DESIDOC Journal of Library & Information Technology, Vol. 33, No. 3, May 2013, pp. 222-235


# 3D Virtual Exhibitions

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**ABSTRACT**

The virtual recreation of a physical three dimensional (3D) exhibition or museum allows a visitor to navigate in this virtual scenario in a way closer to reality. This issue is particularly relevant when the museum building is by itself a piece of art, as it is often the case. In this paper, the use of virtual 3D models in the domain of cultural diffusion is analysed, considering the common aspects of its application either for collections of museum's or for buildings and artifacts deteriorated or destroyed along the time. A wide range of applications are presented to exemplify the different requirements and techniques that can be considered in this domain. Techniques to create 3D models are reviewed as they are the base to generate a virtual environment and special attention is given to applications devoted to the development of 3D virtual museum exhibitions.

**Keywords:** 3D modeling, virtual exhibitions, virtual museums

## 1. INTRODUCTION

The creation of three dimensional (3D) virtual exhibitions is valuable in distinct contexts, i.e., as a medium to conceive exhibitions and as a way to promote museums and cultural places to the public worldwide through the web or in educative and recreational activities performed on-site. A curator of a museum and his staff can interactively use a 3D virtual model to prepare physical exhibitions, for instance, to essay different locations for the pieces of art or to choose which pieces of a collection should be exhibited to the public. This approach is economically and functionally attractive and supports remote collaboration of team members. Besides, it can be used as means to spread art collection of the museum mainly when some masterpieces cannot be visited by the public, due to conservation concerns, space constraints or temporary unavailability.

Software tools associated with creation of virtual exhibitions should be accessible to the museum staff, which is not expected to be composed by experts in information technology. Moreover, these tools should produce realistic models without requiring sophisticated and expensive equipment.

## 2. ONLINE EXHIBITIONS

In the 1960's, André Malraux, a notable French intellectual, in his book 'Le musée imaginaire' proposed the idea of a 'museum without walls', a museum that makes its contents available to both on-site and remote visitors. This author based his idea of museum in photographic reproductions which made thousands of galleries and exhibitions available to visitors all over the world[1]. All technological developments that took place since then have provided the means to raise the concept to a higher level and to a broader scope.

Around the globe, there are open museums to remote visitors through the web, supporting real-time and interactive access to simultaneous users, 24 hours a day, and 7 days a week. Even those visitors who are not able to visit a specific museum in loco, can get acquainted to its collection through the museum website. This is, beyond any doubt, a democratic cultural achievement.

A main goal of most museum web sites is to attract visitors to the museums. Consider the Louvre Museum in Paris, one of the world's famous museums. It's website received between 2002 and 2004 nearly six million online (or remote) visitors, almost as many as the local visitors[2]. According to this site, online visitors fall into four categories: visitors planning a future visit to the museum in Paris; internet users all over the world that want to find out more about the collections of the museum but without necessarily making a trip to the Louvre; students and specialists looking for in depth information about museum collections; and casual online visitors and the young people. This last category constitutes the main target group; the website is intended to encourage the visitors to visit the Louvre museum.

Received 28 January 2013, revised 14 May 2013, online published 20 May 2013

Besides this attracting factor, virtual visits are also valuable in other contexts, namely:

- To extend the period of an exhibition: a temporary exhibition can survive longer if a virtual visit is conceived to reproduce it and continues to be available after the dismantling of the real exhibition. This can be extremely interesting when the exhibition involves seldom exposed pieces, temporarily lent by private collectors or by different museums probably spread around the world. Some of those pieces integrate the so-called 'exhibitions on tour'[3].
- To examine exact virtual replicas of existing spaces or master pieces that can not allow site visitors due to the risk of deterioration or simply because there is not physical space in the museum to expose them.
- To provide additional information or experiences to on-site visitors before or during their visit to the museum. For instance, a virtual visit can give the possibility of looking at paintings on the screen, finding out additional details and creating their own tour through the museum.
- To get inside recreated virtual models of cultural and historical places or buildings that no longer exist or that have suffered considerable changes throughout time. This is usually implemented using installations (kiosks) on specific places. When placed outdoors, these installations are a sort of museums that can be called 'museums without buildings'[4].

The most common approaches to presenting museum collections are html pages containing photographs, text and links to other pages. The use of panoramic photographs, like those based on QuickTimeVR[5], is frequent. These photos offer a 360º view of the space around a fixed location, giving a sense of immersion. Immersive photographs extend further this sensation, offering the possibility of viewing also 180º in the up and down directions. Although creating a feel of immersion inside the exhibition space, these photographs do not allow free navigation inside it. In order to visit the space, the user has to select, in an interactive 2D map, pre-defined observation points[6,7]. Using such contents, the curator can highlight the best pieces and the most attractive visual angles, performing a good marketing task; the user, having no opening hour or any other time constraints, can visit the best locations obtaining a good insight to the physical space of the museum and its master pieces of art.

However, to achieve a more intense sense of immersion, allowing free navigation inside the exhibition space, it is necessary to create 3D models of the exhibition[8,9].

Three dimensional virtual exhibitions provide a compelling environment to recreate the navigation in the physical ambience of a museum. The digital reproductions of the artworks can be seen side by side in a 3D environment making possible to get an idea of their dimensions. This can not happen when the objects are shown individually as images in a web page. Moreover, in the case of a 3D artwork, a virtual navigation allows to view the object in the round[10]. Despite its advantages, creating 3D virtual museums is not an easy task. It requires modeling the 3D virtual space and digitising the artworks. After that, it is necessary to integrate the artworks in the virtual space, either as a reproduction of an actual exhibition or as a virtual exhibition conceived with the purpose of promoting the collection of the museum. These tasks usually require specific tools and informatics expertise, which can be an obstacle, as domain experts, like museum curators, who should create the contents of an interactive exhibition, are not supposed to have informatics skills. Another drawback that can be pointed to virtual exhibitions is that they hardly achieve a photorealistic quality in order to maintain a real time interactivity.

However, some tasks do not demand photorealism and can benefit from a 3D environment where the relative dimension of objects is kept. This is the case of the early stages of conception of an exhibition where it is important to decide the placement of artworks and be aware of object size and available space. Thus an interactive tool for assisting the placement of artworks in selected locations is indubitably a valuable tool for any museum staff to mount a new exhibition. Besides that, the final result is a virtual exhibition which can be available on a website.

In a virtual visit, the navigation inside a 3D virtual space should be performed interactively and in real time, giving the participant the sensation of being inside the recreated space. The intensity of this sensation, called immersion, depends on two main factors:

(i) Imagination of the visitor, and
(ii) Sophistication/quality of the technological device that supports the virtual visit.

There are two kinds of immersion - mental immersion and physical immersion, both are important in order to achieve a successful experience. Mental immersion is the kind of sensation one may experience even when one read a novel, a fiction book or when one plays a video game, that is, when the imagination is being pushed and defied.

Physical immersion depends on the technological installation which exhibits a virtual world. It changes in real-time following body movements or explicit interactions like switching off a lamp or using a knob to open a door. Moreover, one or more senses are stimulated. This total sensory immersion requires wearing a device like a head mounted display, 3D polarising stereoscopic glasses, or a glove to create a feeling of control in actual space[11]. Gaitatzes[12], *et al.* described several examples of immersive virtual reality presentations developed by the Virtual Reality Department of the Foundation of the Hellenic World. However, the most usual virtual reality presentations only relay on mental immersion and are characterised by the display of a 3D environment on a 2D screen.

In the cultural domain, 3D virtual environments can recreate historical sites. The virtual model of a building is sometimes the only way to view the changes regarding architecture of a building over time or its appearance before damage caused by weathering, natural disasters or wars. These virtual reconstructions have in common with museum virtual exhibition the aim of cultural diffusion and also the techniques used both for 3D reconstruction and presentation.

## 3. BUILDING 3D VIRTUAL MODELS

Rendering 3D images can be accomplished without building an explicit 3D geometric representation. This is the case of the images generated using image-based rendering techniques, which take as input a set of images. Although there is a wide range of image-based rendering techniques, that justify its classification in a continuum between images and images combined with geometry[13], common examples of this technique are the panoramic views based on QuickTime VR[5]. These views are generated with computer rendering of panoramic photography or stitching a mosaic of overlapping photographs. In the latter case, the pictures are taken with a camera, in a stationary viewpoint, as it rotates about its vertical axis in one direction only. The adjacent pictures need to have some overlapping in order to be matched and blended. Walking in space is accomplished by jumping to another panoramic view generated with a different viewpoint. In addition to panoramic viewing, it is also possible to simulate the rotation about an object, that is to say viewing of an object from different directions. This technique allows displaying high quality images independently of scene complexity, as it uses real-world scenery directly.

Nevertheless, the ability to move freely around the scene and observe objects from any position can be limited and, in complex environments, object occlusions and discontinuities can affect the output[14]. Moreover, it is not possible to simulate different lightning conditions to recreate other ambiences or to insert new objects into the scene.

Hence, to provide an immersive virtual environment, the first step is to create its 3D geometric model. Different techniques can be used to achieve this purpose. The model can be built from scratch, using 3D modeling tools, or it can be based on 3D scanning systems (range-base modeling) or on images of the object (image-based modeling). As they create models from real objects and/or environments, image-based modeling and range based modeling allow some sort of automation not possible with 3D modeling tools. Although requiring more expensive equipment, in range-based modeling the 3D coordinates of the objects' surfaces are provided directly from active sensors, while in image-based modeling further processing is required to obtain the 3D coordinates from images[14].

Often none of these techniques can fully satisfy the requirements of large-scale environments for applications in the domain of cultural heritage. Therefore, multiple techniques can be combined to produce detailed 3D reconstruction. That is the case of the virtual reconstruction of Abbey of Pomposa, near Ferrara, Italy, described by El-Hakim[15], *et al*. Laser scanning can provide all the details, but for large buildings it produces a huge number of points even for flat surfaces. On the other hand, image-based modeling is less efficient for irregular or sculpted surfaces. So, image-based techniques were used to capture the basic shapes and then the detailed elements, obtained by laser scanning, were added to the global model that was previously created from images.

### 3.1 3D Modeling Tools

The 3D modeling tools, like CAD software, are an option to build 3D models based on drawings, on blueprints and/or on site measurements. When dealing with archeological sites, this is actually the unique solution as the building or object no longer exists. In this case, paintings and text documents are valuable sources of information to complement on site measurements. Although time consuming, these tools do not require expensive hardware. The resulting model is often scarce on details, not providing a realistic appearance but it can be improved by applying texture mapping. There are several examples of virtual reconstructions using 3D modeling tools. For instance, Semião and Carmo[16] presented a virtual gallery built with Autodesk AutoCAD[17]. Other modeling tools are also referred, like 3DS Max[18] used to model the Monastic complex of St. Andrew, in Norwich, UK[19], or Maya[20] employed to recreate the Mosque of Córdoba, in Spain[21], to model the Panagia Angeloktisti, a Byzantine church located in Cyprus[22], or to reconstruct the ancient Egyptian temple of Kalabsha[23].

### 3.2 Range-based Modeling

The 3D scanners acquire the 3D coordinates of numerous points on surface of the objects, in a relatively short period of time, obtaining a 'cloud of points'[24]. To obtain a 3D model, these points must be converted into a mesh of triangles. This requires three steps: the merging of different clouds taken from different locations to complete the object; the elimination of inaccurate points; and the triangulation operation, which corresponds to find the best way to connect the 3D points to create triangles. Finally, to achieve a photorealistic appearance, it is necessary to color the surfaces of the triangles in a way that mimics the original object. This can be accomplished with texture mapping, using textures obtained with digital cameras attached to the scanning device or from external digital imaging systems.

To merge several 'cloud points' it is necessary to convert all the points into a unique coordinate system–the registration process. This consists in matching common points in the adjacent clouds and estimating the rigid transformations–rotations and translations–needed to align them. The matching process can be based on high–reflective targets placed in specific points to allow the estimation of the involved rotations and translations of the equipment[25].

Data acquisition can be performed using two different approaches: triangulation based sensors or time of flight based sensors[24]. Triangulation based sensors project light in a known direction, from a known position, and measure the direction of the reflected light through its detected position[15]. Since measurement accuracy depends on triangle base relative to its height and triangle base is rather short for practical reasons, these systems have a limited range of less than 10 m. Time of flight-based sensors measure the delay between emission and detection of the light reflected by the surface. These sensors provide accurate measurements at long range and the range accuracy is relatively constant for the whole volume of measurements, hence they are the preferred choice for large structures[26]. This means that each scanner is intended for a specific range.

Despite being an expensive technology, it is an expeditious way to create a 3D model either of large buildings or of detailed artworks. Visintini[25] *et al*. have described the use of a terrestrial laser scanning (TLS) and photogrammetric integrated surveying to obtain a photorealistic 3D model of the Church of Saint Anthony Abbot in San Danieli del Friuli, North-Eastern Italy, both inside the church and outside for the main gothic facade. Texture mapping was performed automatically using the photos obtained by the camera. As it was fixed onto the TLS top, the position and orientation taken by each image was known. The obtained model was converted to VRML/X3D and organised in two levels of detail (LOD) to allow fluent web navigation with high detail whenever needed.

Data acquisition with 3D lasers scanning technology is also referred in[27] used to build the virtual model of the cathedral of Notre-Dame de Paris, France. More detailed areas, such as the three portals, the Kings Gallery and the Virgin Railings, were acquired with two spatial resolutions, both of them were more accurate than the resolution used in the rest of the monument.

As mentioned before, range-based techniques can acquire very detailed surfaces, which make them suitable to build 3D models of small works of art, such as jewellery, ornaments, decorated weapons or statues. This is the case of the work presented by Przybill and Peipe[28] that describes the range based techniques and equipment used to model several objects, like crosses, swords, crowns or statues belonging to the treasure of the Essex cathedral, Germany.

### 3.3 Image-based Modeling

Image-based modeling methods use 2D image measurements or correspondences to recover 3D geometric information. Besides photogrammetry, which means extracting measurements and 3D data from photographs, 3D models can be obtained from images with techniques that recover shapes from shading, from texture, from specularity, from contour or from 2D edge gradients[14]. Usually, multiple views are required to acquire 3D measurements. Photogrammetric applications, like Photomodeler, recommend to get reference points at least on three photographs and to get as much overlap ping between adjacent photographs as possible. However, accuracy improvements become less significant when a point is measured in more than four images[14].

Image-based modeling process consists of several steps such as design of sensor and network geometry; 3D measurements; structuring and modeling; texture and visualisation.

The network of sensors should be carefully designed to optimise the accuracy of 3D point measurements. This includes the selection of the suitable cameras, the image measurement scheme, the imaging locations and orientations. This step defines imaging geometry and influences camera calibration, that is, the setting of camera parameters, like focal length or digitising scale.

The measurements step is necessary to obtain the 3D coordinates of the acquired points. It can be performed applying manual or automated procedures. The latter usually rely on constraints and area-based or feature-based matching techniques. Manual procedures can produce more reliable measurements but recover a small number of points for each object, since they are time consuming. After image measurements, the matched 2D coordinates are transformed into 3D object coordinates taking into account the parameters of the camera.

A dense point cloud can be obtained, like in range-based methods, using stereo images, that is, a pair of photographs being close to parallel but separated horizontally, taken to an object or to a scene. This technology is called photo-based scanning, or photogrammetric scanning[29]. While laser scanners usually produce their 3D point data in real-time, photo-based scanning produces point clouds as a computation. Computer vision stereo matching techniques are used to match the same patch on a pair of photographs and 3D coordinates are calculated using triangulation[24].

After obtaining 3D point coordinates by image measurements, it is necessary to create a surface description of the objects. Commonly, as explained before, a triangular mesh is generated through a triangulation operation. Afterwards, to obtain a more realistic appearance, the surface must be colored as close as possible to the object it represents or texture mapping can be applied.

Photogrammetric techniques allow combining information from different periods in time using recent and archive images, as reported by Grussenmeyer and Yasmine[30] about the construction of the virtual model of Beaufort castle, in Lebanon. The goal was to make a 3D restitution of the structures destroyed during the war. Photographs taken between 1935 and 1937 by the French army were combined with recent terrestrial and aerial views of the castle.

Due to irregularities of the terrain, acquiring images is not always an easy task. To surpass this difficulty, in the restitution of Perlo Castle, Italy, aerial photographs were taken using an unmanned aerial vehicle–a mini-helicopter[31]. The aerial photogrammetric survey was performed using a camera positioned in the lower part of the mini-helicopter. It was possible to orient the camera in different directions during the flight and to perform remote controlled shoots.

Despite the advances in 3D modeling reconstruction, further investigation to improve 3D acquisition is still needed, as evidenced by on-going research projects that embrace this topic, like 3D-COFORM (Tools and Expertise for 3D Collection Formation)[32]. This project aims to contribute 'for the sustainable deployment of 3D-acquistion, manipulation, analyses and communication of 3D digital artifacts in real-world practice'.

A noticed limitation in 3D acquisition, that this project wants to overcome, concerns the range of artifacts that cannot be captured accurately due to their material properties, like reflectance.

## 4. 3D VIRTUAL MODELS IN CULTURAL HERITAGE

Virtual reconstructions of 3D models are used both for the museum exhibitions and for cultural sites. In cultural site, when the buildings and artifacts are severely damaged, virtual models are the best mean to visualise their former appearance. So there are several examples of virtual reconstructions of archeological sites or historical buildings destroyed along the time by natural causes or as result of wars. The technologies used depend on: the target audience–researchers or a broader audience; the medium of the exhibition–through the web or on site installations; the reconstruction context – architectonical focus and/or reproduction of traditional customs. For instance, Web3D technologies[33] based on VRML and X3D are often used for diffusion through the web. However, when the aim is to obtain realistic environments similar to real world images, software with more sophisticated renders is needed. On the other hand, on-site exhibitions can take advantages of augmented reality techniques that present virtual reconstructions superimposed on captured images of the real environment.

To provide interactive visualisations of 3D environments through the web, several authors have been using Web3D technologies. For instance, 3D MURALE system[34], which comprises a large set of functionalities to deal with data of archeological sites, also includes a component to provide visualisations through the web based on VRML. This system comprehends tools that support several tasks required in the investigation of data from archaeological artifacts, monuments and sites, like recording, reconstruction, encoding, data querying and visualisation. The ancient city of Sagalassos in Turkey has been used as a test case for this system. In the following sections are described works focused on more specific problems related to the use of virtual reality in the cultural context.

### 4.1 Visualisation of Temporal Evolution

Hetherington *et al*. have addressed the problem of displaying temporal evolution of archeological sites[35]. They proposed an approach for 3D models using a single X3D file containing both geometric data, like structures and buildings, and data about evolution over time. The temporal data is embedded within the X3D file using metadata nodes. This solution was used to show three different stages of Stonehenge site, in UK. The model is displayed in a webpage and each state of the model associated with temporal data is displayed by clicking on hyperlinks. El-Hakim *et al*. have also used a single X3D file containing all the models from different times but their goal was to provide an animation over time, that is, to simulate navigation within a virtual 4D world[36]. To produce a smooth transition over time, the levels of opacity or transparency of the virtual model components are adjusted according to what should be visible in each period in history. The interaction is controlled by a time slider used to select a time period. Alternatively, a static visualisation is also provided to allow the user to observe the different models. Video, audio, and images can be linked to these presentations and shown in a different window to supply additional information.

The use of transparency to visualise changes occurred along the time[36], as exemplified with Stenico Castle, in Northern Italy, was based on the work presented by Zuk[37], *et al.* that suggests visual cues to communicate metadata. They have focused on techniques to express both temporal and visual appearance uncertainty in interactive 3D scene reconstructions. The uncertainty arises mainly from missing data and virtual reconstructions should transmit its speculative nature. Several visual encodings are proposed to convey spatial and temporal uncertainty[37], such as transparency, wireframe representation or rising/sinking animation, that is, an animation that corresponds to a form of displacement of the objects that raise some doubts. The lack of complete data leads also to the consideration of possible alternatives[19]. So, in addition to different representations along the time, Laycock[19], *et al*., have developed an interactive technique for the exploration of alternative interpretations of cultural heritage. This technique was applied to the interpretation of St. Andrew's Monastic complex, Norwich. The user may navigate along the time observing the evolution of the monastic complex. Since the start and end times for an objects' time period are not always completely determined, different levels of transparency are used to enable the visualisation of potentially overlapping time periods for the objects in the scene. Furthermore, to analyse different hypotheses in a given time period, alternative reconstructions for that time period may be selected.

### 4.2 Recreation of Ancient Traditions: Virtual Characters

Besides buildings, cultural heritage comprises also customs. The reproduction of religious or social traditions enriches virtual reconstruction. Ramic-Bric et al. combined the virtual reconstruction of the Church of the Holy Trinity, in Mostar, destroyed during war in Bosnia and Herzegovina[38] with captured images of an Orthodox priest. In this case, the priest tells short stories about the history of the church and important interior objects that were there. His presentation was recorded against a green screen background to enable to process the image and remove the background. The 3D model of the Church was described in X3D format and the image sequence was associated to an object of the scene that would display it. The sound captured was synchronised with the images and, to enhance the immersion of the viewers, traditional church music is also played in the background.

The recreation of the way people lived in the past can be simulated using virtual human beings. Maim *et al*. populated a virtual reconstruction of Pompeii, Italy, with crowds of virtual Romans to simulate life in the streets and houses before the eruption by the volcano Vesuvius[39]. The goal was to generate a real-time simulation with virtual human beings exhibiting realistic and varied behaviors. To accomplish this goal, the virtual reconstruction of the city was annotated with semantic data. This data is automatically interpreted by the virtual human beings to trigger special behaviors, according to the location of the characters. Their motion is based on a navigation graph which is automatically generated from the 3D Pompeii geometry, including in its vertices the semantic data that influences the behavior. Seven human templates were created to perform distinct roles and, to create large crowds, several instances of these templates were generated. To obtain a more compelling result, different techniques were used to color their bodies and clothes.

Pietroni and Antinucci[40] described application of the recreation of virtual environments with virtual human beings in the context of cultural heritage. Based on the painting 'The Rule Confirmation' painted by Giotto in the Upper Basilica of St. Francis of Assisi, Italy, at the end of the XIII century, a 3D virtual environment with all the characters in the scene was recreated. The interaction with this environment helps in the study of Giotto's perspective construction in comparison with the way one conceives perspective nowadays. Besides supporting the spatial and perspective investigation of Giotto's fresco, this recreation was also the basis of an interactive installation to involve the visitors in the scene portrayed by Giotto. The scene was brought to life with an animation where the characters performed the action represented in Giotto's painting. In addition, when the animation stopped, a tracking system identified the movements of the visitor who was in front of the projection area. As the visitor moved, the image was updated according to his new viewpoint, simulating walking in the scene.

### 4.3 Reproduction of Ancient Lightening for Visual Realism

Accurate virtual simulations of historical sites can provide new insights of how these spaces were used, 'enhancing our understanding of the conditions in which our ancestors lived and worked'[41]. The need to create more realistic virtual environments led to the development of new methods to simulate interior lighting of historical sites. More than generating scenes with an authentic visual appearance, it is required that they are perceptually equivalent to the real scene in the past. This means that our perception of past environments should consider the lighting conditions of that time: the use of natural daylight and the use of flames with different fuel types[41]. The perception of color is affected by the amount and nature of light reaching to the eye, so Devlin and Chalmers conducted a study to identify the characteristics of light sources used in the past, such as the olive oil lamps. Using a spectroradiometer, they gathered data about the spectral characteristics of the light of olive oil lamps under different conditions, for instance, adding salt or water to the lamps. After that, the spectral values were converted into RGB values used in computer monitors. The effect of different kind of lighting sources was tested in a recreation of a room with frescoes of the House of the Vetii in Pompeii, Italy. The perception of the frescoes was noticeably different when illuminated by simulated olive oil lamps and when viewed with simulated modern lights. Using a similar approach, Gonçalves[42], *et al.,* analysed the spectral characteristics of olive oil manufactured with old traditional methods[42]. The light obtained with this oil has lower intensity than the one got with oil produced with in a modern mill. They have also explored the capabilities of high dynamic range displays, which allow broader ranges of luminance and color, to produce high quality images. As a case study, they recreated a room with frescoes from a house in the Roman ruins of Conimbriga, Portugal.

Kider[21], *et al*., studied how to reproduce the interior lighting of early Islamic buildings, like the Mosque of Córdoba through the 8th to 10th century. Although none of the original lamps of this site had survived, through information gathered by historian experts on other contemporary sites, they assumed that single jar lamps were used. The light produced by these sources reflects the combination of glass, water, fuel and flame. The authors conducted a series of experimental studies to investigate and validate how various glass fixture shapes, water levels and different mounting heights could affect overall light patterns and downward lighting. Based on the results of these studies, they developed a technique, called Caustic Cones, to simulate the light produced by these lamps in a virtual model of Córdoba's Mosque, trying to recreate the ambience of the past.

Besides interior lighting, outdoor day lighting also contributes to the total illumination. In dark interior cultural heritage environments, like Byzantine temples, the majority of the light inside the church comes from inter-reflection of sunlight[22]. In this case, sunlight has a major visual impact generating directly lit areas and sections in deep shadow. In addition, the scene illumination also changes substantially at different hours of the day. Using a virtual reconstruction of Panagia Angeloktisti, a Byzantine church located in Cyprus, Happa,[22] *et al.,* investigated an approach to the interior lighting using high dynamic range environment maps of photographs and interpolated spectrophotometer data collected on site[22].

The effect of day light was also investigated by Sundstedt[23], *et al.* in the virtual reconstruction of the ancient Egyptian temple of Kalabsha. When the Aswan High dam was constructed, this temple was dismantled and moved to a new location to avoid its disappearance under the waters of the Nile. As the orientation of the Egyptian temples was carefully chosen, the virtual reconstruction allows simulating the orientation of sun rays as they occurred in the original position and orientation of the temple. To achieve a more accurate reproduction, the texture of the materials used in the temple was reproduced and the hieroglyphs drawn on the walls were represented in 3D. To light the interior rooms, the authors reproduced the characteristics of olive and sesame oil lamps as Devlin[41], *et al.* did. This kind of light produces significant differences in the visualisation of colored hieroglyphs. The lighting model of Kalabsha temple was improved taking into account the effect of light scattering due to participating media, such as dust in the atmosphere[43]. In rooms with small windows and practically no direct sun light entering, the participating medium plays an important role in the transport of light throughout the scene. Despite increasing severely rendering times, the simulation of the influence of dust from the sandy environment creates a new luminance distribution and a better perception of the original ambiance.

Furthermore accurate physically based simulations of light on virtual environments can be used to investigate about the optical effects of polychromic buildings, namely on medieval churches[27]. These authors conducted a study using a virtual reconstruction of Notre-Dame de Paris, France, with polychromatic restitution based on the remains found on sculptures, on some architectural details and on research on the classical organisation of the paint layers used for this purpose. Their aim is to understand the complex relationships between light, paint, and gilt.

## 5. VIRTUAL MODELS AND AUGMENTED REALITY

Virtual models can be mixed with images captured from real world. Augmented reality is a variation of Virtual reality that allows the user to see the real world with virtual objects superimposed upon or composited with the real world[44]. This technique has been explored either inside the museums or in the open-air in archeological sites. On-site virtual reconstructions can be presented outdoor in real environments to substitute physical rebuilding of historical remains, which could interfere with archeological research. These presentations help the visitor to understand and experience the past through the representation of virtual reproductions of monuments over their archeological remains. These augmented reality experiences have been tested either using on-site kiosks or with mobile equipments.

### 5.1 Augmented Reality Outdoor Experiences

At the archeological site of Ename located in the province of East-Flanders, in the Dutch speaking region of Belgium, an on-site kiosk offers the visitors a virtual reproduction of the Benedictine abbey over its exposed foundations[45]: a 3D model of the abbey church is superimposed over a real-time video of its remains. The kiosk can also provide multimedia presentations that convey local historical information.

A more challenging approach in augmented reality experiences is mobile presentations. In this case, a new problem arises: as the user moves freely, it is necessary to track his position and viewing direction to integrate virtual reconstructions in the user's field of view in their correct position. Therefore, it is necessary to provide a mechanism to determine location and orientation of the user. This can be accomplished using a GPS (global positioning system) to obtain outdoor location and a digital compass to determine orientation. Inertial sensors and gyroscopes can also be used to determine orientation, but the errors of these sensors tend to sum up over time[46]. Another approach to determine user's orientation and location is to use a camera to capture the current view and use vision algorithms to identify what the user is looking at[46]. However this process is computationally more demanding.

Another concern in augmented reality mobile presentations is to provide equipment that can be carried by the visitor: it has to integrate sensors to determine position and orientation and a display to combine virtual objects with real images. Two main types of equipments can be used: head-mounted displays (HDM) or small displays of palmtop devices. Regarding head-mounted displays, they can be based on optical or on video technologies[44]. In the first case, called optical see-through HMD, the graphical objects are displayed in front of the user's eyes on optical combiners partially transmissives, allowing the user to see the real world through these. On the other hand, a video see-through HMD is a closed-view HMD with one or two video cameras that capture images of the user's view of the real world. The video from these cameras is combined with the graphical objects and displayed on the monitors in front of the user's eyes in the closed HMD[44]. When a palmtop device is used, its display shows the virtual objects combined with real images captured by the device, corresponding to the video technology described above. The drawback of palmtop displays is that they may not have enough contrast to produce intelligible images in outside environments with bright sunlight.

In the scope of Archeoguide project, a mobile unit for outdoor augmented reality tours in cultural-heritage sites was developed and tested at ancient Olympia in Greece[46]. The mobile unit is composed of a laptop computer, a wireless network (WLAN) antenna, a GPS receiver in a backpack and a video see-through HMD with a camera and an electronic compass. The authors preferred this kind of HMD, as it can be worn and removed from the user's head during a tour visit requiring no extra calibrations. Providing a wireless network interface allows communicating, for instance, with a site-server to distribute contents[46]. User's position and orientation is obtained combining two techniques. First, an approximate estimate is obtained using GPS and the electronic compass. More exact values are then determined using image based techniques that compare the captured image of the user's field of view and a set of images of the site indexed according to the spatial coordinates from which they were taken[47]. In this project, real images are combined with 3D virtual models in VRML.

A similar approach was used in Lifeplus Project to provide interactive audiovisual guided tours presentations to visitors of ancient Pompeii, Italy[48]. In this case a richer set of communications infrastructures was considered to obtain user's location inside buildings, since GPS cannot be used in this case.

### 5.2 Augmented Reality Indoor Experiences

Augmented reality presentations can also be performed inside museums to provide a richer and compelling experience to the visitor. Hall[49], *et al*. described an interactive activity using a HMD. The used equipment enables the visitor to see simultaneously, real artifacts and virtual embodiments of related artifacts. This was complemented with audio information through the HMD headphones. However, this kind of equipment can raise some difficulties: it can be obtrusive, is a non-collaborative technology, and novice users usually require assistance to manage it.

Instead of real-time images, photographs can be used as the real world reference to place 3D virtual models[50]. At the Provincial Archaeological Museum of Ename, close to the Ename archeological site, referred above, this was achieved using QuickTimeVR technology[5] to show the evolution of the entire village over the past ten centuries considering 12 distinct periods in time. A 4-D QTVR object was built based on a two dimensional matrix of images: each column contained the images representing the evolution of the landscape along the time from a specific point of view and each row fixes the images obtained from 36 evenly spaced points on a predefined circle. So a horizontal movement corresponds to a rotation in turn of a focus of interest and a vertical movement shows the evolution along the time. Photographs of the archeological site were taken from a helicopter flying around the site. As is unlikely to obtain the images exactly from the 36 target viewpoints, the images had to be processed to create a kind of interpolated view from each viewpoint[50]. Later on, virtual models were combined with the resulting processed images aligning both the coordinate systems.

Taking advantage of softer lightning conditions of indoor spaces, mobile phones equipped with a digital camera can be used to display mobile augmented reality presentations. As mentioned before, mobile presentations require automatic capturing of visitor’s location and GPS cannot be used to provide indoor location. This is a problem faced by all the multimedia mobile museum guides.

In the pioneering multimedia tour developed in Tate Modern, in London, visitor’s location was obtained through a wireless network. Fourteen galleries were covered with seven access points, defining sixteen unique content zones which were delivered to visitors taking into account their location in the gallery[51].

To allow the visitor to freely choose information about an object he is looking at, location detection techniques are not sufficient, as they only provide user’s location, not his line of sight. A solution is to recognise a special identification marker placed close to an individual artwork. In Cicero project, RFID (radio frequency identification) technology has been used to accomplish this purpose[52]. The RFID tags, placed close to the artworks, are detected by mobile devices equipped with RFID readers. Two types of tags were experimented: passive RFID tags and active RFID tags. Passive tags can only be detected within a few centimeters’ range. This feature forces users to stand too close to the displayed identified by them. To overcome this limitation active RFID were also tested. Nevertheless, there are still some limitations. It is difficult to distinguish two or more objects that are too close to each other, so a single tag must be used to identify neighboring objects. Moreover, the visitor may be close to an artwork but not looking at it. So user’s orientation should also be detected to support a better approach to detect his focus of interest.

In augmented reality software applications, each individual object can be identified with a special type of marker, which is recognised analysing the images captured with the camera of the mobile device. Besides identification, these markers are also used as a spatial reference to place graphical representations over the images captured by the camera. On the device’s displayed, visitors can watch digital objects and animations superimposed onto real exhibits[53]. However, using tags require additional space and may disturb the visual concept of the exhibition. Another approach is to use more general computer vision algorithms to identify an arbitrary exhibition object by its features. This solution is time consuming and is constrained by hardware limitation of the device, although some advances have been done on natural features recognition with mobile phones[54]. To lighten computer vision processing, Bruns, *et al*. have combined location awareness to restrict the number of objects to be analysed[55]. They have tested the use of a grid of Bluetooth emitters to obtain an estimative of user’s location. They have distributed eight Bluetooth emitters over 15 rooms in two floors of the City Museum of Weimar, Germany. This ensured the partition of the environment into spatial cells, each one associated with the set of objects which are exhibited in that area. So the recognition process is limited to each set of objects. When the museum visitor presses a button on the mobile phone to take a picture, the object recognition process is triggered. Instead of identifying an individual object, computer vision algorithms can also be employed to recognise a small area of a painting and provide contextualised information about it[56].

## 6. TOOLS TO BUILD VIRTUAL MUSEUMS EXHIBITIONS

Creating 3D virtual models of exhibitions may serve several purposes, such as to offer educative and recreational activities inside a museum, to promote a museum collection through a webpage or to help preparing an exhibition.

In any case, the content of virtual exhibitions should be created by domain experts, like museum curators and their staff, usually not experts in computer science. Therefore, interactive software applications, not requiring users' informatics skills, would help domain experts to accomplish this task. Some tools have been proposed, providing not only a means to develop virtual exhibitions, but also to help a museum curator conceive and mount an exhibition.

An example of a tool for this purpose is presented by Hrk[57]. It provides a 2D graphical editor that allows, on one hand, editing the floor plan of a gallery, including its graphical properties, like color and texture of each wall, and on the other hand, mounting paintings on the walls. The latter task is accomplished using two auxiliary windows opened by double-clicking on a wall in the floor plan: one of the windows represents the layout of the paintings placed on that wall; and the other window presents the interface to add, delete, resize or move the paintings. This tool deals only with 2D paintings and does not support 3D artworks.

Within the scope of the ARCO (Augmented Representation of Cultural Objects) project the creation and management of virtual exhibitions have been addressed[58]. A set of tools has been developed comprising the generation of digital representations of artifacts, the management of these media objects and their visualisation in a 3D environment. The goal is to help museum curators to build virtual exhibitions for the web and to be used in local interactive kiosk displays. This goal is achieved using parameterised templates developed by content designers with knowledge in computer science and 3D technologies[59]. These templates are developed in X-VRML which is a high-level XML-based procedural language that adds dynamic modeling capabilities to virtual scene description standards, like VRML and X3D. In an X-VRML template, X-VRML commands are interleaved with fragments of native scene description allowing the program to read data from a database and use parameter values as input. Database access allows dynamic update of the virtual scene, and, reciprocally, user interaction or programmed dynamism of objects in the scene may generate updates to the database[60]. The actual content of a presentation depends on the actual parameters of the template which can be preset by the curator through a content management application, supplied by the user or obtained by database queries. However, the curator depends on content designers to update or to create new templates.

XVM is another XML-based language designed to describe virtual museum exhibitions[61]. The scene is organised in a tree structure whose nodes correspond to the objects in the scene. There are specific built-in nodes that contain the attributes needed to describe the basic elements of an exhibition room. 3D models of the artworks are described in VRML/X3D documents. Virtual exhibitions are built using an authoring tool that helps placing artworks into the 3D scenario. Along with the authoring tool, a XMV server and a XMV viewer were developed to allow the navigation in the 3D virtual exhibition.

A recent virtual recreation of the Museum of Contemporary Art of Macedonia in Thessaloniki, Greece, is described by Patias[62], *et al*. The physical space of the museum and its collection were digitised and converted into a Web3D format[33] to be disseminated through the web. Although there is no reference to a specific application used by the museum staff, one of the features created for virtual visitors is the interactive construction of an art gallery. The artworks are selected by database queries based on keywords, such as, author or artwork name among others, and then in the virtual space by dragging and dropping. No specific details are given about this application.

In Katalabs[63] a video presents a 3D gallery builder based in WebGL. An editor allows the user to place pictures on the walls and adjust their positions. 3D models, defined in the COLLADA format, can be inserted into the scene. No details are given about the creation of the 3D environment and how the 3D models are inserted in it.

The VEX-CMS (Virtual Exhibition Content Management System) is a tool that aims to help curators to create 3D virtual exhibitions and on-line guided tours with explanations to visitors[64]. Even though this tool provides the arrangement of artworks in the virtual space, its main focus is to help curators to create the more appropriate points of view to observe the artworks in a guided tour and to add textual information about them. To place 3D objects, it is possible to specify the side of the object that should be attached to a surface and, the object will move in a direction perpendicular to that side until it finds a surface to support it. Position of the object may be adjusted with translations, rotations and scale operations. No further details are given about object placement[64].

Based on Web3D technology, the Virtual Art Gallery tool was conceived as an auxiliary tool to assist museum teams to mount an exhibition[16].It requires a 3D model of the exhibition space in an X3D file and access to the digited database artworks. This tool has been recently reformulated to enable the extension of the functionalities provided. The next section describes the main features of this work.

## 7. VIRTUAL ART GALLERY TOOL

Virtual Art Gallery tool was developed in collaboration with the Azores Institute of Culture (Instituto Açoriano de Cultura), and it was conceived with the aim to support the creation of virtual exhibitions by the museum curator and his team[16]. This tool was designed bearing in mind the following goals: to be used by people with no expertise in computer science, to be capable of dealing with different exhibition spaces and to produce a virtual exhibition that could be accessed through the web. To attain these goals the interactive tool was built based on Web3D technology. The tool handles scenarios described in an X3D file, it was developed in Java, the manipulation of the scene in the X3D model is done using Xj3D, and information about 2D artworks, such as paintings or tapestries, are stored in a MySQL database. The user does not need any knowledge on computers programming to build a virtual exhibition: given an X3D file with the description of the physical space of the exhibition, the user interactively selects paintings from the database of artworks and chooses, with a mouse click in the scenario, the appropriate place to display it. The resulting exhibition is described in an X3D file.

The tool requires the description of the exhibition space in an X3D file. However, to allow the user to select surfaces in the 3D model, this description must be extended to include a touch sensor associated with each surface that can display artworks. To accomplish this goal the tool comprises two applications: Space Picker, which allows the user to choose the surfaces that must become available for art display in the X3D model, and the Virtual Exhibition Builder, the main application, that uses the model transformed by the Space Picker and permits the user to place artworks on the available surfaces.

The Space Picker application prepares the X3D file to be used by the Virtual Exhibition Builder. It imports the X3D file with the description of the exhibition space and adds touch sensors to all the surfaces of the scenario. As not all the surfaces are appropriate to display artworks, due to its area, slope or localisation, some of these touch sensors should be removed or deactivated. To achieve this goal, the user selects interactively the surfaces that can be picked by the Virtual Exhibition Builder, that is, the ones that will keep their touch sensors marked as active. As the user selects a surface, its color changes (it turns red) to highlight the selected status. A subsequent selection of the same surface will revert the selected status. When the user finishes surface selection, he saves the results in a new X3D file that contains the initial scenario as well as the touch sensors of the selected surfaces.

The Virtual Exhibition Builder application creates the virtual exhibition, using the X3D file that was modified by the Space Picker application and the 2D artworks in the database. To place an artwork in the scene it has to be chosen from the database through a graphical query, which filters the items by author's name and the name of the work. A thumbnail of the chosen work is shown in the query area of the interface. This artwork is added to scene by clicking on any surface selected with the Space Picker application. Each added object has a touch sensor to allow its selection, either to adjust its position or to remove it. The position is adjusted through interface buttons that apply vertical or horizontal displacements, whose coarseness is controlled by radio buttons. After placing the artworks, the user can save the initial scene with the artworks to a new X3D file. This file contains the virtual exhibition that can be navigated with any X3D browser.

This first prototype had some limitations, namely; it supported only a subset of all the possible representations in X3D format, it did not allow changes in a previous created exhibition; it only permitted the placement of 2D pieces. To overcome these limitations, a new version of the tool with additional features was implemented[65], combining in a single tool the functionalities of the Space Picker and of the Virtual Exhibition Builder. This allows managing in a flexible way the redefinition of the set of surfaces appropriate to dispose artworks and scene re-edition. To simplify the surface selection process, a set of filters are available to choose the surfaces according to its geometrical properties.

As there are a wide variety of nodes in X3D to describe the geometry of an object, the same visible result can be obtained with multiple internal representations. To allow a more general use of the tool, it needs to interpret any X3D file and deal with the geometry of the described model. To treat a scene independently of its original description, it was conceived a mechanism that transforms any X3D model of an exhibition into a generic geometric description enabling a uniform treatment of any scene. It creates a layer that abstracts the original geometry of the scene and allows managing new objects added to the scene, like touch sensors, to provide interaction with the scene, artworks or auxiliary objects.

One important feature of this new tool is the re-edition of previously created exhibitions. It allows insertion, removal and successive adjustments in the artwork displacement by all elements that are involved in the exhibition mounting, comprising the museum team, artists and external consultants. The re-edition process requires storing all the information about the structure of the virtual exhibition model and all amendments in order to support future alterations. This information is saved in a file–called the state file–that reflects the editing state of the scene.

The types of objects that can be inserted in the scene were extended. Besides 2D artworks, it is also possible to dispose 3D artworks and to insert removable structures, such as plinths to display 3D objects or diving walls that can be used to display paintings or tapestries. The removable structures are built by defining the dimensions and color of parallelepiped objects that are interactively placed in the scene. The surfaces of these objects can be selected to exhibit artworks. To deal with the placement of different types of objects in a uniform manner, a set of basic parameters that characterise an object were defined, such as the bounding box and the base of contact with the surface where it is placed.

This tool was developed based on a modularity concept to allow the integration of new functionalities that could be demanded by museum specialists.

## 8. CONCLUSIONS

To produce virtual models of museums and exhibitions it is necessary to model 3D objects reproducing the real ones and to compose them in a 3D interactive space. These tasks usually need informatics' skills and are time-consuming, making them expensive and restraining its use. Even though requiring an initial set of 3D models, interactive tools, which could be used without specialised informatics knowledge, would allow a more widespread use of this technology. This is the case of interactive tools to build virtual exhibitions. They can help a museum team in the initial stages of an exhibition conception as a means to test and discuss the placement of artworks in the exhibition space. These tools usually demand, as pre-requisite, the virtual model of the exhibition space and of the artworks to be exhibited. In the case of paintings or tapestries, the model is created by the application based on photographs of the objects. The models of 3D objects can be produced with different levels of detail, ranging from detailed models that accurately reproduce the real objects to more simplified ones.

In the cultural domain, 3D virtual environment and models are used in a wide range of situations with different purposes, such as: reproducing destroyed buildings, accordingly to ancient images or textual descriptions, to provide a means to discover their primitive appearance and sometimes an historical evolution of their architecture; simulating ancient environments, to get insight into the way they could be used once; integrating interactive activities in museums as a means to attract visitors, specially young people, and enrich their visit offering educational contents in a recreational way; helping museum curators and their teams in the preparation of new exhibitions; providing virtual visits available through the web to spread collections of the museum. All these applications have in common the aim of contributing to a global cultural diffusion.

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