The role of gaming industry and open source philosophy in the creation of affordable virtual heritage solutions

Chapter Number

The Role of Computer Games Industry and Open Source Philosophy in the Creation of Affordable Virtual Heritage Solutions

Andrea Bottino and Andrea Martina
Dipartimento di Automatica e Informatica, Politecnico di Torino
Italy

1. Introduction

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). Its main function is therefore to communicate the research results to the public and the way to communicate must meet the expectations of the reference audience, using the most appropriate tools available. During the last decades of 20th century, there has been a substantial change in this role, according to the evolution of culture, literacy and society. Hence, over the last decades, the museum's focus has shifted from the aesthetic value of museum artifacts to the historical and artistic information they encompass (Hooper-Greenhill, 2000), while the museums' role 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 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. 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 their 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, curators 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).

Despite its advantages, the diffusion of virtual museums and VH approaches has not been as wide as expected, due to several drawbacks. For instance, 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 two factors:

- the computer games industry drives technological advancement which is then used by other industry sectors. Demanding players require a constant increase of the visual realism and immersion, which in turns require a constant improvement of graphics hardware and CPU capabilities, and the availability of novel interaction devices that provide a better control, in terms of naturalness and usability, of the game reality. Furthermore, in order to allow a widespread diffusion of such products in the consumer market, their cost is kept as low as possible and often the hardware is sold at cost price while profits are made on the contents
- the increasing availability of Open Source software solutions, free to use and modify, allows to drastically reduce the costs of developing applications and creating the digital elements that will be displayed in the virtual exhibits, and facilitates a seamless integration of different interaction devices to provide a reach user experience

The rest of the paper is organized as follows. In section 2, we will show how the most recent contributions in these areas enable the development of affordable multimedia interactive application for enhancing the fruition of archive material and building effective edutainment exhibits. In section 3 the various types of virtual museums will be presented and analyzed. In section 4 we will show how computer game technologies and Open Source software can be used to design and develop all the elements of a virtual museum. Finally, in section 5 we will present the conclusions.

2. Affordable Virtual Heritage solutions: the enabling factors

Before tackling this point, let's first briefly introduce some basic concepts all the readers might not be familiar with. Virtual Heritage is mainly related with some key technologies, multimedia applications, Virtual Reality and Mixed reality, which are based on the idea of interactivity, offering different solutions for the user to interact with the technology itself, and obviously with the contents.

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 co-exist 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.

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 (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 PlayStation3 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 Museums (McLaughlin et al., 2000, Severson et al., 2002 and 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 mobile phones and PDAs. 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. In our case, they are particularly appealing for Virtual Heritage: users can receive audio explanations, complementary videos and images, text information and 3D graphics and, on the other side, users' activities can be mapped into and interact with a 3D virtual environment (Prasolova-Førland et al., 2007, Santangelo et al. 2006, Farella et al., 2005, Hope et al., 2009, Sauer & Göbel, 2003).

Concerning content creation and handling, until the last decade, the few available authoring and management tools 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 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 and designing and developing applications have reduced considerably. Furthermore, recent products emphasize the simplicity of use in order to allow their use 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.

3. What exactly is a Virtual Museum?

Virtual Museum is a general concept, appeared for the first time in 1991 (Tsichritzis et al., 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.

3.1 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, 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* that presents a chronological, geographical, and thematic exploration of the world Art history through the Metropolitan Museum of Art's collection (Fig. 1). 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.

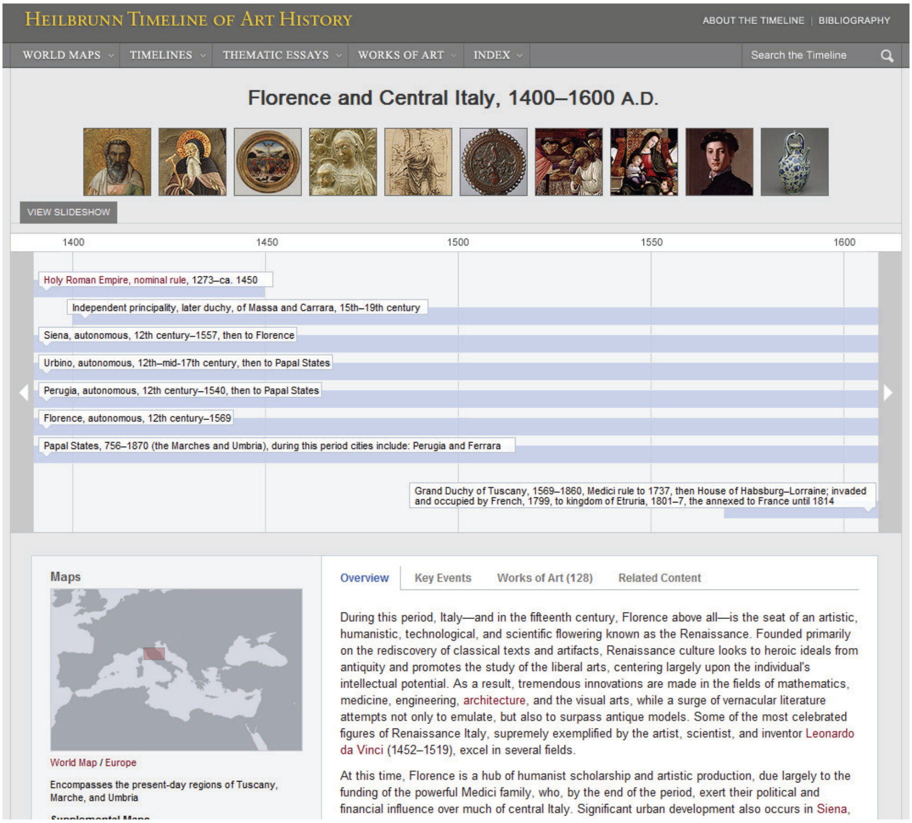

Fig. 1. The Heilbrunn Timeline of Art History in the Metropolitan Museum of Art's website.

3.2 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* (Fig. 2). 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.

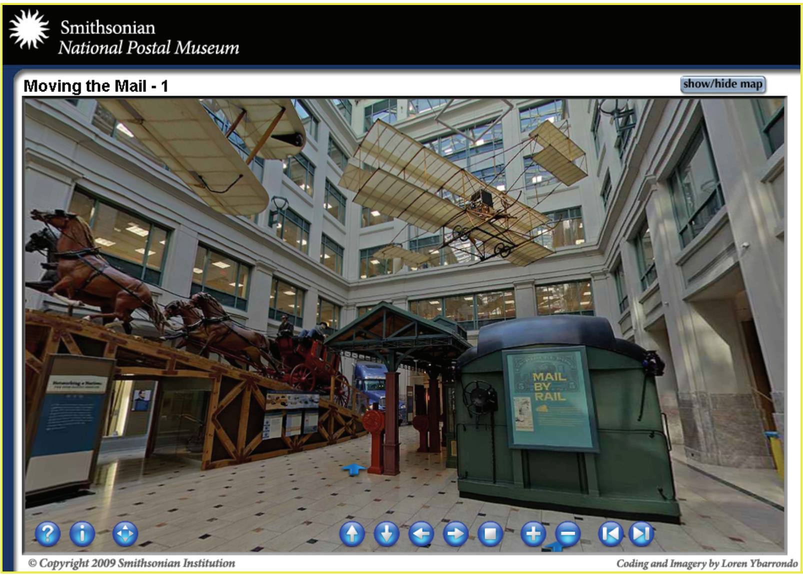

Fig. 2. The Smithsonian National Postal Museum online virtual tour.

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*, developed by the Polytechnic of Turin. The project focuses on the Sands in the 1964, one of the most prestigious and oldest casino in Las Vegas. The aim of the project is to entertain visitors by giving them the chance to spend a whole day in the Sands and to discover the stories and the characters behind the Fabulous Las Vegas. 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 (Fig. 3).

Fig. 3. The One day at the Sands online experience.

3.3 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*, which offers a SecondLife like exploration of historical sites virtual reconstructions from all over the world (Fig. 4).

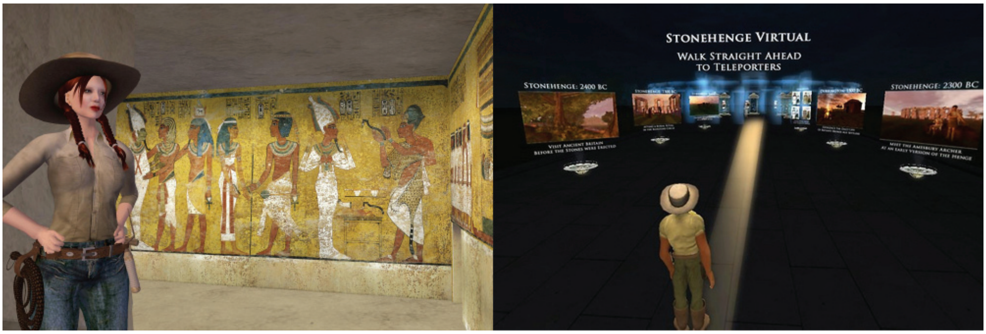

Fig. 4. The Heritage Key online environment.

The Danish Centre for Urban History has presented for the centenary of the *Danish National Expo in 1909* 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 (Fig. 5).

Fig. 5. The interactive 3D model of the Danish National Expo 1909.

3.4 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" (Styliani et al., 2009). 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*, 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 (Fig. 6).

Fig. 6. 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, offers 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 allow users to explore the environment through avatars, while the rest of the audience can follow their actions on a central screen, which displays also complementary visual and informative contents (Fig. 7).

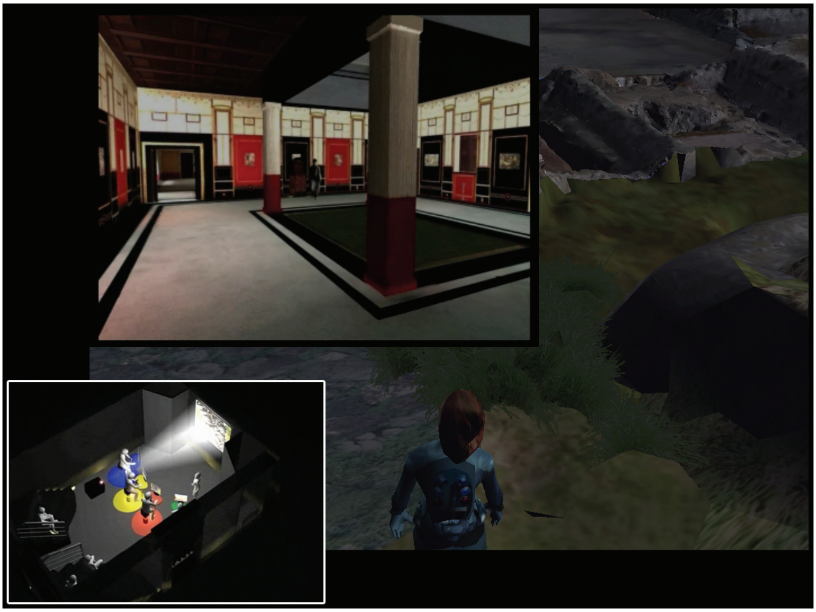

Fig. 7. A view of the Virtual Museum of the Ancient via Flaminia.

3.5 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 (Fig. 8), where people, looking a dinosaur's skeleton through a telescope can see an animation that overlap the bones with organs, muscles and then 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.
Another interesting application is *Streetmuseum*, released by the Museum of London. Users, installing Streetmuseum on their own iPhone, transform London into a huge open-air historical museum (Fig. 9). 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 iPhone, which acts as a window through time. Historical information connected to the images can be accessed tapping on the device screen.

Fig. 8. The Jurascope experience.

Fig. 9. The Streetmuseum application.

4. Developing affordable Virtual 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;
- 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.

4.1 Contents creation

The first step in building a virtual museum, whatever its final design and form will be, is the creation of all its digital elements. This process is often referred to as *Digital Content Creation* (DCC), and it 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 Museums 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 de-facto 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. As we have seen, video contents can be inserted into any virtual museum, from the content gallery to VR/MR environments. 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. Complex lighting, for instance, is better handled with external rendering engines.
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 (Fig. 10). 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 virtual museums.

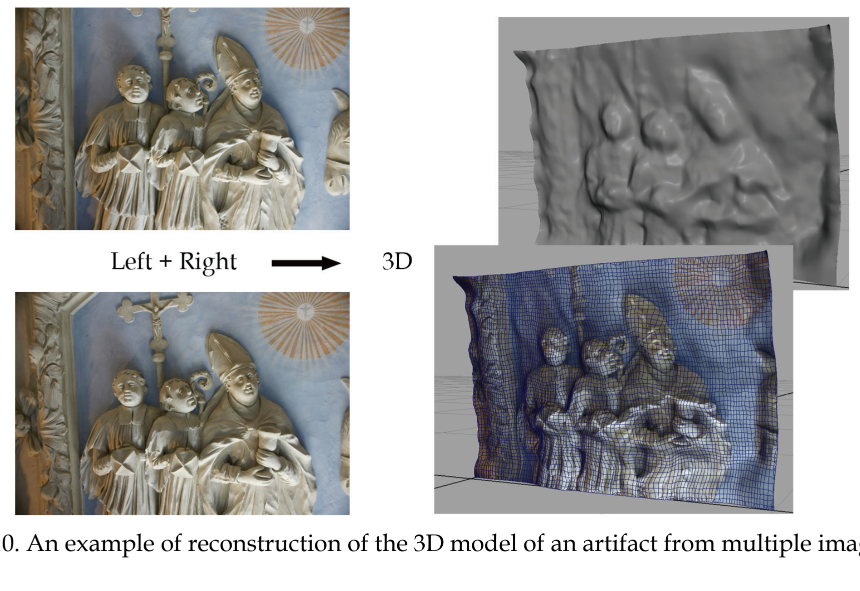

Fig. 10. An example of reconstruction of the 3D model of an artifact from multiple images

In order to produce high quality 2D images and animations from 3D models, several photorealistic renderers, like 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 museum 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.

4.2 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 behavior 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 and Cry Engine 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.

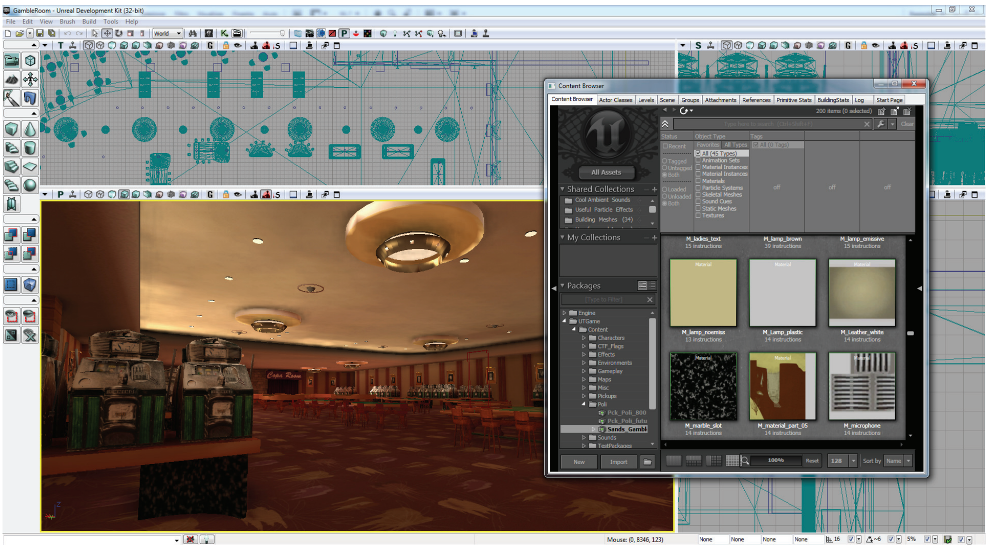

Fig. 11. The User Interface of the UDK, showing the virtual reconstruction of the Gamble Room, developed for the "One day at The Sands" application in Fig. 3

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).

4.3 Interaction design and development

The final step in creating a virtual museum it is to design and implement the interaction between the visitors and the VR system. For virtual museums that are accessible through Internet the interaction is clearly 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. 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, know 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 announced a new motion controller for the PS3, which looks like a wand with a color-changing ball on top and buttons to issue commands. It's designed to work in conjunction with the PlayStation Eye2, a low cost camera, to track its position. 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, and 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. Recently, Microsoft has announced the release of Kinect, a peripheral for the Xbox 360 console acting as game controller through gestures, spoken commands, or presented objects and images. The device will include a color camera, a depth sensor and multi-array microphone and is claimed to provide full body 3D motion capture and also face recognition. Many VH applications will benefit from this device as soon as the software libraries to interface it with other applications will be released. 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). As we have seen, 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 (Fig. 11) 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, and Hochenbaum, 2010).

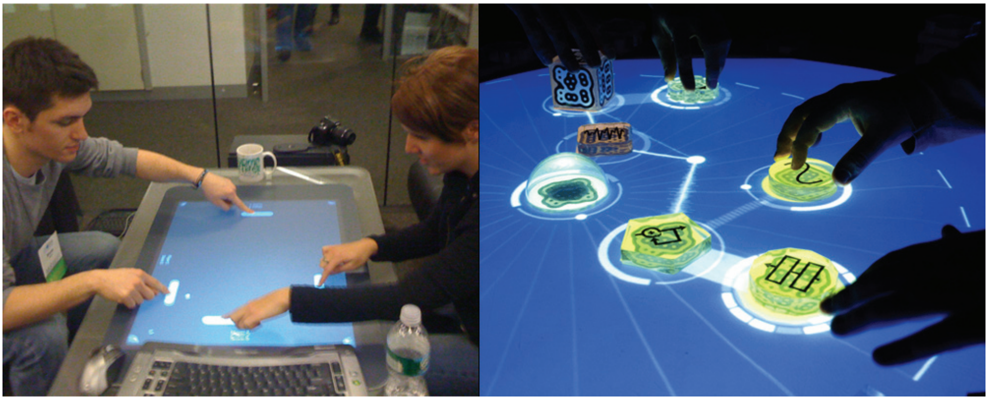

Fig. 11. Examples of interactive table (left) and use of fiducials for interaction (right)

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.

3DTV and 3D projectors are becoming largely available at a price slightly higher that 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. However, the recent announcement of the upcoming release of the Nintendo

3DS, the first autostereoscopic portable game console, shows that affordable solutions can be expected in the near future.

5. Conclusions

Virtual museums experiment the integration of cutting edge multimedia and VR/MR technologies with original archival material in order to create interactive, multi-user, mixed-reality edutainment environments. Cultural contents, enhanced through the use of technology, can be re-proposed in a captivating and engaging environment that allows visitors to learn something through an entertaining experience. This is particularly important for museums, which are facing a drastic change in their role, from mere containers of cultural objects to narrative spaces where the pedagogical level must be combined with the entertaining one.

The current potential of new technologies ensures that the digital artifacts are as communicative as the original. Therefore, ICT technologies can become a real tool for people working in museums since they are a valuable tool to help curators in the settlement of novel exhibitions, for instance allowing the creation of context and atmosphere around artifacts, or providing new dimensions and concepts for the arrangement of collections. Moreover, virtual museums allow developing versatile and scalable environments. Versatile means that they can range through contexts, events, purposes and physical environments, since the digital provides a permanent container, the technology, whose content has the possibility to be changed infinitely. Scalable means that the digital contents can be adapted to different media, from personal computers to mobile devices.

However, despite their advantages and potentials, the introduction of emerging technologies in museums and cultural contexts has not yet been as wide as expected. The main reason for this small infiltration is mainly related to the affordability of both their development and execution. Virtual museums impose heavy demands in terms of computational resources, require high quality interfaces, especially high resolution displays and suitable interaction devices, and the availability of software for designing, developing and managing the complexity of a virtual environment. All this comes with a cost. On the contrary, museums are often confronted to limited budgets, and therefore the development of affordable VH solutions is sorely needed.

In this paper, we have shown that recent dramatic advances in technology, in the computer games industry and in the OS software scene can help to reach these objectives. In fact, spurred by a demanding consumer market, game industries are constantly driving technological advances in the field of CPU and graphics processors in order to support new complex games with more and more advanced visual capabilities, and are in the front line for developing new interaction devices allowing to fully exploit the potentialities of 3D environments and to improve users' experience. A Game Engine, the software that forms the core of any computer game, is a perfect and cost effective all-in-one solution for developing complex VR applications, since it can handle all their aspects, without requiring a specific expertise in programming. Other Free/Open Source software solutions are largely available for designing and developing every component of virtual museums, from the creation of their contents, to the implementation and deployment of the final applications. As a result, the costs of creating digital contents can be reduced considerably.

Therefore, as we demonstrated in this paper, the development of effective VH solutions can be focused on using off-the-shelf components, low cost hardware and open-source software solutions. It is our firm belief that this will be the trend in VH in the next future, and that this approach, accompanied by further improvements in the technology and mainly in the field of computer games, will bring unthinkable benefits, as far as curators and archivists are concerned with the development process, to the widespread diffusion of new ICT-based approaches in cultural heritage.

6. References

Addison, A.C. (2000) Emerging Trends in Virtual Heritage, *IEEE MultiMedia*, Vol. 7, No. 2, Apr-Jun, 2000, pp. 22-25.

Anderson, E. F.; McLoughlin, L.; Liarokapis, F.; Peters, C.; Petridis, P. & De Freitas, S., (2009) Serious games in cultural heritage, *VAST 2009: 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage*, pp. 29-48

Bowman, D.A.; Coquillart, S.; Froehlich, B.; Hirose, M.; Kitamura, Y.; Kiyokawa, K. & Stuerzlinger, W. (2008). 3D User Interfaces: New Directions and Perspectives, *IEEE Computer Graphics and Applications*, Vol. 28, No. 6, Nov/Dec, 2008, pp. 20-36

Burdea, G. & Coiffet, P. (2003). *Virtual Reality Technology*, Wiley, 2003, New Jersey

Butler, M. & Neave, P. (2008). Object appreciation through haptic interaction, *Proceedings of the 25th Annual Conference of the Australian Society for Computers in Learning in Tertiary Education (ascilite Melbourne 2008)*, pp. 133-141, December 2008, Deakin University, Melbourne Vic Australia.

Caulton, T. (2002). *Hands-on exhibitions: managing interactive museums and science centres*. ISBN: 978-0-415-16522-8, Routledge, London

Chalmers, A. & Debattista, K. (2009). Level of Realism of Serious Games. *Proceedings of the 2009 Conference in Games and Virtual Worlds for Serious Applications*. ISBN:978-0-7695-3588-3, Washington, DC, USA

Deru, M. & Bergweiler, S. (2009). *Surfing Google Earth on Wii Fit*. http://www.psfk.com/2009/02/surfing-google-earth-on-the-wii-fit.html, last accessed July 2010

Encyclopaedia Britannica Online, available at http://www.britannica.com/EBchecked/topic/630177/virtual-museum, last accessed July 2010

Farella E.; Brunelli D.; Benini L.; Riccò B. & Bonfigli M. E. (2005). Pervasive Computing for Interactive Virtual Heritage, *IEEE MultiMedia*, Vol. 12, No. 3, July-September, 2005, pp. 46-58, ISSN:1070-986X.

Fassbender, E. & Richards, D. (2008). Using a dance pad to navigate through the virtual heritage environment of macquarie lighthouse, Sydney. *Proceedings of the 13th international Conference on Virtual Systems and Multimedia*, pp. 1-12.

Fikkert W., Hakvoort M., Van der Vet P, Nijholt A. (2009). Experiences with Interactive Multi-touch Tables. *Proceedings 3rd International Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN '09)*, pp. 193-200

Hirose, M. (2006). Virtual Reality Technology and Museum Exhibit, *International journal of virtual reality*, Vol. 5, No. 2 , pp. 31–36.

Hochenbaum, J.; Vallis, O.; Diakopoulos, D.; Murphy, J. & Kapur A. (2010). Designing expressive musical interfaces for tabletop surfaces. *Proceedings of the 2010 Conference on New Interfaces for Musical Expression (NIME 2010)*, Sydney, Australia

Hooper-Greenhill, E. (2000). Changing values in the art museum: rethinking communication and learning. *International Journal of Heritage Studies*, Vol. 6, Issue 1, (March 2000), pages 9–31.

Hope, T.; Nakamura, Y.; Takahashi, T.; Nobayashi, A.; Fukuoka; S., Hamasaki, M. & Nishimura, T. (2009). Familial collaborations in a museum. *Proceedings of the 27th international Conference on Human Factors in Computing Systems (CHI '09),* pp. 1963-1972.

Hoptman, G.H., (1992). The virtual museum and related epistemological concerns. *Sociomedia, Multimedia, Hypermedia and the Social Construction of Knowledge*, pp. 141–159

Hornecker E. (2008). "I don't understand it either, but it is cool" – Visitor Interactions with a Multi-Touch Table in a Museum. *Proceedings of IEEE Tabletop 2008*. pp. 113-120

ICOM News, no. 3, (2004), available at: http://icom.museum/pdf/E_news2004/p3_2004-3.pdf, last accessed July 2010

Jacobson, J. (2002). Configuring Multiscreen Displays with Existing Computer Equipment, *Proceedings of Conference on Human Factors HFES'2002*

Jacobson, J. & Lewis, L. (2005). Game Engine Virtual Reality with CaveUT. *IEEE Computer*, 38(4), pp.79-82.

Jordà, S.; Kaltenbrunner, M.; Geiger, G. & Bencina, R. (2005). The reacTable, *Proceedings of the International Computer Music Conference (ICMC2005)*, Barcelona, September 2005.

Juarez, A.; Schonenberg, W. & Bartneck, C. (2010). Implementing a Low-Cost CAVE System Using the CryEngine2. *Submitted to EC journal*.

Kaltenbrunner, M.; Bovermann, T.; Bencina, R. & Costanza, E. (2005). TUIO - A Protocol for Table Based Tangible User Interfaces. *Proceedings of the 6th International Workshop on Gesture in Human-Computer Interaction and Simulation (GW 2005)*, Vannes, France, 2005

Lanier, J. (2010). *The Top Eleven Reasons VR has not yet become commonplace*. Available online at http://www.jaronlanier.com/topeleven.html, last accessed July 2010

Lepouras, G. & Vassilakis, C. (2005). Virtual museums for all: employing game technology for edutainment. *Virtual Reality*. Vol. 8(2), 2004-2005, pp. 96-106

Masuch, M. & Röber, N. (2003). Game Graphics Beyond Realism: Then, Now and Tomorrow, *Proceedings of 1st Digital Games Research Conference, Utrecht, Netherlands, 2003*

McLaughlin, M. L.; Sukhatme, G.; Shahabi, C.; Hespanha, J.; Ortega, A. & Medioni, G. (2000) The Haptic Museum. *Proceeding of the Conference on Electronic Imaging and Visual Arts (EVA 2000)*, 2000.

Milgram, P. & Kishino, A. F. (1994). Taxonomy of Mixed Reality Visual Displays, *IEICE Transactions on Information and Systems*, Vol. 12, pp. 1321-1329

Noh, Z.; Sunar, M. S.; & Pan, Z. (2009). A Review on Augmented Reality for Virtual Heritage System. *Proceedings of the 4th international Conference on E-Learning and Games*, pp. 50-61

Packer, J. (2006). Learning for fun: The unique contribution of educational leisure experiences, *Curator: The Museum Journal*, Vol. 49, No. 3, 2006, pp. 329–344, ISSN 0011-3069.

Prasolova-Førland, E.; Wyeld, T. G. & Divitini M. (2007). Battle of Stiklestad: Supporting Virtual Heritage with 3D Collaborative Virtual Environments and Mobile Devices in Educational Settings. *Proceedings of Mobile and Ubiquitous Technologies for Learning (UBICOMM 07)*, pp. 197-203

Rheingold, H. (1991). *Virtual Reality*. Summit Books

Santangelo, A.; Augello, A.; Gentile, A.; Pilato, G. & Gaglio S. (2006). A Chat-bot based Multimodal Virtual Guide for Cultural Heritage Tours. *Proceedings of the 2006 International Conference on Pervasive Systems & Computing*, pp 114-120

Sauer, S. & Göbel, S. (2003). Focus your young visitors: kids innovation – fundamental changes in digital edutainment, in: M. Bergamasco (Ed.), *Proceedings of the Conference Museums and the Web 2003*, Charlotte, USA, Toronto, pp. 131–141

Scali, G.; Segbert, M. & Morganti, B. (2002). Multimedia applications for innovation in cultural heritage: 25 European trial projects and their accompanying measure TRIS. *Proceedings 68th IFLA Council and General Conference*

Schuemie, M. J.; Van der Straaten, P.; Krijn, M. & Van der Mast, A. C. (2001). Research on presence in virtual reality: A survey. *Cyberpsychology and Behavior*, Vol. 4, No. 2, 2001, pp. 183–201

Severson, J.; Cremer, J.; Lee, K.; Allison, D.; Gelo, S.; Edwards, J.; Vanderleest, R.; Heston, S.; Kearney, J.; Thomas, G. (2002). Exploring virtual history at the National Museum of American History. *Proceedings of the 8th international conference on virtual systems and multimedia (VSMM 2002)*, Gyeong-ju, Korea, 25–27 September, pp. 61–70

Stallman, R. (1999). The GNU Operating System and the Free Software Movement. In *Open Sources : Voices from the Open Source Revolution*, O'Really publishing, 1999

Sylaiou, S.; Liarokapis, F.; Kotsakis, K. & Patias, P. (2009). Virtual museums, a survey and some issues for consideration, *Journal of Cultural Heritage*, Vol. 10, No. 4, October-December 2009, Pages 520-528

The International Council Of Museums. ICOM statutes, 2007

Tsichritzis, D. & Gibbs, S. (1991). Virtual Museum and Virtual Realities. *Proceedings of the International Conference on Hypermedia and Interactivity in Museum.*

Valli, A. (2008). The design of natural interaction. *Journal of Multimedia Tools and Applications*, Vol. 38, No. 3, July 2008, pp. 295-305

Weiser, M. & Brown J. S. (1995). Designing calm technology. *Xerox PARC*

Wojciechowski, R.; Walczak, K.; White, M. & Cellary, W. (2004). Building Virtual and Augmented Reality Museum Exhibitions. *Proceedings of the Web 3D 2004 Symposium – the 9thInternational Conference on 3D Web Technology, ACMSIGGRAPH*, Monterey, California (USA), pp.135–144.

Xin, M., Watts, C., & Sharlin, E. (2007). *Let's get physical: How physical control methods make games fun*. Technical report, Computer Science Department, University of Calgary, 2007-849-01, January, 2007.

Zyda, M. (2005). From Visual Simulation to Virtual Reality to Games. IEEE Computer, Vol. 38, No. 9, Sep. 2005, pp. 25-32