 19th century is presented in [Bertino et al., 2005]. Users are guided in their tour by a virtual avatar, telling them the history of the theater, and can query, through a text-based form, a multimedia database to browse the available documents, which, however, are not integrated into the VE. Another framework combining VR and database technologies has been presented in [Pecchioli et al., 2011]. The main idea was to embed information into a 3D spatial context, and to exploit sight, naturally used by humans to focus on something, to retrieve this information. An innovative aspect of this approach is the definition of *relevance of information*, defined as the percentage of overlap between the view area of the user and the *information zone*, a region around each data, to sort the contents available in the user surroundings in order of importance. However, this system does not provide any tools to directly browse the database and, therefore, it is not possible to follow the backward path from each cultural object to its spatial/historical context.

In order to deeply analyze what techniques can better allow a complete fruition of contents, helping users creating meaningful connections with digital material, we studied and developed different approaches. The first one simply inserts hotspots within the navigable environment through which the user can access multimedia content. Icons are placed next to the object, character or area related to the contents. In this way visitors can get more information about the element of interest simply by clicking on the associated hotspot. This ease of interaction allows both easily managing the user's curiosity, and showing which elements are associated with additional content. In *One Day at The Sands, Interactive Virtual Past* and the *Visual interfaces for DBs of cultural contents: the Riviera casino* projects embedded hotspots enable, when selected, to access different types of digital media (e.g. commentary, textual documents, photos, audio and video), providing an integrated multimedia experience.

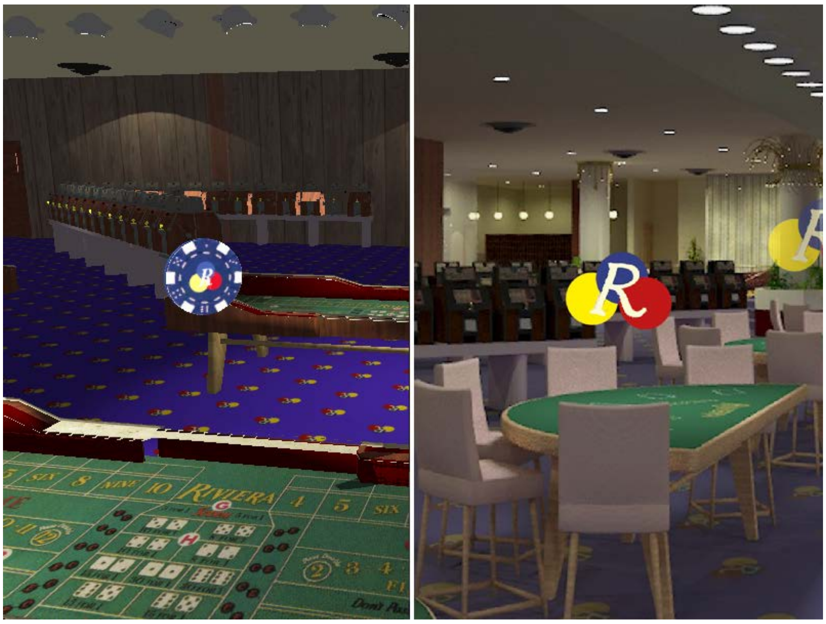

Figure 64. Hotspots in the *Visual interfaces for DBs of cultural contents: the Riviera casino* project.

In *Virtual Tenochtitlán* the access to contents is mediated by interactive binoculars. When the user selects one of them, the binocular queries the database, presenting multimedia materials. If an image is shown, it can represent a snapshot of the current state of the ruins or a representation of past times. To enable a better understanding of the archival material, the user's point of view moved to coincide with the proposed prospective of the image, so that the comparison can be more effective. Each image is accompanied by a short explanatory text.

After experiencing the integration of the cultural contents into virtual environments, we further explored the problem exploiting the VLE as a visual interface to DB contents. Objects in the DB can be queried not only by keywords or metadata, but also by navigating the virtual environment and interacting with objects.

Figure 65. The interactive binoculars in the *Virtual Tenochtitlán* project.

In the the *Visual interfaces for DBs of cultural contents: the Riviera Casino* project we developed novel interfaces for accessing and managing a cultural database. The VLE is used to recreate the original context of the DB contents and it can be virtually explored to gain new insights on specific elements, and to improve the awareness of relationships between objects in the database.

The general organization of the proposed interface, sketched in *Figure 66*, is the following:

(i) A *graphic panel*, laid out on the left of the main application window, showing a virtual representation of the reconstructed environments. Users are free to navigate into the VE to discover the context related to the cultural objects stored into the database. The database items are inserted into the displayed environments as *sensible* objects (hotspots) that, when clicked, send a query to the database to access the information related to that specific object, information that are accessible through the right panel, described in the following item. Hotspots are highlighted into the environment by means of specific graphic elements, which makes them immediately recognizable by users. The VE is associated with a 2D map of the reconstructed spaces, which provides users with a general overview of the reconstructed area, showing at the same time their current position, and allows them to be teleported into a specific location of their choice. When entering an area of the environment, information related to its historical, artistic and social traits are shown in the right window panel. Moreover, the list of hyperlinks to database objects present in that area is shown, allowing to immediately access them. As for the characteristics of the VEs, in order to understand which are the most suited to reach the proposed goals, we experimented two different types of VEs, an interactive real-time VE and an image-based VE.

(ii) A *form*, laid out on the right of the main application window, allowing both a "Google-style" textual query within the database and the visualization of the contents of the database cards. The query can be targeted to different elements of the stored objects (name, keywords/tags, description, associated multimedia contents and so on), and the results are shown as a list of hyperlinks, allowing to access the full description of each element. A panel can be overlaid on the interface to display images and videos related to the selected object, while associated audio contents are managed through a simple player embedded into the form. When an object is selected, the view on the VE can be changed to show the same object into its original context. Finally, at the bottom of the form, a list of objects correlated to the selected one are presented to the user, suggesting possible navigations through contents that can help to delve into the topics of interest.

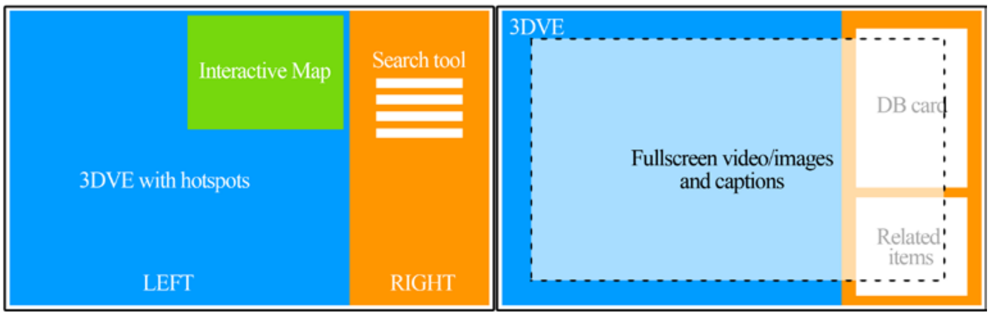

Figure 66. Layout of the proposed interface: the graphic view and the form-based search panel (left); results of a research and the overlaied fullscreen document window (right).

It is important to underline the close relationship between the left (graphic) and right (the textual search) panels. When the user navigates into the VE, he/she can always access information related to hotspots into the environment or to the displayed area. This information is presented through the right panel, which allows also accessing the multimedia contents related to the cultural objects. On the contrary, when users look for items into the right panel, they always have the possibility to access their related context in the left panel. Therefore, both types of queries, the visual and the text-based one, coexist and are fully integrated in order to provide users with an immediate and easy to use interface.

Users navigate the VE as if they were browsing among the records of the database. They can always re-contextualize the search item within its historic ambience and perform searches of different types using the possibilities offered by both textual and visual methods.

In order to test our interfaces, we built, as case study, a prototypal application aimed at presenting the collection of historical documents related to the Riviera casino-resort, in Las Vegas. We developed two different virtual environments with two techniques, in order to analyze the advantages and disadvantages of both.

Firstly, we used a GE for developing and managing our Real-Time VE (*Figure 67*a). Users are free to move within the environment discovering all the ambiences. The main disadvantage of this approach is that, to enhance the realism of rendering, the complexity of geometry and lighting must be increased, and this can have a dramatic effect on the computational resources.

A practical and cost effective alternative approach is the so-called Image-Based Virtual Reality (IBVR). With this technique, the virtual world is represented as a set of initial images, which are used to synthesize the user's view at new and arbitrary viewpoints. High-quality photorealistic views of the environment can be displayed in real-time and manipulated interactively with simple algorithms. Navigation in such VEs is provided allowing the user to move between predefined viewing locations, which are linked together to create a specified path (*Figure 67*b).

In both cases, items in the database were modeled and added to the reconstructed environments, and used as hotspots.

Figure 67. Images of the rendered VEs: (a) RTVE, (b) IBVE.

The two interfaces were evaluated, and compared with a classical textual interface, through a usability test that involved 51 subjects. After a brief explanation we submitted to each participant 12 assignments to be performed with different interfaces, and finally we asked them to fill a questionnaire. The results showed that the two visual interfaces – especially the RTVE – appear to be the effective in improving the accessibility to cultural databases contents. This is particularly relevant for tourism and leisure purposes, where visitors with a not professional background approach the cultural experience with curiosity and interest, attracted not only by the works of art, but also by the relationships between them and by the historical period to which they refer to. Additional details about the results can be found in [Martina & Bottino, 2012].

Finally, we explored the integration of conceptual maps into VLE, in order to create meaningful connections among digital contents. Using *concept maps* the system can suggest items related to the contents the user is viewing. The arrangement of concept in a deductive consequence strongly helps users to create their own personal narrative and to build by their own knowledge. Concept map can be explained as a map showing the inter-relationships among concepts in a convenient and concise representation. In the interconnected map the connections between items are marked by words and/or phrases. Each link explains why and how those elements are related to each other. The power of the concept maps is the creation of a clear relationship among concepts that enhance meaningful learning. Those maps are often used for constructive and collaborative learning activities [Cañas et al., 2003]. In *The evolution of the Italian radio and television: virtual museum* project the main goal was the creation of a system to present and facilitate access to contents of the Museum of Radio and Television in Turin. We then recreate a VLE where users can explore a typical Italian living room in different period of time of the last century. Some objects represented the access point to multimedia information. Selecting these elements the informative window with database contents is showed to users. Here the user can freely move among other contents by following historical/social/cultural links based on *concept maps*. Through this process people generate knowledge not only by studying cultural materials, but also by observing their relationship among each other.

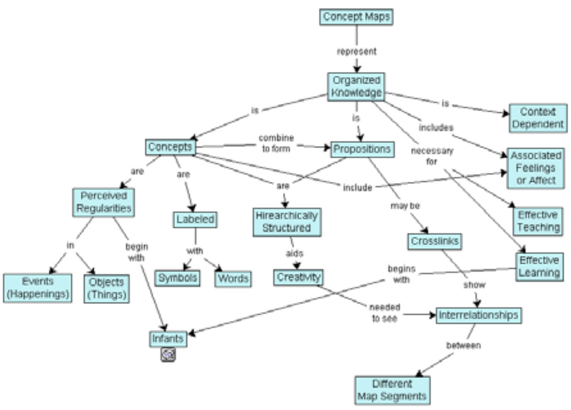

Figure 68. An example of concept map.

CHAPTER 8 – NATURAL INTERACTION

The effectiveness of any VLE is also related to the quality of the user experience. One of the main elements affecting the user experience is the interaction with the environment and its digital contents, which should be designed in such a way to be the most intuitive and immediate as possible. Interfaces represent the paradigm of communication between users and digital world. Through interfaces humans can write an e-mail, play video games or listen to music: users' commands are processed for computers by the interfaces. Obviously the concept of interface is extremely broad and includes hardware and software components, but when we limit the scope on VLE, interfaces consist in physical modalities and controllers with which users can interact with the virtual environment. The history of interfaces and interaction in general is very long and follows a process of simplification, from the complex systems of the past to those intuitive and natural of today. The most recent and extremely successful methods are named Natural Interaction. Valli [2008] explains that as: *"people naturally communicate through gestures, expressions, movements, and discover the world by looking around and manipulating physical stuff; the key assumption here is that they should be allowed to interact with technology as they are used to interact with the real world in everyday life, as evolution and education taught them to do"*. The basic idea of the natural interaction is to develop techniques allowing users to interact with technology as they are used to interact with the real world, which is by looking at objects, touching them and using gestures and voice to issue command. To this end the digital world has to adapt to the human language, and not the contrary, as it was until now.

In the last decades, computer games industry has heavily invested in new natural interaction technologies. Consoles controllers like Wii Balance Board, PlayStation Move and Microsoft Kinect, have introduced brand new ways of interaction between players and games. The new gaming devices allow people to play and interact with objects or entire virtual worlds, simply behaving as they would in the real world.

Natural Interfaces can be categorized in:

- TUI, Tangible User Interfaces, which utilize physical objects and concrete representations of digital data to interact with virtual worlds. System interprets the manipulating of real objects as digital commands.
- NUI, Natural User Interfaces, which mainly utilize gestures and human behaviour to interact with the digital world.

With these new interfaces, it is possible to make people interact with very complex worlds through simple approaches, dramatically increasing the possibilities of use and enjoyment. In Cultural Heritage these new interfaces can really change the point of view of art and history, as well as break down the barriers between people and culture.

8.1 TUI – TANGIBLE USER INTERFACES

The use of gaming as a medium for teaching have been deeply studied and used in several different research and application projects [Clark et al., 1987; Castel et al., 2005; ESA, 2011]. Studies on learning methods show that the classical process - such as teacher-student lectures, homework and assessments - have a limited effect compared to the experiential modalities. Edgar Dale, an American educationist, for example, wrote the theory of *"Cone of Experience"* which notes that 90% of *What people Do* is remembered in the long term as opposed to 10% to 20% of *What they Read* or *Hear* [Dale, 1969]. Similar studies, as Richard Felder's Cone of learning, have shown that the direct experience involves a high level of learning. Many theories such as Constructivism, Collaborative Learning, or even before the Montessori Method, illustrate how the learning process is not only based on the acquisition of new concepts, but also on experiments. Through the direct experience the person learns more easily, and what has been learned will remain for longer and with greater vividness. Moreover children learn primarily through play and direct experience (especially tactile) and it is still presents even in adults. And it is the tactile component, as several studies referred [Resnick, 2004; Xie et al., 2008; Sylla et al., 2011], that provides a huge help in acquisition of knowledge. Being able to physically manage elements allow to enter in communication and direct interaction with the system. The player enters in a concrete experience with the educational environment. TUI is a new type of interfaces that in recent years have made the appearance in the research world, as a symbol of the connection point between physical and digital worlds. TUI utilizes physical objects and concrete representations of digital data to interact with VLE. Tangible Interfaces are more user-centric than the classical ones. Manipulating real objects allow different type of public to access and interact with digital contents. [Xie et al., 2008] and [Sylla et al., 2011], through various experiments, describe that tangible interfaces, compared to PUIs – Physical User Interfaces – and GUIs – Graphical User Interfaces – are easier to use and better involve users.

The *GAINE* project is precisely based on the TUI paradigm. The implemented framework manage tabletop games, as well as interactive applications, using tangible objects with which users can interact with the game, getting an immediate visual feedback. In our project, TUI is composed by two elements: (i) an interactive table and (ii) marked tiles. Similar to Reactable [Jordà et al., 2005] our interactive table is basically a large touchscreen and that can also recognize objects that are placed on the table.

The user can interact with the system in two ways, using the semi-transparent surface of the table as a touch-screen or placing tiles (marker) on the surface. *Markers* are generally two-dimensional images representing pattern in black and white, easily recognizable from system. The system once identified a marker using image-detection algorithms, assigns a unique identifier to the marker and then tracks all its changes. Any movement or rotation of the marker is identified and sent to the system that will appropriately handle it. In our case, each marker identifies an element of the game that the user can choose where to place and how to manage it. The program can identify besides markers, also the points where players place their fingers. In this way the system can manage the multi-touch feature on the surface.

To test the platform we developed an AR strategic management game, where users can build their own nineteenth century city. As a case example, we chose the reconstruction of the city of Turin in 1861 when Turin was the first capital of Italy. The goal of the game is to give users the opportunity to first assemble their own nineteenth century city and then manage it, trying to reach the highest level of "welfare" for citizens. Players, in front of the interactive table, arrange on the game board - the table top - some markers, each identifying an element of the city (e.g. houses, hospitals, streets). A monitor is also positioned in front of them to allow viewing the AR 3D scene. Moving a marker on the table correspond to a movement in the virtual environment. Each item that users add/remove from the game (streets, houses, markets, hospitals, etc...), will cause a modification of the game parameters (health, population, richness, crime, wealth) that together contribute to the level of "welfare" of the city. For instance, adding many factories get an increase of richness, but a subsequent decrease in public health, due to air pollution.

In addition to these possibilities, players can also interact with the game through external parameters. Directly on the table top, users can choose the level of taxes to be charged and wreaking general events, such as earthquakes, simply by clicking buttons or selecting menus.

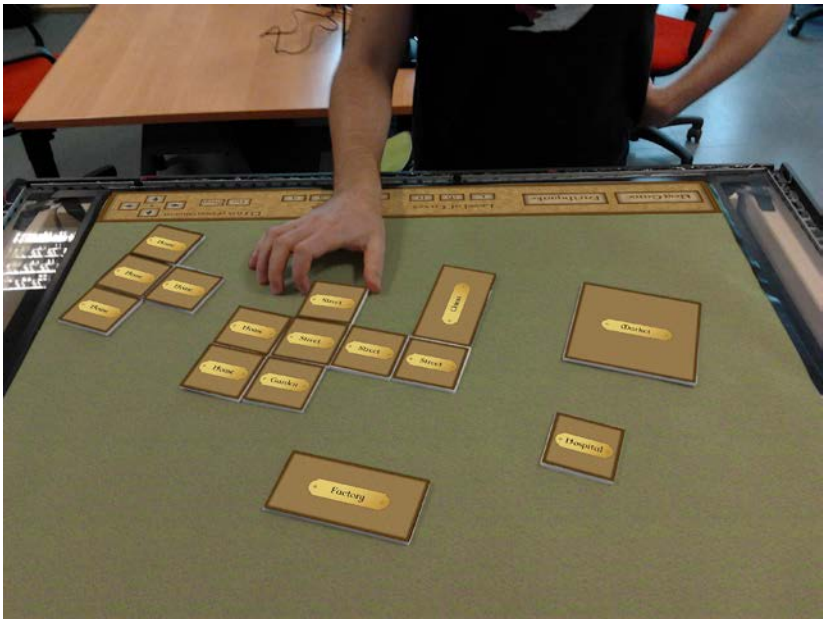

Figure 69. The Tangible User Interface of the GAINE project.

The game was designed for children aged 9-15 years and the goal is to make users aware of the difficulties in managing a city and a society, and how all elements are interconnected to each other. Once players achieve predetermined levels of welfare, they exceed the level of the game and enable the use of new buildings, such as the Theater and the Royal Palace. To help the players during the game, some warnings have been implemented.

GAINE consists of some functional blocks that deal to perform different tasks and are able to communicate among them. They are:

- *GameManager*, the main block. It initializes the program's functionality and starts all the other main blocks: the *ObjectManager*, the *EventManager*, the *RuleManager* and *WidgetManager*. It also takes care of creating the game plan, define backgrounds, initialize the sound system, the cameras with their views, reset the game clock and optionally enable shading system.
- *ObjectManager* is responsible for managing the messages received from the server reacTIVision through the TUIO protocol. It is therefore the only block in direct connection with data coming from the camera. Mainly it

handles the creation / destruction of tiles and updating their position. Furthermore when it identifies that two or more tiles are placed side by side, it ensures that they have the *"groupable"* characteristic. If the answer is affirmative the tiles can be transformed into a group. The *TilesGroup* can have five different configurations according to the position occupied by the tiles in the group: "Start" when the current Tile has only one neighbor; "Linear" when Tile has two neighbors in positions 0 and 2 or 1 and 3, "Curve" when Tile has two neighbors in positions 0, 1 or 1, 2 or 2, 3 or 3, 0, "TShape" when Tile owns three neighbors; "Cross" when it has occupied all four neighbors (*Figure 70*). However, when a tile has no neighbors or is not stackable is called "Single".

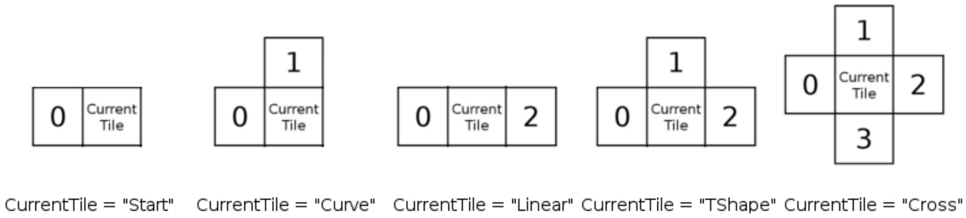

Figure 70. The possible configuration of the TilesGroup.

In addition, if the TilesGroup have the property *"alignInGrid"* active, the system keep the tiles aligned within a virtual grid dynamically calculated. This is to make sure that the grouped tiles have a common organization and a better graphical display.

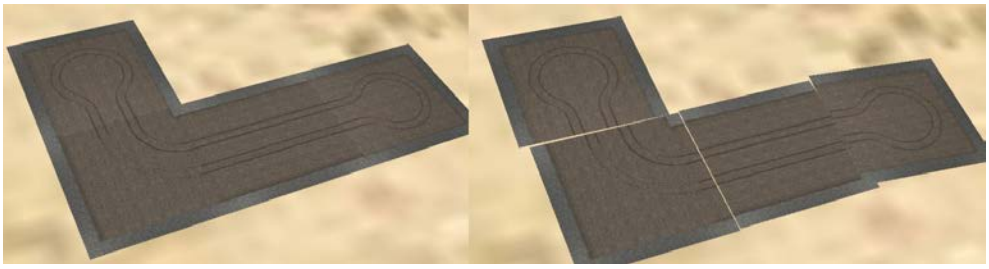

Figure 71. The “alignInGrid” enabled (left), and disabled (right).

From single tiles and TilesGroup can be generated agents called *FreeObject*, which are independent or semi-independent from tile generators. Examples would be people walking in the street or means of transport.

- The *FreeObjectManager* and *ObjectManager* together deal with the management of *FreeObject* regarding their creation, destruction and definition of the paths. The *FreeObject* associated to a TilesGroup are managed directly by the *ObjectManager*. At the time of their creation a fixed route is calculated and they will travel following it until the group is active. An example is the tram that is generated only when a TilesGroup is formed by at least three tiles. Once generated, it will travel along the chosen path. Intead, *FreeObject* associated to a single tile are managed by *FreeObjectManager*. These elements born within the creator tile and move randomly throughout the scene. They are managed by the OpenSteer library[24] which, suitably modified, allows to manage the objects (called vehicles) that move freely on a plane (containers) avoiding other objects.

- *EventManager* deals with the management of events that may occur in the system. The *EventManager* is connected to the *ObjectManager*, the *RuleManager* and the *WidgetManager*. It can receive events from *RuleManager* (event generated by rules and parameters) and *WidgetManager* (event generated by buttons on the GUI). Once an event request arrives it checks the type of the event and it dispatches it to the *ObjectManager*, *RuleManager* and *WidgetManager*. Their listeners receive the event and appropriately handle it.

- The *RuleManager* is responsible for managing the rules and parameters of the game. The configuration file defines some parameters that can change according to the objects (Tile and FreeObject) present in the scene and their status.

- *WidgetManager* deals with the creation and management of the 2d graphical interface. This is generally composed by a background and some interactive elements such as labels and buttons. The label displays an associated parameter calculated by the *RuleManager*, while button is a clickable buttons that generate an event. The *WidgetManager* communicates with both the *EventManager*, receiving and sending events, and with the *RuleManager*, from which it receives information on editing parameters. However, the entire interface is fully customizable from the texture of the background, to the size, color, font of labels and buttons.

One of the peculiarities of *GAINE* is the ability to be easily modified and adapted through external configuration XML files. Through these files each part of the program can be modified without having to recompile the source code. Indeed, *GAINE* can create a system that simulates a city (as in the case study) in which each

[24] http://opensteer.sourceforge.net/ - (Last Accessed, February 2014)

marker corresponds to a historic building, and at the same time, only changing the configuration files, it can simulate a room of a historic building where the tiles represent the furniture, or still a theater, where the Tiles or FreeObjects represent the public, actors and musicians.

8.2 NUI – NATURAL USER INTERFACES

Natural Interfaces allow interacting with the digital world as we interact with objects in real life. The main elements that form the basis of the Natural Interaction are the gestures. A gesture is defined as body movements that involve significant and expressive actions of the fingers, hands, head, face, or body with the intent to: (i) communicate information or (ii) interact with the environment [Sushmita & Tinku, 2007]. Most of interpersonal communication occurs through gestural language, and consequently most of the study on natural interfaces should focus on that language. To this end we analyzed the use of gestures to interact with the digital world. We developed a head tracking software that allowed to change the view on the virtual world according to the current user's position. Following the natural approach of human beings to move their heads in order to control their point of view, we though to reproduce the same concept into the cultural field, transforming a static painting into a dynamic view on a virtual world recreating the painting contents.

Paintings, indeed, are not only important artist's works, they also represent an important historical source, a faithful witness of the past of society, fashion, transportation and any key element represented in the picture. They are an important element of the cultural heritage, but are static artifacts and the viewer does not feel a sense of immersion. In order to provide one, we proposed *Beyond the picture*, a new and exciting way for enjoying paintings by immersing visitors into them and exploiting natural interaction to navigate their contents. In order to achieve this, first a 3D model of the painting that is both accurate and visually pleasing is created and displayed on a large screen from the painter viewpoint. Then the visitor is provided with the capability to change the viewpoint on the world depicted into the painting by moving its observation position. A computer vision technique is used to capture the position of the user's head, which is in turn used to render a novel view of the 3D model. Such a natural interaction is immediate and intuitive for the visitor, providing a high level of user experience in approaching the artifact.

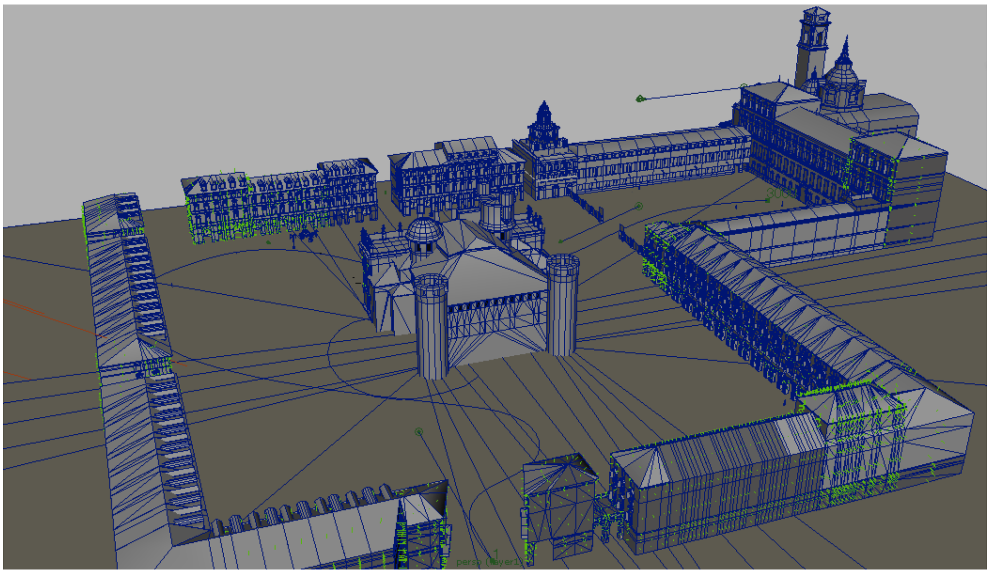

Figure 72. The 3D model of the environment.

As a running example, we show our work on “Piazza Castello”, a tempera painting of Carlo Bossoli dated to 1852. In order to recreate the represented environment we modeled the famous square with a particular attention to the accuracy (as close as possible to the representation in the painting) and the aesthetic (“looking how it should”). To create a 3D model suitable for our application, some more steps are necessary. First, the parameters of a virtual camera reproducing the painter’s view must be computed. Then, objects not belonging to the background scene must be created. Finally, the painting must be transferred, as texture, on the models. These processes are:

1. *Camera calibration*. The goal of this step is to compute the intrinsic (focal length) and extrinsic (rotations and translations) parameters of the virtual camera. These can be evaluated from a set of correspondences between 3D vertices of the model and their corresponding position on the image plane with a procedure similar to that described in [Trucco & Verri, 1998]. A minimum of six correspondences is required, but the more are available, the lower is the calibration error. Correspondences are given by the user. Since the painter’s work is an artistic reproduction of the reality, and not its exact photography, small differences between the painting and our model appeared and were manually corrected.
2. *Foreground objects*. The painting contains two classes of objects, the elements composing the background scene and the foreground objects that

populate it. These latter can be modeled as simple “billboard”-like planar objects standing in front of the background.

3. *Texture mapping*. When the model of the background scene has been obtained, the next step is to create a variety of textures ready to be applied to its elements in order to "paint" them with the same brush strokes the artist used for the painting. To reconstruct the texture, we have to cope with occlusions of foreground objects, resulting in holes in the texture, and missing textures of part of objects that are hidden in the painter view but can become visible changing the viewpoint. Those problems can be dealt with applying different techniques, like *image inpainting* (for filling narrow gaps in images), *texture synthesis* (for reproducing a texture from a sample) and *image completion* (dealing with larger gaps to be filled). The interested reader is referred to the survey [Fidaner, 2008] for further details on these techniques. An example of their application can be seen in *Figure 73*. Once the final version of the texture of each building has been obtained, it is applied to the corresponding model with UV mapping techniques.

Figure 73. Foreground object removal and texture reconstruction.

The key element of the proposed system is its interactive component. The application presents itself to the visitor as a normal monitor that displays an image, a rendering of the reconstructed model that is identical to the original painting. But, approaching the picture, the visitor will notice that it slowly comes to life. Each time he/she will move his/her head, the picture will respond appropriately, changing the view in the same direction. This approach is very intuitive and the user immediately understand that he/she can control the view on the painting with its own movements, discovering elements and details of the scene. Once the user moves away from the panel, the displayed image returns to the initial view. To enable this interaction, we have developed a simple real-time computer vision based face tracker, which analyses images taken with a camera placed on the display. This module is a state machine. In the detection state, the input image is processed until a face enters the image. Then, the face is tracked until it exits the image. Two different algorithms are used: the Viola-Jones framework [Viola & Jones, 2001] for face detection and CAMShift [Bradski, 1998] for face tracking. When multiple faces are present in the image, we must analyze two different cases. When the module is in the detection state, the face region with the biggest area is retained. In the tracking state, the CAMShift algorithm is very robust against distracters. Once it is locked onto the mode of a color distribution, it will tend to ignore other nearby but non-connected distributions. Problems can be caused when two faces form a connected component. We have decided not to handle these events with more sophisticated algorithms to prevent performance worsening.

We also developed an extension of the project to enjoy a presentation of the contents in stereo 3D (S3D), which further enhances the sense of immersion of the visitor. By creating a virtual stereo camera, the user can see the contents in S3D by means of a pair of active glasses. Two different fruitions are possible. In the first, the head is tracked as in the monoscopic visualization, and the stereo camera is moved according to the viewer's motion. In the second, the viewpoint is fixed and the display initially shows a monoscopic image. This can be obtained by setting the stereo base, that is the distance between the camera lenses, to zero. Then, when the computer vision detects the face of a visitor and, therefore, its presence, the stereo base is slowly increased until its final value, providing a convincing and amazing effect of objects popping up from the screen. Finally, when no more visitors are detected, stereo base is slowly zeroed.

8.2.1 The usability of Gesture Interfaces

Although natural interactions are available for the last years the research on gesture is still extremely poor. Several NUI devices have been recently developed, but all of those are not yet fully exploiting the possibilities offered, especially in the context of the Virtual Environments. Most VLE with natural interactions, in fact, are based only on few gestures, generally limited to movement or rotation of the whole human body. So, we conducted a thorough user survey to develop a vocabulary of gestures that can be used to interact with a virtual environment to navigate, select and manipulate objects and interact with the system that are natural, effective and easy to remember.

The process can be identified in 4 steps:

1. Recognition of actions normally used in a virtual environment. After a carefully study on the taxonomy and gesture, we identified the possible kind of gestures generally used in VLE. They can be categorized in 4 groups: *navigation, selection, manipulation, system control.*

2. Through the *Wizard of Oz* approach and the *Think Aloud* protocol we conducted the Explanatory Test in order to identify the most natural gestures for the majority of users. For this test our group of participants performed actions in a virtual environment properly created in Unity3D. The identified natural gestures composed the initial gesture vocabulary.

3. Definition of the initial gestures vocabulary. The gestures of the explanatory test were implemented with FAAST and Backon Motion libraries.

4. Final user experience evaluation. Three virtual environments were created in Unity3D for the assessment test. A group of participants tested the ambiences in order to identify the final set of natural gestures for VLE. Each participant experienced the 3 environments using the most natural gestures among those get in the task 2. At the end they had to answer a questionnaire to assess the usability of the gestures. The survey was properly composed by four different questionnaires, each part dealt with a different aspect, screening, satisfaction, perceived exertion and usability. To summarize the principal results we get a high rate (4.14/5.00) for the overall evaluation of the input system and a 4.31/5.00 for the general usability. Also intuitiveness (3.97) and ease of use (4.00) obtained excellent results. The perceived exertion of the gestures was evaluated low for all the actions, a key condition for natural interaction.

Through this study we could identify natural gestures to interact with VLE. In cultural scenarios the application of this analysis could be many. The use of natural interaction to enjoy a VLE may reduce the problems of synergy that exist among people of different ages and technological capabilities. The introduction of VLE with an appropriate natural interaction method could indeed allow new, engaging and effective learning systems in museums.

A complete description of the process and results is available in section *4.12*.

CHAPTER 9 – CONTENTS IN MOBILITY

Today tourism is one of the world's most important and profitable sectors. As we stated in section *3.1* several studies have identified changes in global tourism, especially in terms of needs and preferences of the public. Tourists' requests have changed on the concept of experience, rather than visit. Current tourists want to learn while having fun, enjoying a full cultural experience. In particular, cultural tourism is gaining increasing attention in recent decades. Although the numbers of cultural tourists represents a minimal quantity compared to the total, 9% according to the ATLAS survey [Richards, 2007], that number is growing thanks to the multitude of services and products offered. Tourism authorities all over the world have pointed to the improvement of the attractiveness of cultural sites, developing novel and interesting tourist information services. In this context, technologies play a very important role, thanks to their enormous development and progress.

In the field of Virtual Heritage AR is receiving a growing interest. AR combines real objects and computer-generated data, so users could see virtual and real object living in the same space [Azuma, 1997; Azuma & Ronald, 2001]. Another advantage is the possibility to integrate into the system video, images, text and audio commentaries related to the virtual elements. Therefore, visitors of a cultural heritage site can be provided with a large amount of information about objects and monuments within the site, which can be consumed according to their interest and curiosity, improving their cultural, historical and scientific understanding.

Recent advances in mobile devices, which have evolved to provide powerful computational and connectivity capabilities, makes the adoption of AR particularly appealing for such devices. Recent products offer enhanced multimedia features, like high quality displays, video cameras, touch screens, advanced audio support and 3D rendering. Current communication networks (GPRS, UMTS, HSDPA) allow them to receive large amount of data in a short period of time. Furthermore, mobile phones are personal devices that users carry with them most of the time and are, therefore, especially suited for developing applications supporting tourists in mobility [Proctor, 2011; Economou & Meintani, 2011; Boiano et al., 2012] with interactive multimedia information and, in the specific context, with cultural contents.

Moreover multimedia interactive guides are rapidly replacing the old-fashioned audio and textual guides in city and museum tours. The increasing potential provided by mobile guides has been underlined by several surveys [Kray & Baus, 2003; Raptis et al., 2005; Kenteris et al., 2011; Emmanouilidis et al, 2013]. Nowadays, their functionalities cover a wide range of services aiming at helping users to create meaningful connections with both physical and digital environments.

There are many services that can be offered to users through mobile devices. Location-based services (LBS), recommender systems (RS), navigation tools and gamification approaches are only some of the available opportunities for mobile applications. According to the cultural scenario we focused on some of them.

9.1 PERSONALIZATION OF CONTENTS

Nowadays visitors require cultural experiences oriented to their interests and needs. Cultural contents have to be presented tailored on the person to whom they are intended to. Systems have to allow designers to properly manage cultural contents, also having an easy customizable presentation layer. E.g. *MusA* offers the possibility to manage a large variety of different data and to organize them in many different ways. The system supports the following content types:

- text, composed by an HTML document and a CSS sheet defining its presentation semantic to allow better presentation flexibility and improved content accessibility (e.g., designing pages for dyslexic users);
- images, graphics, video and audio;
- high-quality 360° panoramic images, enhanced with embedded hotspots that, when selected, allow the linking of different types of digital media;
- 3D models, showing virtual reconstructions of objects, rooms or even buildings;
- Augmented Reality contents, registered with the camera view according to the positional data extracted from the markers.

Contents can be accessed in different ways and with different deep. As a first option, entries in the content database can be linked to a marker ID and activated when the marker is recognized by the mobile guide. Alternately, contents can be directly reached from the application interface, e.g., through buttons, hyperlinks or hotspots.

In order to allow visitors to explore the information related to a specific item in as much detail as they like, contents can then be layered at different level of depths. Thus, for instance, curators can prepare an introduction with a limited amount of text followed by an in depth analysis, which relies on different combinations of accessory multimedia material (audio/video commentary, image galleries, references to other object inside or outside the collection, and so on). An XML file defines the list and organization of the contents related to a specific item and how they should be presented to users.

9.2 DEFINITION OF CUSTOM EXPERIENCES

Moreover different exhibit paths can be designed by curators and managed by mobile application. The paths include a number of selected stops, each corresponding to the exploration of a specific museum room or cultural object. Conversely, the works of art on display can be included in different thematic paths, which are played around specific topics identified by the curators. Thus, cultural objects and themes are combined in *MusA* in a matrix structure that allows to communicate the information of a specific object under a variety of perspectives, i.e., according to the path theme or to the specific target group identified by the curators.

Different arrangements of the cultural objects include the possibility to offer free-choice approaches that allow visitors to organize contents according to their curiosity and interests and to make their own connections, thus building their own learning path.

Another relevant aspect to consider is that nowadays more people are visiting museums with the expectation to learn something, while having an entertaining experience. To this end, the thematic themes can also be played around narratives and interactive storytelling. Such narratives can be built on top of the elements supported by *MusA*, i.e., combining video overviews or short stories, exploiting VR/AR contents to display objects otherwise not accessible or to show how a location looked at different periods in history [Alciatore & Miranda, 1995; Gîrbacia et al., 2012] and comparing side by side paintings or sculptures that have common or contrasting traits [Kang, 2012]. Engaging characters can populate these stories and even interact with visitors at different levels [Iurgel, 2004; Stock & Zancanaro, 2006; Streetmuseum, 2010]. The system can also support games and game-like experiences, which are becoming increasingly important to museums seeking to engage new audiences and to provide deeper engagement with existing ones, due to their ability to involve visitors in new and unexplored ways [Traum et al., 2012].

9.3 SOCIAL NETWORKING

The networking capabilities of modern mobile devices enable to extend the museum experience to the universe of social networks. On the one hand, sharing comments and multimedia content with friends allows visitors to reinforce their experience and take active part into a process of participatory communication with the museum [Yiannoutsou et al., 2009]. On the other hand, the act of sharing has a remarkable marketing potential, since it facilitates the spreading of the electronic word of mouth, it contributes to the reinforcement of the brand reputation of the museum and it may also play a positive role to reduce friends' hesitancy to visit a specific cultural venue [Russo et al., 2008; Hausmann, 2012].

To this end, *MusA* offers interfaces with the most popular social media platforms. Thus, users can exchange with their social companions commentary, notes, ideas and impressions on the collections.

Visitors can also be profiled. Information on the use of the application is stored within the guide, in strict anonymous form, for subsequent analysis about how users moved into the museums, which contents they accessed and how they used the guide. This analysis is a valuable support for exhibit curators, to fine-tune or modify their design according to the feedback received from visitors, and for the museum manager, to build up customer loyalty.

9.4 HIGH QUALITY MULTIMEDIA CONTENTS

In *MusA*, for example, users access high-quality multimedia contents: historical documents, paintings, video, audio, have been selected and proposed at the highest resolution possible, according to the visualization device. In addition, the IBVR approach was also used which, as we have already described, allows to view panoramic visualizations of environments at high resolution without having problems of heaviness or performance delays in the application.

In *SkylineDroid* according to the user's position and orientation different types of content can be displayed. In addition to multimedia contents related to historic elements 3D reconstructions of past environments are available. Different

3D models of the most prestigious and oldest casinos, the Stardust, the Sands and the Riviera were completed for the whole timeline (1952-2006). For each of the 16 timeslot 3D reconstructions of the casinos were realized and imported into the application. On the augmented view virtual elements are superimposed to the live camera video stream, showing the old version of the building exactly in the same position, orientation and scale of the real one. The user is able to change smoothly in real-time the transparency level of the rendered objects, from full transparent to opaque, with a slider. This allows a straightforward comparison between real and augmented view and an easier way to highlight their differences.

As for lighting, during daytime, position, orientation and intensity of lights in the virtual environment are set in order to mimic that of the real world. Given the current date - taken from the phone's calendar - and the location of the observer, the application checks in a table the Right Ascension and Declination of the Sun on that day, which, combined with the current clock time, provides in real-time Sun azimuth and altitude. This table has been created with the algorithm described in [Flandern & Pulkkinen, 1979], which guarantees position errors of few arc minutes. At night, lighting has been studied to recreate that of the original buildings, according to an interpretation of the available iconographic archive material.

9.5 OUTDOOR AND INDOOR NAVIGATION

A huge difference among mobile applications is based on the operation context: outdoor or indoor. This is because some key services, such as GPS, require open spaces to work. Inside buildings, in fact, services such as navigator, LBS and RS do not work. This has forced researchers to find new solutions. According with this problem, we have studied different approaches. The first, for outdoor use, is based on mobile sensors. *SkylineDroid* supports location based tracking using device positional data, obtained through mobile phone GPS, digital compass and accelerometer. These data are used to evaluate the location and orientation of the virtual camera that will provide the view on the augmented world. In order to guarantee a seamless integration of real and virtual elements, device positional values are queried at high frequency (around 25 Hz) and are, therefore, affected by a certain amount of noise. To reduce it and to ensure greater stability of the displayed objects, a moving average filter, taking into account the last 10 samples, is applied to the data stream. Such filter introduces a certain latency between the changes in the device position and the display of their effect, which, however, remains negligible for smooth movements.

The virtual buildings are reconstructed to scale with the real ones. They are positioned and oriented, according to original buildings' locations, along a global reference system, where GPS units are used as metric. The Z-axis of the reference system is the normal to the ground plane, its Y-axis points towards the North Magnetic Pole and X-axis is obtained as the cross product of Y and Z. Virtual objects are then rendered using OpenGL ES library according to position and orientation of the virtual camera. The picture on the OpenGL surface is finally overlaid on the image taken with the device camera, which represents the current world view.

When no virtual models can be seen from the current position, that is when the user is not inside any of the model visibility regions, his/her position and orientation are used to display the location of virtual buildings as POI on the AR view (*Figure 74*). Each POI is represented as a balloon, containing the POI description and its distance from the actual position. A series of concentric circles are also present to improve the user's perception of distances.

Figure 74. AR view of POIs as balloons.

Another feature provided by the application is the ability to access at any moment a full screen 2D map of the area showing the current user's position and the location of the surrounding POIs (*Figure 75*). The map is activated by simply displacing the device parallel to the ground plane and is rotated according to the user's orientation.

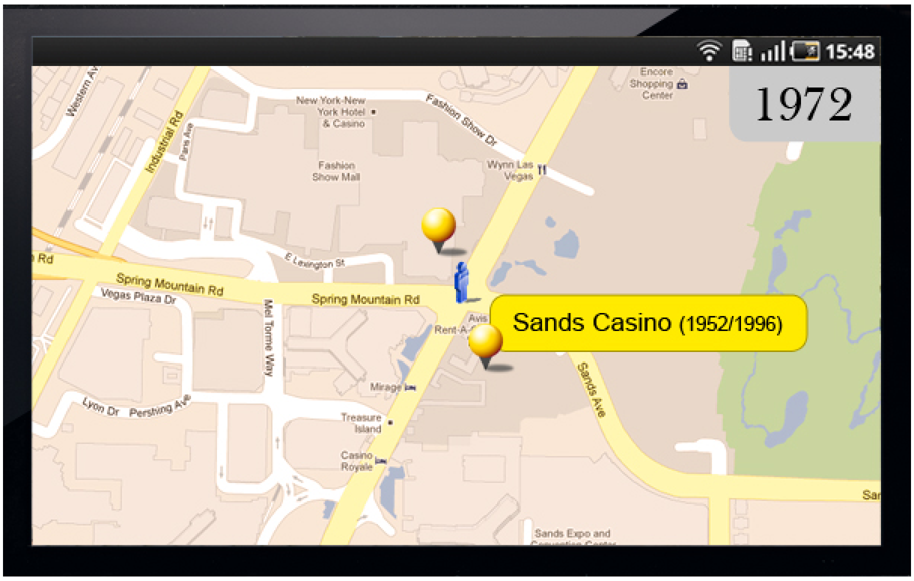

Figure 75. The 2D map showing user's position and POIs locations.

In indoor scenarios the navigation system is quite more complicated. In a museum, the knowledge of the visitors' location allows to enhance their cultural experience, delivering them contextualized multimedia content related to the observed artworks or to the surrounding location [Klopschitz et al., 2010]. In this frame, the main problem to solve is getting accurate users' location and orientation data. The unavailability inside buildings of GPS signals, or their unreliability, turns out in the need to deploy a suitable technology for indoor positioning. Several approaches presented (surveyed in [Yanying et al., 2009]) are based on the coverage of the area with various sensor types, exploiting (i) different radio signals, such as Wi-Fi [Ruíz et al., 2011; Kuflik et al., 2012], RFID [Hsu & Liao, 2011; Perry-Lube& Lefkowitz, 2011] and NFC [Blöckner et al., 2009], (ii) perturbations of the earth's magnetic fields [Storms et al., 2010], (iii) modulated infrared lights [Ciavarella & Paternò, 2003] or (iv) ultrasounds [Bihler et al., 2011]. Though providing a set of valuable solutions, many of these techniques require to face some drawbacks. First, they often entail installing and maintaining complex and often expensive physical and electronic infrastructures to guarantee the pervasive availability of the sensed signals. This aspect still represents an issue in historic buildings such as museums, where the provision and deployment of these infrastructures can be difficult due to conservation and financial or structural reasons. Second, these positioning techniques might rely on special purpose devices to sense the localization signals, thus ruling out a significant part of off-the-shelf mobile devices. Third, indoor LBS requires a very high precision, since errors not exceeding few meters are necessary to tell one corridor from the other and one floor from the next. This is a matter of choosing the type of sensing signals, as some could be inherently inaccurate. Finally, navigation planning requires not only a precise localization but also a correct orientation, which still turns out to be a big unsolved issue depending on the type of sensing signals used by the system.

Vision-based localization system can address in efficient and satisfactory ways most of the previous points. They rely on the extraction of image features, like points, edges or regions, which are matched with those in a reference database to compute device position and orientation. In order to make the feature detection and matching problems easier, most of the approaches rely on visual markers, depicting specifically designed two-dimensional patterns, such as QR codes, bar codes or tags similar to those used in Augmented Reality applications. Alphanumeric information can be encoded into the marker and used as key to obtain the fiducial position and orientation from a database. Finally, the peculiar visual appearance of the markers makes them easily identifiable as information hot-spots in complex environments and fiducials can be easily deployed at a minimal cost [Mulloni et al., 2009; Mulloni et al., 2011].

In *MusA* we decided to use a vision-based approach. We designed a novel visual marker (*Figure 76*), whose peculiar shape and geometric properties allowed to develop an approximate algorithm for the computation of the camera pose with the following characteristics:

- it does not require prior knowledge of the intrinsic parameters of the camera;
- it is not iterative, guaranteeing a fixed execution time;
- it is computationally light (i.e., it can be executed in real-time on any mobile device), while ensuring, at the same time, a sufficient level of robustness and reliability for its expected use.

The inner part of the marker contains the data area, divided into a regular grid of N^2 blocks each of which represents a data bit, where the extra information associated to the marker is stored.

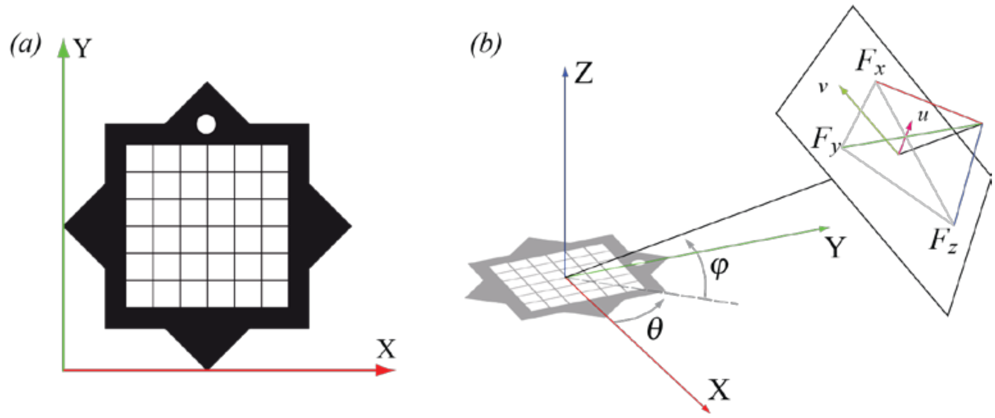

Figure 76. The structure of our marker (a) and the relative position of camera and marker (b).

Markers were then placed in the halls of the museums. When a visitor want to go in an exact point of the building, or the mobile guide wants to take him in another part of the exhibit or in any case a navigation system can be useful, the user should only frame with the camera of the device the closest marker and the system will guide him to destination.

The routes calculated from the visitor's position to the destination are internally represented as a graph, where nodes are the turning points and edges are the path segments. The route between two points is computed with a shortest path algorithm. Besides user's location and target destination, the routing algorithm can take into account other contextual information. For instance, it considers the user preferences for stairs or elevator, the temporary availability of path segments (e.g., due to restricted opening hours of corridors, floors or venues), and the particular disabilities of the user, thus providing accessible routes for walking-impaired people.

Once the route has been computed, one relevant question is which is the best way to describe this path. Communicating the route effectively enables users to easily find their way through spaces that sometimes they have never seen before. Thus, navigation information should be as clear and intuitive as possible, requiring a minimal cognitive load. In light of this, *MusA* offers the developers different presentation interfaces:

- A 2D (*Figure 77*a) or a 3D map (*Figure 77*b), showing users their current position and the path to follow. The displayed section of the map is adapted to the user's position and its graphical representation includes all the significant geometric and semantic elements in the surroundings. The map is oriented to show upward what is in front of the user. Since the precise user localization is available only at sparse points, i.e., when the device camera observes a marker, an interactive graphical animation can be played to show the detailed turn-by-turn instructions to reach the destination.

- A visualization of navigation information in Augmented Reality [Mulloni et al., 2011] overlaying the device video with signs and arrows showing the current walking direction (*Figure 77*c). The AR view (as any other view) can be integrated with a list of graphics icons summarizing the step-by-step instructions to reach the destination ([Mulloni et al., 2011], *Figure 77*d).

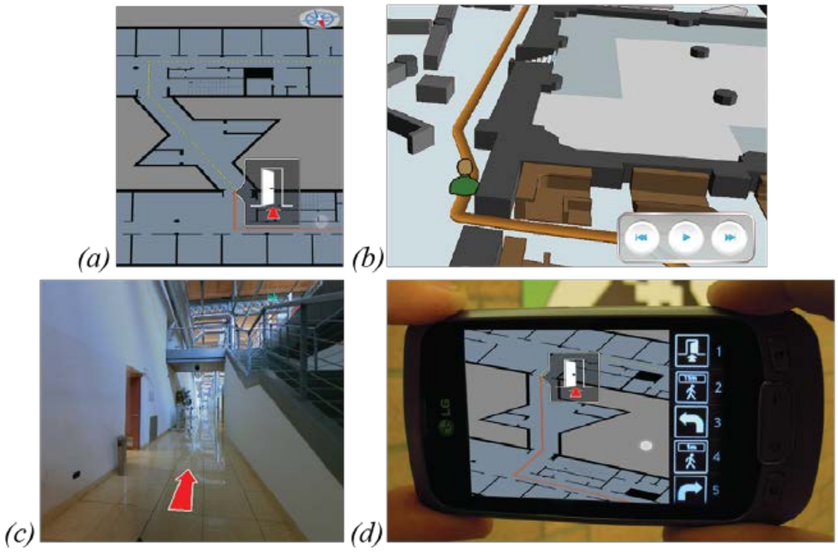

Figure 77. Communicating the route through: a 2D map (a), a perspective view of a 3D map (b), information in augmented reality (c), and a list of step by step instructions (d).

As we experimented, the integration of some, possibly all, of these features improves the system usability and the effectiveness of navigation information, since map reading appears to be a major problem for most casual users.

CHAPTER 10 – GAMIFICATION

Gamification can be defined as *"an informal umbrella term for the use of video game elements in non-gaming systems to improve user experience and user engagement"* [Laine & Joy, 2009; Deterding et al., 2011]. As already stated in the section *3.6* in recent years, gamification has been applied to many areas, and also the cultural one can reap significant benefits. Gamification techniques reinforce the aspects of competition, achievement, status, self-expression, altruism natural for human beings. The basic concept of gamification is to give users prizes and awards after a successfully completing of a task. Rewards can be different according to the context and the project's goals [Hamari & Eranti, 2011].

The gamification of culture can be a benefit for both learners and cultural institutions. Through the use of game mechanics the learning process becomes a more enjoyable experience [Kapp, 2012]. Instead of being passive users, learners, being more motivated to explore and question, learn with greater ease and effectiveness.

In cultural heritage projects different gamification approaches can be applied.

10.1 SIMPLE GAMES IN VLE

The easiest step to create a more engaging experience is to insert mini-games within the virtual environment. Quizzes, puzzles and riddles are just a few possibilities that can be implemented. Obviously this type of gamification is very basic and involves users for a short time. The ability to attract and convey information is low, but the advantage lies in the fact that these mini-games are simple to create and to be included within the VLE. Games can also be added within virtual environments already created, with few modifications.

In *Virtual Tenochtitlán* the application challenges users. The simple game consists in collecting historical objects dispersed in the VLE through time. Each object gives user access to additional multimedia contents. Once one object is founded the application launches another challenge to find the next one. If the user collects all the items in a random order, he will simply have access to the contents, but if he collects them in the order suggested by the challenge, he achieves a victory. The order is not a chronological one, to stimulate the curiosity and the gaming sense of the user, encouraging to discover the evolution of the Recinto Sagrado.

10.2 GAMIFYING THE NARRATION

Another aspect of gamification in VLE is related to the narrative experience. The user starting his personal experience entering into the virtual environment also begins to follow the narrative that the application suggests. The sequence of information, data and materials that are proposed to users are properly tailored to them based on a narrative structure identified by the creators. The narrative is gamifyed when the presentation process of historical and artistic contents follows the procedures drawn by games mechanism. For example, in *One Dat at The Sands* visitors can access and explore the Sands through a guided or a free tour. In the former, the user follows a pre-defined visiting path that takes him/her through a 24 hour journey at the Sands, starting in the morning with his/her arrival at the casino and ending at night with a show in the Copa Room. When the user starts the application he is informed that he won a radio contest where the prize was a weekend at the Sands Resort and Casino in Las Vegas. It should be emphasized that this competition really existed in the 60s and was banned from radio KTNT.

In the guided tour, the user is taken from place to place in the casino, following a storyline that justifies the movement. In doing so, the visitor is inclined to anticipate the evolution of the main narrative to satisfy a sense of expectation and curiosity that is unconsciously created. Moreover the narration presents some elements, such as small tasks to complete or items to look for to continue to the next environment that can stimulate the user's participation in the educational experience [Willis, 1996; Bellotti et al., 2011].

Conversely, the free tour allows the visitor to access the environments in any order and to create his/her own personal path.

In *The evolution of the Stardust* project, indeed, users instead of having to face a classic timeline, they navigates through time "playing" cards. On a gambling table, in fact, there are 11 different cards with the indication of the reference year and some chips. Hovering the mouse on the cards a brief description of the period with an indication of the major changes is presented. To select the card user can simply "bet" on it, putting down the chips available on the chosen card. With this gamification approach, the user plays and "wagers" on their own learning. He/She is deciding what information to access and in what order. In addition the chips, icons of Las Vegas, better contextualize the application. When the user places the chips on a card, an animation of the camera shows the game board and at the center of it the Stardust casino in the version of the chosen year, with all the multimedia material available.

Figure 78. The gamified interface.

10.3 SERIOUS GAME

Opposite to the previous solutions is instead the one of serious games (SG). In this case there are no game mechanisms that are used in the cultural experiences, but the cultural contents are enjoyed through a game. SG can be defined as a class of games whose primary goal is not entertainment [Gee, 2003; Prensky, 2003; Greitzer et al., 2007]. The main reason because they are developed is to let people play with games specifically designed to transfer information and data. SG are often used for training people, such as astronauts or military, or for medical or driving exercises. The game associated to learning, as indicated by many learning theories - including constructivism - is very effective, and it is for this reason that SG are attracting growing interest from educators [De Grove et al., 2010]. In the cultural sphere they are very useful especially for inviting people who are not familiar with art and culture to discover the beauty of heritage, in addition to historical reconstructions. SG are available in many different forms, as mobile applications, web-based solutions, or more complex programs [Anderson et al., 2010].

We studied serious games with the *GAINE* project. Here we developed an AR strategic management game, where users can build their own nineteenth century city. As a case example, we chose the reconstruction of the city of Turin in 1861. The goal of the game is to give users the opportunity to first assemble their own nineteenth century city and then manage it, trying to reach the highest level of *"welfare"* for citizens. Players, in front of the interactive table, arrange on the game board - the table top - some markers, each identifying an element of the city (e.g. houses, hospitals, streets). A monitor is also positioned in front of them to allow viewing the AR 3D scene. Moving a marker on the table correspond to a movement in the virtual environment. Each item that users add/remove from the game (streets, houses, markets, hospitals, etc...), will cause a modification of the game parameters (health, population, richness, crime, wealth) that together contribute to the level of "welfare" of the city. For instance, adding many factories get an increase of richness, but a subsequent decrease in public health, due to air pollution. In addition to these possibilities, players can also interact with the game through external parameters. Directly on the table top, users can choose the level of taxes to be charged and wreaking general events, such as earthquakes, simply by clicking buttons or selecting menus.

The game was designed for children aged 9-15 years and the goal is to make users aware of the difficulties in managing a city and a society, and how all the elements are interconnected to each other.

10.4 A GAME AS EXHIBITION PATH

Games, and game-like experiences, are becoming increasingly important to museums seeking to engage new audiences and to provide deeper engagement with existing audiences [Lombardo & Damiano, 2012]. Game mechanics are used to involve visitors through new and unexplored ways.

But in the museum experience the goal is not the game or the fun, the goal is to arise interest in the exhibits or in stories by using gaming techniques. While gaming focuses on extrinsic motivation - the interest is in the game and prizes – in gameful design the attention is on intrinsic motivation – the contents. In museums the gamification approach has to involve users through games mechanisms, conveying serious contents.

In *MusA* project we developed *Intrigue at the museum*, a location-based mobile game targeting a young audience, 7–13 years old children. The aim was to facilitate engagement in young museum visitors, an audience that can easily get annoyed or even worse, frustrated, in such a context. Nonetheless it pursues also the objective of making this, visitors not only enjoy this time but also learn about the exhibits.

In genaral the game was developed to:

- facilitate visitors knowledge and understanding about the main historical characters who lived in the building in the past, the variety of collections on display and the presence of ceiling decorations;
- challenge children's ability to observe the decorations and the works of art on display in detail, their short-term memory and their capacity of orientate themselves in the building;
- contribute to arise in children a positive attitude towards the exploration of the museum itself and of museums in general, leveraging on curiosity and fun.

The goal of the game is to identify a virtual thief in a set of suspects, with the help of different clues obtained by the player as he/she explores the environment solving puzzles and mini-games activated by the markers deployed in the building. These mini-games are related to the artworks or the museum venues (*Figure 79*). In order to progress in a mini-game, different pieces of cultural information received by players at the game start and a careful observation of the artworks and their surrounding environment are necessary, thus encouraging children to pay attention to details that could be easily unnoticed.

The mini-games were developed following the paradigm of Task Based Learning [Bellotti et al., 2011], and belong to one of these categories:

- Observation tasks, pushing players to carefully observe the masterpieces looking for the details needed to solve the game;
- Reasoning tasks, where initial clues, such as temporal information, factual details and so on, have to be absorbed by players in order to solve the riddles or quizzes;
- Arcade tasks, used to provide observation stimuli entertaining the players with animated graphics and high interaction.

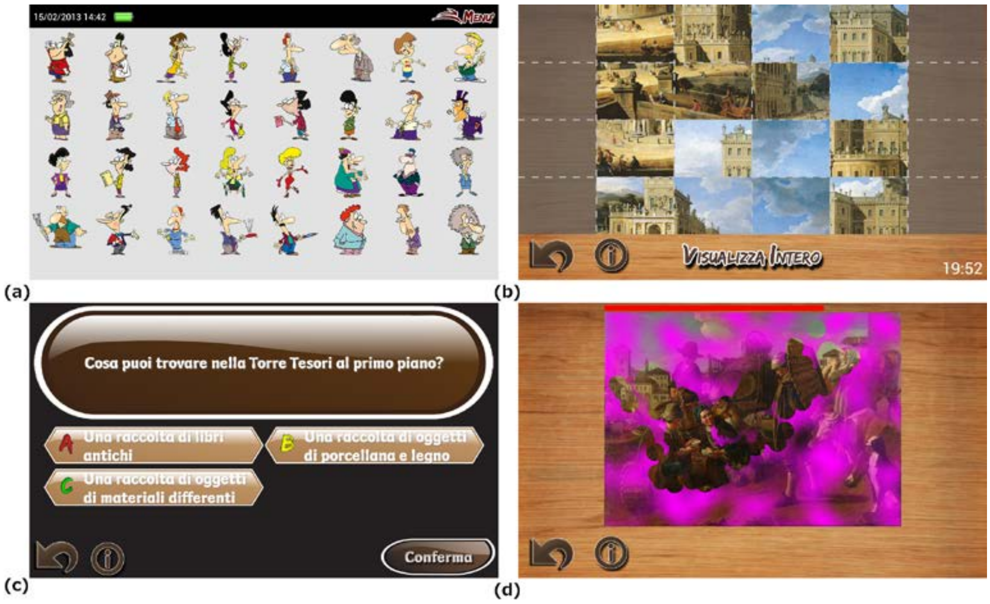

Figure 79. Intrigue at the museum: the list of suspects (a), examples of observation (b), reasoning (c) and arcade (d) mini-games.

This gamification approach has several objectives. First, it tries to make the museum visit more appealing, interesting and fun for younger visitors by letting them observe the museum collections from a different perspective. Second, it motivates players to explore the exhibit, since virtually all rooms have to be visited to collect an amount of clues sufficient for solving the main game. Third, it communicates educational contents and help visitors focus their attention on them.

CONCLUSION

In recent years the cultural environment has undergone significant changes, mainly related to the actual role of cultural institutions and to the evolution of the end-users characteristics. As already mentioned, the main function of the museums is to communicate and exhibit the tangible and intangible heritage of humanity. The way to communicate such contents must meet the expectations of the reference audience, using the most appropriate tools available. In the last two decades, the role of cultural institutions has changed from a mere "container" of cultural objects to a "narrative space" able to explain, describe, and revive the historical material in order to attract and entertain visitors. These years witnessed a change in the characteristics of the users too. New technologies, the advents of Internet, the strong social changes have led to a reversal of users' needs and a strong demand for personalization of services and tools. Nowadays, people want to be constantly connected to their social networks, accessing information and creating their own. Moreover in a museum context, visitors are not satisfied with 'learning something', but would rather engage in an 'experience of learning', or 'learning for fun'. These changes require creating new exhibits, where the objective that museums pursue is reflected by the concept of Edutainment, Education + Entertainment. Hands-on and interactive exhibitions allow their visitors to interact with archive material, to learn while they play with it and to transform them from passive viewers and readers into active actors and players.

Recent advances in digital technologies offer archivists and exhibit designers new interesting and captivating ways to present and disseminate cultural objects, meeting the needs of personalization and interactivity requested by visitors and allowing to create novel exhibition paradigms, rich in those informative and emotional contents often missing in the classic ones. Particularly relevant, to this end, are the VR technologies, which offer the possibilities to reconstruct the original historical and artistic context around artefacts and provides an effective presentation layer which allows to access and display reach multimedia cultural contents and, at the same time, enforce the creation of meaningful connections among them. A strong support to the effectiveness of using Virtual Learning Environments (VLE) in the cultural context come from the constructivism theory, according to which people generate knowledge and meaning from the interaction between their experiences and ideas. Each of us constructs her/his own understanding of the world experiencing things and interacting with the surrounding environment. To this end, VLE are valuable tools due to their capability to involve and engage visitors, to allow a factual interaction with cultural contents, with past events and with places and spaces no more existing or no more accessible.

Based on these considerations the main objectives of this dissertation were:

- The study and implementation of VR and AR applications for Cultural purposes.
- The analysis and development of Virtual Learning Environment for education and entertainment.
- The study and development of novel interfaces for Virtual Heritage fruition.

The study and development of any Virtual Heritage application is a complex process, which can be divided in different steps. According to the step categorization proposed by Addison, this thesis was focused on the dissemination stage. This stage refers to the way in which contents are displayed and presented to users by means of interactive digital media. The actual implementation of the dissemination process can be extremely heterogeneous, according to the final goals of the cultural heritage project, to the characteristics of the target users, to the available tools and, of course, to the available budget. Thus, innovative devices and technologies, novel interaction paradigms, storytelling and gamification approaches and advanced methods for accessing and enjoying contents are the basic elements that nowadays developers of VH approaches can exploit to meet the users' interest, curiosity and expectations while, at the same time, guaranteeing the transfer of knowledge to the end-user and an effective, compelling and (why not?) funny user experience.

In the previous chapters we analyzed different dimensions of the problem through concrete projects, which were developed according to the guidelines outlined in *Chapter 2*. This development process was continuously revised and refined during the entire period of my research activity, and it ultimately allowed to analyze in detail several aspects related to the use of VLE as educational environments for cultural purposes.

During this dissertation we first discussed the problems related to presentation of historical and cultural content in their "*original*" context. In "standard" exhibits, heritage contents are generally disclosed to the public through simple presentations media, such as labels, simple comments, leaflets books or pictures. Their fruition is sometime negatively experienced by users as something complex, distant, boring or even not very instructive. Accompanying texts are often too narrow and not oriented to the wide public but written with specialists in mind. On the other hand, Virtual Reality technologies combine accurate 3D reconstructions with the provision of interactive environments, thus fostering users' immersion and emotional engagement. Through the recreation of the historical and artistic context of objects, users can better understand the relationships among cultural elements acquiring better knowledge of their cultural significance while having fun.

To this end, we discussed different projects aimed at investigating the various possibilities offered by VR, first identifying, through the analysis and prototyping of applications, the most suited (and actually achievable) solutions among the different platforms, systems, devices and software available. Online and offline applications, interactive and non real-time approaches and different application contexts were analyzed. One peculiar detail of this analysis was the identification of a wide set of open-source solutions that were positively exploited in all the steps of the development pipeline, providing high-quality of the results at an affordable cost, which, due to their budget-conscious attitude, is one of the main concerns of any cultural institutions. Moreover, usability studies have demonstrated that the proposed solutions would reach high level of appreciation for the audience.

In order to enhance the users' sense of presence in the VLE we specifically addressed three elements of a VR environment: its visual quality, its sound and its population with (more or less) autonomus agents. For the visual component, we investigated different approaches to reach photorealism ranging from high resolution models to Image Based rendering. As for the audio component, again we explored different solutions up to the offline-hyper realistic auralization of virtual environments and the integration of the data obtained into a real-time navigable environment, as in the*"Experience the soundscape of San Salvario district"* project. In particular, this approach was highly innovative and not largely discussed in the literature.

Concerning the problem of populating the environments, different approaches were explored. The most complex led to the development of VIRTUAL-ME, a library of autonomus characters whose behaviour is based on emotions, human needs, sensing capabilities, memory and goals. While all these aspects of the problem of emulating the human behaviour have been already discussed individually in the literature, it is quite rare to find an implementation encompassing all of them at the same time, as we did.

According to the Constructivist theories people have to build their own knowledge interacting with the world and the new information learned are generated by comparison between elements. Thus, we investigated methods that can foster the raising of such interconnections, from the integration of the digital contents related to cultural items into the virtual environments to the use of conceptual maps to support the meaningful discover of knowledge. In addition innovative ways of interacting with cultural database were also investigated. Usually, the information included into these databases have been collected with specialists in mind and require a specific knowledge to be accessed, thus hampering their use by non-professional users. Through the integration of cultural databases in VLE, we have created a new interface where users can naturally interact with items in the database by simply navigating their original context. To the best of our knowledge, the application of this idea in the cultural sphere is novel.

Another relevant aspect analyzed is the interaction design, which is relevant to enhance the effectiveness of any VR environment. We have mainly experimented with two innovative kinds of interfaces, TUI and NUI, which, in our projects, were exploited to allow users to interact with the system through physical objects or their own body. A particularly relevant outcome of our research was the development, through a usability design process, of a library of visual gestures to control and interact with the virtual environment which were the most usable and acceptable by the end-users.

We have also explored the mobile dimension, which is becoming more and more relevant in the cultural field. Mobile devices guarantee high computing power, can manage rich multimedia contents, geo-localization and high capacity communication capabilities. These features can be used to support users in mobility and detect the user context, thus allowing to develop a plethora of location-based services, from way-finding to the contextualized communication of cultural contents, aimed at providing a meaningful exploration of exhibits and cultural or tourist sites according to visitors' personal interest and curiosity. Besides supporting the users in outdoor environments, we also experimented novel methods to provide indoor localization and thus increasing the set of contexts where such applications can be usefully exploited.

Finally we have dealt with the question "How can we improve the users' engagement by using gamification approaches?". Gamification is a powerful tool that can be used in many different scenarios in order to create a better fruition of contents. Using game mechanisms it is possible to involve users in cultural activities, modifying the classical learning activity in a funny and effective experience. In our projects we tested different solutions in order to achieve this goal, obtaining in all cases positive feedbacks from users in terms of satisfaction and engagement.

In conclusion, I am pleased to emphasize that my research field is in greedy development. It is a recent multidisciplinary area, which involves computer science, history, art, economic and marketing, and it is also very challenging, since it requires studies of usability, accessibility, management and art-historical coherence. The relevance of Virtual Heritage in the forthcoming years is likely to increase in a relevant manner, thanks to the continuous technological improvements. For the future there are many challenges to face and they will go at the same pace with technological innovations. It is therefore difficult to trace the possible developments of VH, but we can certainly say that it actually is and it will increasingly represent a very relevant tool for presentation and fruition of historical contents. And I really hope cultural institutions can finally understand the strong advantages in the introduction of these technologies in museums.

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