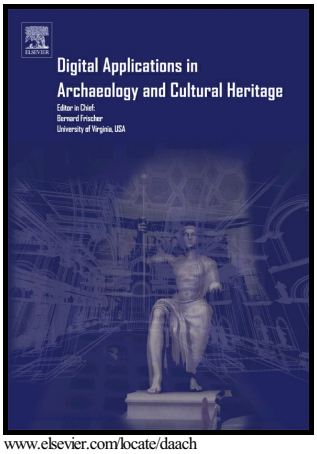
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A flexible platform for the creation of 3D semi-immersive environments to teach Cultural Heritage

Abstract:

The virtual visualization of historical objects opens the door to a variety of new teaching applications in the classroom. In this study, we present a flexible platform for the creation of semi-immersive 3D environments. First, we describe the software and hardware tools that generate the 3D models and the Virtual Reality Environments. We then present an optimized design methodology, adapted to the generation of light 3D models of sufficient visual quality for teaching purposes. The most suitable option for such purposes proved to be CAD tools coupled with extensive use of image textures on low-resolution 3D meshes. Finally, we report an ad-hoc teaching method to test the platform during a short teaching session on Cultural Heritage and Computer Graphics for high-school and undergraduate students. The evaluation of their experiences, based on post-session surveys, points to the effectiveness of this approach to communicate different types of knowledge and to stimulate student learning.

Keywords: Virtual Reality, 3D Modelling, Teaching, Cultural Heritage

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1. Introduction

The visualization of an historical object in the form of a 3D model is a holistic experience for the spectator, especially when compared with traditional visualization techniques, such as paintings, which limit the experience to fragmentary perspectives. This aspect is especially important, if the main goal of the visualization experience is to gain a better historical understanding of the background to the object and its characteristics, as is so often true for teaching experiences like visits to museums and art galleries. Before the turn of the century, limited computer-processing capabilities meant that the use of 3D Cultural Heritage models generated rendered images off-line, giving the images only very limited advantages over traditional painting [1]. However, the recent development of 3D graphic design hardware and software has led to new approaches for the analysis and dissemination of Cultural Heritage, most of which include real-time rendering, such as virtual museums [2], Virtual Reality 3D rooms [3], serious games [4], etc.

Real-time rendering in virtual environments prompts a variety of different questions. The first one is: which technique is the best to create the complex, but at the same time light 3D models that have to be visualized? Different approaches have been proposed to create 3D digital reconstructions of Cultural Heritage: photogrammetry, topographic techniques using a Geodesic Station, laser scanning and the use of CAD tools or hybrid technologies that combine two of the aforementioned approaches. The second question is: which visualization platform is the most suitable for the target audience to interact with the 3D models? Some answers to this question are virtual museums, Internet portals, and immersive or semi-immersive environments for one or more persons. And finally, the last question refers to the purpose of the generated virtual environment: historical and archaeological research, educational experiences, and management and conservation tasks. All these possibilities and their relations in the case of complex 3D models are discussed in Section 2, on the state-of-the-art, because high-quality 3D models are not easily rendered in real time and limit end user interactivity with the virtual reconstruction in many applications, especially those related to teaching.

This paper presents a flexible platform for teaching various topics, especially related to Cultural Heritage, 3D Modelling and Virtual Reality, through a 3D semi-immersive environment based on existing hardware and software technologies. The development of such a platform implies different multidisciplinary research: mainly in teaching methodologies, but also considering hardware and software integration and the standardization of 3D design methodologies. We describe the hardware and software associated with this flexible platform used for the virtual reconstruction of an historic-artistic monument and discuss its educational uses. The study goes further still by developing specific methodology for this task and reporting on a final example of its use: a short teaching session (Virtual Reality applied to Cultural Heritage) during the tenth Science Week of the University of Burgos was organized to stimulate interest in historical buildings and to introduce students to 3D Computer Graphics. This methodology is useful for developing light 3D models of medium-level detail, suitable for visualization in a Virtual Reality environment with real-time rendering and human interaction. It obtains a final rendering of sufficient quality for teaching and interpretation of the artistic and historical values of the building. With these reasons in mind, we chose CAD tools and images of medium-to-high quality as the methodology for this virtual reconstruction. Finally, the main novelty of this study is the evaluation of the effect or suitability of semi-immersive environments to teach different disciplines at high-school and university level, unlike most of the existing bibliography that focuses mainly on the software tools and the hardware to create the 3D models and the semi-immersive environment that is outlined in the following section. In our case, the different knowledge disciplines to be taught simultaneously are: 3D modelling, 3D animation, art history, and the history of Cultural Heritage. Its multidisciplinary educational approach is especially appropriate in modern-day society.

The paper is structured as follows: Section 2 presents a discussion about the related work on real-time visualization of complex 3D models and their application to teaching purposes; Section 3 describes the hardware and software that comprise the flexible platform; Section 4 describes the process followed to

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build the virtual reconstructions used in the semi-immersive environment; Section 5 shows a case study of the flexible platform in the context of a teaching session on 3D modelling and Virtual Reality that includes an analysis of the objectives achieved in the session. Finally, Section 6 summarizes the conclusions and future lines of work.

2. Related Work on real-time visualization of complex 3D models

Following the open questions presented in the Introduction, different techniques are used to create complex models of various Cultural Heritage items: from small finds to archaeological sites taking into account the modality of the 3D models (preservation, documentation, research, promotion, etc.). Real-time rendering is required for many teaching purposes, such as augmented-reality applications [5] and immersive environments [6]. Therefore the discussion over the suitability of the different techniques will be restricted to 3D models and real-time rendering applications.

Photogrammetry mainly uses 2D images to reconstruct 3D surfaces. Due to the availability of image acquisition devices and the quality obtained in the 3D reconstructions, photogrammetry appears to be the standard technique for creating 3D models of existing small objects [2], such as ceramic pieces [7, 8]. Over the last 10 years, research into photogrammetry has been focused on the reconstruction of larger-sized objects [9] and on the automation of the 3D surface generation process [10]. But complete automation of the reconstruction of 3D surfaces is still an open research topic, in particular for huge items like architectural scenes and very complex geometries, like man-made objects [8, 10]. In this last case, it involves very irregular objects and the 3D models used to be very heavy, because the algorithms try to extract as much information as possible from the images. Another disadvantage of photogrammetry is its requirement for a level of user interaction in the different steps of the 3D reconstruction and modeling pipeline, restricting its use mainly to experts. Therefore, there are two main disadvantages to the use of photogrammetric creation of 3D models for teaching purposes: the need for experts to create the 3D models and the high weight of the meshes in the case of irregular objects [11-16].

Laser scanners and other similar kinds of sensors are able to take optical measurements of the distance between the acquisition device and any surface, generating point clouds that have to be converted to 3D surfaces by means of automated or semi-automated procedures [12,17]. These techniques are very suitable for huge items, like architectural scenes, although they present some disadvantages, due to their high cost, weight and the usual lack of good texture (or, in some cases, the problem is to match image textures with 3D surfaces) [10]. Although very accurate 3D models can be generated with these devices, their heavy meshes make them more useful for documentation and research, than for on-line render applications like teaching packages and virtual museums [2, 6].

Although many experiences try to combine photogrammetry with 3D range sensors [10, 12], their results are mainly useful for research and documentation purposes, and they have a very limited application to teaching. Especially, if the object is mainly destroyed or lost, these techniques are of little or no use. In such cases, the most common approach is to use CAD tools [19-22] to create the 3D models in consultation with experts in that particular historical period. The alternative might be the use of parametric modelling, but this technique is mainly suitable for the generation of cities with standard building characteristics and may not be suitable for the generation of complex irregular surfaces, like the altar piece of a church from the Middle-Ages for example [23]. Finally, there are also some examples of hybrid technologies that combine CAD tools and 3D range sensors [3, 24]. The first approach generates 3D models of higher accuracy, but presents two serious disadvantages: 1) the creation of the virtual object is complex, because the scanners only provide point clouds rather than 3D digital surfaces, and it is not easy to match the 3D model with the texture image [12]; and, 2) the re-creation is too heavy to render in real-time on standard computers in medium-sized universities and business enterprises [7, 14].

As pointed out, careful consideration should be given to the visualization technique that is chosen from among the various available options and to the final use of the 3D model with which the target audience

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will interact, when selecting the method for the creation of a 3D digital reconstruction of Cultural Heritage. The final uses reported in the bibliography mainly refer to: public presentations of historical artefacts and structures in virtual museums [2, 8, 14, 15, 16, 17, 21] or over the Internet [3, 25], historical and archaeological research [6, 12, 13, 18, 19], educational experiences [22, 26] and management and conservation tasks [27]. Different visualization techniques have been proposed over the past twenty years, going further than simple rendering images for these final uses: 3D animations with interactive dialogues [26], real construction of the 3D meshes by means of 3D printers [27], 3D caves and semi-immersive 3D environments [6, 15, 16, 19, 21, 28], multimedia material [14, 17] and easy virtual environments rendered on-line with a web engine and visualized on internet [3, 26, 29].

Most of these uses require very accurate 3D models and very complex visualization techniques, in terms of human, hardware and installations resources. The difficulty of rendering the 3D models in real time often makes it necessary to limit the interactivity between the end user and the virtual reconstruction [5, 11, 16]. In any case, as the existing solutions are very expensive [6, 8], their application as teaching aids in high-schools and universities is very rare. Target audiences have shown high receptivity to virtual reconstructions and have improved their learning rates following the use of 3D animations and interactive environments [22, 29, 30]. Moreover, the existing semi-immersive educational environments at graduate and undergraduate levels [15, 21, 26] are focused on teaching one knowledge discipline, while this new proposal is aimed at teaching 3D modelling, 3D animation, art history, and the history of Cultural Heritage, as well as programming skills. Its multidisciplinary educational approach is especially appropriate in modern-day society.

Finally, the main novelty of this study is that, unlike most of the existing bibliography that focuses mainly on the software tools and the hardware to create the 3D models [3, 5, 7, 9, 13-16, 18-20, 24, 25] and the semi-immersive environment [6, 8, 2, 15, 16, 19, 21] very few works [22, 29, 30] have evaluated their effect or suitability for final use and even fewer are related to the teaching of Cultural Heritage topics [26], which is one of the aims of this research. There are, moreover, very few examples of specific methodologies for teaching topics such as 3D Modelling and Virtual Reality combined with Cultural Heritage [4]. Most examples of 3D models applied to Cultural Heritage teaching use gaming approaches [21, 26, 29], but gaming sometimes also disturbs the learning process of abstract concepts in Cultural Heritage [26]. Again, most proposals focused on software tools to introduce the process of generating 3D Computer Graphics and to introduce Virtual Reality [25, 31]. In other cases, researchers focused on the use of Information Technologies, especially 3D modelling tools and Virtual Reality environments, for the teaching of topics such as second languages [5, 29], architecture [5, 32], history [21, 22] and archaeology [19]. In this research, we propose a new methodology for short teaching sessions on complex topics that belong to different knowledge areas, such as Cultural Heritage and 3D Computer Graphics.

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3. Platform description

The platform is composed of three inter-connected rooms: a 3D-Graphics Editing Room, a Visualization Room and a Server Room. The activities in each room each serve a different purpose. However, the three rooms are connected for the purposes of teaching objectives and workflow. First, the Server Room works as a Render Farm for the workstations in the Editing Room controlled by software modules developed by Computer Science Engineering students. Second, the 3D models built in the Editing Room are exported to the Visualization Room for their use in teaching Cultural Heritage topics. 3D-Graphics techniques are taught in the Editing Room and Virtual Reality is taught to students of different disciplines in the Visualization Room. Fig. 1 summarizes the connections and the uses of these rooms.

Fig.1 Main scheme of the new flexible platform

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The 3D-Graphics Editing Room was designed as a space in which to develop 3D models. It was equipped with 25 workstations with 3D modelling and animation software (both Blender and Maya©). The workstations incorporate an Intel Core 2 Quad processor (2.8 GHz, 4 GB RAM DDR2, ECC HDD memory. The rendering of the final videos for internet use are sent to the render farm, while the light 3D models are exported to the visualization room for their incorporation in a real-time rendering engine. The teaching activities in this room are focused on 3D animation, 3D modelling and programming of render farms and Virtual Reality engines.

The Server Room includes a render farm and three high-performance servers: a storage server, a streaming server, and a web server for streaming Internet content. The render farm consists of an 8-node cluster with a core quad processor, each with an 8 GB RAM memory (model HP ProLiant DL370). Only render farm programming tests are done in this room and it is never or only rarely used for teaching activities.

The Visualization Room is a semi-immersive 3D virtual environment with two projection screens for floor and front view (see Fig.1). It consists of two 3D projectors, a high-quality sound system, a motion capture system, a 3D positioning system, and a workstation to generate 3D renders in real time. The workstation is a powerful HP Z800 Desk Top Computer with an Intel Xeon E5504 processor (32Gb RAM, GDDR3 memory) and a NVIDIA Quadro FX 5800 graphics card. Teaching activities in this room are focused on Virtual Reality, aspects of Cultural Heritage (mainly Art but also historical facts and their representation), and programming tests on Virtual Reality engines. This 3-room configuration is also described in other studies [19]. At times a different approach is followed, in some cases [15] the 3D Visualization Room is set up in an exhibition space and the generation of the two stereoscopic images is done on two different computers with lower processing capabilities than those used in this work (two dual core processor, 2 GB RAM equipped with a Nvidia 8800 graphics card).

Various interfaces for human interaction in the Visualization Room were tested and selected for different final applications. There are two 3D viewing modes: 3D active glasses (model CrystalEyes 3 by StereoGraphics) and a 3D helmet mounted display with a resolution of 800x600 and a field of view of 26º (model 5DTHMD237 by IngeVideo). Two datagloves with 6 degrees of freedom (model 5DTLG156 and 5DTRG176 by IngeVideo) were also used for hand-held interaction with the virtual world.

There were also three different systems for user positioning in the Visualization Room; the first one used 6 CCDs (model Optitrack FLEX-V100-R2), a cap and two gloves with 3 reference points each. Three software packages were also necessary: the first one collected the images from the CCDs (3D Motion Captor OTV100), the second (STT VRPN Server) transferred them to the last module by means of the Virtual-Reality Peripheral Network protocol, and the third one (WorldViz-Vizard© 4.0) built the graphic environment of the Virtual Reality world. This arrangement presented some disadvantages: its high cost and its lack of mobility, which meant that many 3D applications could not be arranged.

A second option was based on Kinect. First, a Kinect 1.0 acquired the position of the user. A software package (Autodesk Motion Builder) processed the motion data, extracted the relative position from a multitude of references points, and sent this information to the WorldViz module. The library Live Character was used to export data from Autodesk Motion Builder to WorldViz and to build an armature from the reference points that would define the movements of each avatar. WorldViz played the same role as in the first arrangement. This 2-step process required 2 computers: the first (running the Autodesk Motion Builder package) with medium processing capabilities and the second (running WorldViz) with high-processing capabilities. As acquisition and processing data tasks were performed by the same computer, complex real-time applications could easily overload it; for example, the visualization of a virtual environment with 600,000 polygons and two Kinect devices that simultaneously moved two avatars (two on-line users) caused computer-hang and jumps in real-time visualization of the scene.

A third option was also based on Kinect equipment. First, a Kinect 1.0 acquired the position of the user. In this case, the Autodesk Motion Builder software package functions were divided between two software

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modules/computers. The motion data were processed by a software package (Brekel) that converted the tracking to a FBX binary file that provided interoperability between digital content creation applications. The file was then sent to the Autodesk Motion Builder software package that built the armature of the avatar, and its movements and sent this information to the WorldViz module. The library Live Character was once again used to export data from Autodesk Motion Builder to WorldViz. WorldViz played the same role as in the second arrangement. As a 3-step process, it required 3 computers: the first two (running the Brekel and the Autodesk Motion Builder packages) with medium-processing capabilities and the third (running WorldViz) with high-processing capabilities. This configuration allowed us to split the acquisition process and the manipulation process between two computers, using the Brekel library for this second task. More complex processes may therefore take place, such as motion acquisition of two or more users at the same time; processes which might not be possible with the first and the second configurations.

4. Virtual Reconstruction Process

Different 3D models were built in the 3D-Graphics Editing Room and then exported to the Visualization Room for teaching purposes. The proposed methodology to build 3D models of complex buildings has been described in a previous publication [28]. A five-step process was followed: 3D modelling, texturing, lighting, rendering and post-production. These steps have been widely used to build virtual recreations of historical and artistic buildings [21], although some novelties that are outlined in this section have been introduced into the overall process. The first four steps were performed with Blender software and the fifth using Adobe Premiere Pro©.

The proposed methodology was followed to generate a 3D model of the Church of the Charterhouse of Miraflores (Burgos, Spain), as it was at the beginning of the 15th Century. As a royal mausoleum, it is a perfect example with which to explain Medieval eschatological religious thought. The building is still in existence, but its appearance has been altered in various reforms over the centuries. The virtual visit presents these Medieval philosophical concepts that are not apparent in a visit to the actual building without a guided tour. The church of the Charterhouse of Miraflores is a single-nave structure. Two of its unique elements are the royal mausoleum of John II of Castile and Isabella of Portugal and the choir stalls. Fig. 2 shows an interior view of the Charterhouse of Miraflores, as it appears today.

Fig.2 Interior view of the Church as it is nowadays

4.1 3D Modelling

Three different strategies to create as light a 3D model as possible were followed. The first was applied to all the elements of simple geometry; these elements were modelled using well-established 3D CAD techniques. Following this strategy, the building volume (including walls, doors, the rose window, the ribbed vaults and the stained glass windows) was generated, together with some auxiliary elements, such as the choir stalls, the grids and the lectern.

The second strategy was necessary for modelling highly complex elements such as the royal tomb and the altarpiece. A specific 3-step technique was developed for this issue consisting of: 1) generation of a single geometric element; 2) the application of an Image Texture to this element; and, 3) modification by hand of the geometric element mesh using the Blender sculpt mode to adapt it to the Image Texture. This technique provided a medium-quality result with a very limited number of polygons, substantially reducing the time required for the generation of complex meshes [28]. Fig. 3 compares the mesh generated by this technique for a small sculpture of praying Carthusians, forming part of the lower surround of the royal tomb, and the mesh produced by 3D laser scanning using a Minolta Vivid 910 laser scanner. This scan was not part of this project and is only included here as a standard for comparison. The scanned figure is composed of 4,000,000 polygons, while the modelled one, with only 44,427 polygons,

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had a reduction rate of 98.9%. Although the visual quality of the 3D models created by this technique was clearly inferior to the scanned models, it was sufficient for the final applications for this work and allowed real-time rendering in the Virtual Reality platform, a central requirement for teaching applications.

Fig.3 Comparison of mesh-generating systems for a Carthusian prayer group: original sculpture, mesh generated with the technique described above and mesh obtained with digital scanning

The third strategy was used with some secondary elements for which a 3D structure is not important, but which have to be included in the 3D model for historical reasons, such as the crowns on the ribbed vaults. Instead of using modelling, these objects were substituted by a plane to which an image texture was applied, which is a real image of the object to be built. In this real image, a transparency or alpha channel was added, which defines the highly complex shape of the object. One example of this third strategy will be included in Section 3.2.

4.2 Shading

As in the case of the 3D models, different strategies were used for shading, depending on the importance and complexity of the architectural elements of the church. The first strategy was used for large homogeneous surfaces: shading was defined by using three layers and making extensive use of procedural textures. The first layer defined the general diffuse and specular surface colour. The second layer generated colour irregularities using a procedural texture or a low-quality image. The third layer produced irregularities on the surface using a procedural texture for Normal Mapping. This technique was followed for the surfaces of the stone walls and vaults.

The second technique was applied to complex elements that needed high realism, such as the altarpiece and the royal tomb. In this case, a first image texture was applied. This texture reproduced an image of the object with medium resolution and provided the mesh with its colours. Then, the same image texture was applied as greyscale for Normal Mapping, thereby improving the three-dimensionality of the object. The quality of the textures differed depending on the function of each element to which they were applied. For example, high-quality images were used as textures for the stained glass. However, the quality was not as high where each element was less central to understanding the artistic and historical meaning of the building, such as the lower surround of the royal tomb. This same principle has been used in previous studies [19, 21], which described the need for light 3D models in real-time rendering [14] and proposed the use of 3D meshes generated by CAD tools with image textures, to avoid the problem of real accurate and heavy 3D Models [21] and other heavy 3D mesh decimation methods, for export to Virtual Reality engines [16].

The third technique was applied to objects that required medium-level detail, because their 3D modelling was not essential. This technique has already been explained in section 3.1. Fig. 4 shows an example of this technique and its application to the shields in the vaults. It reduces both modelling time and rendering time and gives a medium visual quality, which is sufficient for these secondary elements.

Fig.4 Shields without image texture and render of the shields with image texture using alpha channels

4.3 Illumination

Illumination plays an essential role in highlighting each element of a virtual reconstruction of any Cultural Heritage item. In this case study, illumination was defined by two types of light: coloured light, in simulation of the daylight entering through the church windows; and, torches placed around the Royal Tomb. This step was only taken for the presentations by the teachers (step 1 of next section), because the

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illumination of the 3D models in the semi-immersive cave was done directly by the render engine in the Visualization Room in real time.

The daylight filtering through the stained glass was recreated by area lights allocated beside each window. The orientation of these lights was changed during animations to simulate changes in daylight from mid-morning through to sunset. An image texture was applied to these lights to reproduce the light of the stained glass. Thus, their projection onto the opposite wall created a multicoloured effect (Fig.5a). In addition, a low intensity halo effect was applied to them, to simulate an atmosphere created by smoke from candles and torches. The halo effect enhanced the sense of quiet meditation in the church. Torch light was recreated using lamp light with a procedural texture that emulates fire. These lamps were set at a relatively low intensity.

4.4 Rendering

Once the lighting step was ready, different renders were calculated for each main view of the church under different lighting conditions (night, morning and evening). Each render was an attempt to show some of the fundamental artistic or historical values of the building that should be transmitted to students and other visitors. Therefore, before the camera and lights were fixed for the render, a script was designed including the main concepts of the render that the teacher would outline. This step was only done for the teacher presentations (step 1 of next section), because the render of the 3D models in the semi-immersive cave was done directly by the render engine in the Visualization Room in real time.

Fig.5b shows a central view of the nave, showing the church as a "burial ship", reflecting medieval philosophy on death as a transition from this life to a new life. The colourful lighting provided by the windows can be clearly seen in the higher parts of the walls. The vaults are also highly illuminated by the stained glass, although the choir stalls, at ground level, remain darker. The interplay of shadow –down- and light –up- can be clearly outlined to students, reflecting the two steps of life for Christians: dark life and the light of salvation after death. The render reflected mid-morning daylight. Fig.5c shows an aerial view of the Royal Tomb with night lighting. This render shows the play of light and shadow cast by the torches and the reflections coming from the golden altarpiece. A further 10 renders were created to show different historical and artistic concepts that the students were expected to learn.

Fig.5 (a) Projection of daylight through the windows on the opposite wall; **(b)** Central view of the Church; **(c)** aerial view of the royal tomb

4.5 Evaluation of the Virtual Reconstruction Process

A study of time allocation for the completion of this virtual recreation was conducted to conclude the virtual reconstruction process. The whole virtual recreation described in Section 3 took 300 working hours. The distribution of working time between the different activities was as follows: 12% field work (taking pictures, collecting information, etc), 22% modelling, 27% image texture preparation, 5% shading, 5% lighting, 20% rendering, and 9% post-production. It may be concluded that the selected CAD tools required intense image pre-processing, which proved very time-consuming. Compared with the methods outlined in previous studies, this method is quite rapid. Martin et al [12] reported 170 working hours to build a 3D model of a Medieval church of a similar size, based on scanning and automated technologies with CAD Tools, while, in our case, it only took 130 working hours. The same church created by a conventional delineation technique and CAD Tools might need 285 working hours [12]. Table 1 summarizes the tasks performed to generate the final video/rendered images, the data required in each task, the software tools that were applied and the time consumed in each task.

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Task	Data	Software tools	Time (%)
Field work	Building Plans and Canon EOS D40 pictures	None	12
3D modelling	Building Plans and Canon EOS D40 pictures	Blender	22
Image texture preparation	Canon EOS D40 pictures	Photoshop Crazy Bump	27
Shading	Image textures and 3D models	Blender	5
Lighting	3D textured models	Blender	5
Rendering	Lights and 3D textured models	Blender	20
Post-production	Rendered images	Adobe Premiere Pro	9

Table 1. Summary of software tools and time consumed in the production of the virtual reconstruction

5. Study case: Teaching session on 3D modelling and the History of the Middle Ages

Once the 3D Model of the church was integrated in the Virtual Reality Room, the platform was prepared for tests with young students. A first teaching session, called "Virtual Reality applied to Cultural Heritage", was designed for this purpose during the tenth Science Week of the University of Burgos (12-19th November 2010). The objective of the Science Week is to bring research work closer to the public and especially to high-school students. The intention behind the session was to allow young students to identify the main stages and concepts involved in 3D Computer Graphics generation, while also learning about history, medieval thought, and the artistic qualities of the Charterhouse of Miraflores. As outlined in Section 1, there are no teaching methodologies for short sessions that teach topics of such a different nature and most teaching methodologies usually refer to long-term projects [26, 30], hence the complex design of this teaching session.

5.1 Teaching session goals and student profiles

As well as teaching topics of History, Art and Computer Graphics, the session attempted to stimulate the interest of students in those same topics. The following objectives were proposed to reach those two general goals:

- Understand the various stages in a Virtual Reconstruction of an historical building
- Assimilate the main historical and artistic aspects of the Charterhouse Church
- Assimilate the concepts of 3D modelling, texturing, lighting, rendering and 3D virtual environments
- Stimulate the interest of students in Art, History, 3D Computer Graphics and Virtual Reality, through the use of Information Technologies

The students were separated into two groups in accordance with their main interests. The first group was formed of high-school students studying technical subjects. The activities of the first group in the teaching session focused mainly on the process of generating 3D Computer Graphics and, to a lesser extent, on the study of the historical and artistic value of the building. The second group was formed of high-school students studying humanities and first-year students following a Humanities degree course. The activities of this latter group focused mainly on the historical and artistic value of the building and, to

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a lesser extent, on the process of 3D Computer Graphics generation. In total, 398 students participated in this teaching session. Table 2 shows the gender division, age and numbers of students in these groups.

	High Schools		University undergraduates
	Science - Baccalaureate	Humanities- Baccalaureate	
First course	148	112	86
Second Course	41	12	0
Female	104	76	56
Male	85	48	30
Total	**189**	**123**	**86**

Table 2. Profile of the students attending the teaching session

5.2 Four stages of the teaching session

The proposed methodology involved the four stages shown in Fig. 6, where the height of each box is proportional to total student time. First, a teacher from the Department of History of Art and another from the Department of Computer Science presented the story behind the virtual reconstruction of the Medieval church. Then, the students, closely accompanied by the teacher, were given the chance to modify the 3D model (meshes, shaders and lighting) of the church. In a third stage, they moved on to the Virtual Reality Room to interact with the 3D Model. Finally the students were asked to fill in a survey to provide feedback and conclusions on this practical experience. The duration of each session was approximately 40 minutes with 15 to 20 students in attendance.

Fig.6 Stages of the teaching session

The first step was a short introduction to the main concepts of Virtual Reconstruction of Cultural Heritage. This 7-minute presentation, with slides and a beamer, presented the main sources of information on Cultural Heritage needed to create the virtual reconstruction, from historical documents and prints to modern 3D scans. The presentation then focused on the construction of the 3D model: the basic concepts of 3D modelling (reference system, basic operators, etc), the differences between procedural and image textures, and the conceptual and computational requirements for rendering 3D Computer Graphics. The example of the virtual reconstruction of the Church of the Charterhouse of Miraflores was used to make the presentation more interesting to the students.

Subsequently, the students received a brief practical introduction to the Blender interface (movement through the virtual space and selection of objects) and they had the chance, through two supervised exercises, to modify some elements of the 3D model of the building by themselves. These exercises took around 20 minutes. In the first exercise, the students had to change the image texture of one piece of stained glass for an image they had downloaded from internet (Fig.7). In the second, they modified the render of the lectern located at the centre of the church, working on the lighting properties (colour, intensity and halo effects), as shown in Fig.7. In both cases, the students performed final renders (before and after their modification in the 3D scene) for the evaluation of their work. The render farm, rather than the computational capacity of each student's workstation, was used to speed up the render process.

Fig.7 3D models: **a)** the stained glass and its final render and **b)** the lectern and its final render

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Although the student groups were small, two teachers were needed, to maintain student interest, to keep levels of frustration to a minimum, and to achieve satisfactory results within a short time: while one teacher slowly worked through the supervised exercises, with the help of a beamer, the students repeated the exercises by themselves, and the second teacher directly supervised individual students, answering their questions and helping them, if they appeared lost. Depending on their skills, the time that each student needed to adapt to the 3D environment was radically different in each case. The most advanced students were able to do the two exercises relatively quickly and they then moved on through some of the different layers of the Blender file that when rendered together, completed the 3D model of the church.

The third stage overlapped with the second one: the students went to the Visualization Room in small groups of 4-5. Once inside, a teacher briefly explained the main components of a virtual environment: 3D beamers, positioning system and 3D glasses. Then, the students performed a virtual tour of the Church of the Charterhouse of Miraflores, to handle various interactive elements of the 3D model (videos, images, text, etc). At the same time, they discussed the significance of the main elements of the building with the teacher, from the perspective of the medieval architects, and the artistic value of each element (history, style, patrons, etc). This part of the session lasted approximately 7 minutes. The students tested two of the three positioning and interactive interfaces presented in Section 2: camera positioning with datagloves to interact with multimedia elements, and the Kinect 1.0 system to move through the virtual reconstruction. Obviously, all 5 students would never have the chance to test both systems within 7 minutes, but each student could at least test one, while working together in pairs (one moving and one interacting with the multimedia elements).

The session usually took place as follows: the first pair of students, after listening to an explanation on the positioning of the camera with datagloves, was asked to move to two parts of the church (the lectern and the altar piece) and activate an interactive button at each place (a presentation of 3 slides at the first, on the Medieval concept of life and death, and a short video, at the second, on the altar piece as it is nowadays). Then the next pair was asked to fulfill a similar task with the Kinect 1.0 system: visit one of the stained-glass windows and fly over the royal tomb and activate two new interactive elements (again a presentation of 3 slides: the first on the Medieval class-structure of the society and a short video on the royal tomb, and the second on the history of the King who founded the building). Finally, the teacher gave them some free time to move with the Kinect 1.0, because the students feel more comfortable with this device while the teacher discusses with them what they have heard or seen in the slides and videos. Although the time that each group of students should spend in the virtual environment was fixed, the teacher showed flexibility on this point, depending on the interest of the students. Therefore, the quickest group spent 5 minutes in this stage, while the slowest took 12 minutes to complete the visit. The time each group of students spent on this third stage was measured and used in the analysis.

Finally, the students had around 4 minutes to fill in a survey, on a voluntary basis, to evaluate their understanding of the concepts explained to them and to measure their interest in the Virtual Reconstruction of Cultural Heritage.

5.3. Evaluation of the teaching session

The short survey, designed to be quickly completed, consisted of only 13 questions. Eight had five possible answers, from among which the student had to choose two. Four questions had only two possible answers (yes/no) and the last question was rated on a scale of 1 to 10. The questions were split into three groups, to evaluate whether all of the goals of the session had been fulfilled. The first group was composed of six questions on general concepts related to history, artistic value and 3D Computer Graphics. These questions concerned the sources of information needed for a virtual reconstruction; the monarchs who patronized the church building; its most prominent artists; why it was necessary to apply textures to the 3D model; and what a render is. The second group included four questions on the advantages and the limitations of virtual reconstructions; the questions referred to problems of real-time rendering and how to display realities that are no longer available in the real world. Finally, the third

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group was composed of three questions that evaluated student interest in the real church and in the 3D Computer Graphics generation process; these questions related to their willingness to visit the real building and to prepare a 3D Model by themselves.

From among the total number of 398 students (312 high-school students and 86 undergraduate students) who attended the session, a total of 309 surveys (226 from high-school students and 83 from undergraduate students) were returned. The responses were normalized to the number of valid surveys for analysis and representation and their main results are discussed below.

On the whole, the students answered the three questions on 3D graphic design and Virtual Reality (use of textures, concept of render and main difficulties for 3D semi-immersive environments) correctly, showing a clear understanding of the main stages of the construction of 3D Models and the requirements for a Virtual Reality environment. Fig.8a shows the percentage of students that correctly answered these three questions; the evaluation of these questions are complex, because the students should choose two correct answers out of a group of five. Some students selected the two correct answers, some selected one correct and one incorrect answer, and others selected two incorrect answers. In this case, 68% of the high-school students correctly answered the 3 questions, (other 25% answers half-right the 3 questions), a rate that increased to 81% in the case of undergraduate students (plus 16% with only one correct answer). These rates are sufficiently high, if we take into consideration that none of the students had previously been introduced to 3D Computer Graphic design, the short duration of the session, and the number of concepts of a different nature that were introduced. There was a small difference in gender, which was not statistically significant.

Fig.8 Student knowledge of **(a)** the 3D modelling process and **(b)** Cultural Heritage topics after the teaching session

In relation to Cultural Heritage topics, the surveys show that the teaching session helped students to develop an understanding of the artistic style of the building, the monarchs who patronized the church building, the principal artists that worked on it, and the century in which it was built. Fig. 8b shows that more than 80% of students correctly answered these questions in all cases. High-school students answered the 4 questions with 1% -10% lower results than those of the university students, although there was no statistically significant difference between gender and high-school-undergraduate students.

After the teaching session, most students responded positively when asked about their interest in the different topics presented in the session: Cultural Heritage, 3D Graphics and Virtual Reality. When asked whether they would like to create a 3D model by themselves (Fig. 9a), 77% of the male high-school students and 61% of the female high-school students responded positively. These proportions hardly differed in the case of undergraduate students: 76% of the male students and 65% of the female students. The different patterns were also remarkable in relation to their willingness: the male students, more so than the female students, expressed greater interest in creating a 3D model, a gender difference that was also present when asked about their interest in Virtual Reality

Fig. 9 Willingness of students to create a 3D model by themselves

Fig.10a shows that most of the students were more interested in Virtual Reality after than before the session (82% and 55% male and female high-school students and 89% and 61% male and female undergraduate students). The male students (82% and 89%) were clearly more interested than the female students (55% and 61%).

Fig.10 Interest in (a) Virtual Reality and (b) the Cultural Heritage Building after the teaching session

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Fig.10b shows that a majority of students (61% and 77% male and female high-school students and 65% and 76% male and female undergraduate students) responded positively when asked if they were more interested in visiting the Church of the Charterhouse of Miraflores after the teaching session. The increased interest in Cultural Heritage was clearly higher among all female students than among all male students. This result is very promising, considering that high-school students from the Science Baccalaureate (40% of the students attending the teaching session) do not often express a keen interest in Cultural Heritage.

Finally, an analysis of the time the students spent in the virtual environment and their knowledge of the Cultural Heritage topics (b) (Figure 8.a) was performed. Figure 11 shows this analysis: the relation between the number of right answers to the 4 questions in the survey on Cultural Heritage topics and the time the groups of students spent in the virtual environment. The Y-axis has two scales: on the left the percentage of correctly answered questions (e.g. 400% means all the students in the groups that spent a certain time in the virtual environment (X-Axis) correctly answered all 4 questions, 200% means they only gave correct answers to half of the questions) and on the right the number of surveys that have been filled in by students who spent a certain time in the virtual environment. Figure 11 shows that there is a clear relationship between spending more time in the virtual environment and achieving a higher learning rate. In the case of undergraduate students, their results are mainly better than high-school students, an expected result that was also shown in Figure 8.a in mean value for each question, although the students in the range 9-10 minutes in the virtual environment coming from High-schools were slightly better than the undergraduate ones. The difference between the best and the worst students in each case was higher in the case of High-schools students. This result may be explained, if we remember that the High-school students were studying different disciplines (from Science to Humanities Baccalaureate) and were therefore open to learning about Cultural Heritage to varying extents, depending on their own interests. In the case of the undergraduates, they were all from Social Studies (Communication Media Bachelor), therefore, although not very close to Cultural Heritage topics in their studies, were more of a homogenous group. The strong fluctuations in the undergraduate group are due to its small size (only 83 surveys).

Fig.11 Learning rate of Cultural Heritage topics related to time spent in virtual environment

In general, the survey results confirmed that the underlying methodology of the teaching session was effective. The students had assimilated the basic concepts related to 3D Computer Graphics within 40 minutes and had understood the advantages and limitations of using Virtual Reality, both of which are fundamental concepts in the most promising Computer Graphics applications. The teaching session had also helped students to understand the artistic and historical value of a Cultural Heritage Building. We may therefore conclude that the teaching session was a useful teaching tool that stimulated the interest of the students in different kinds of knowledge, from Humanities to Computer Science. In agreement with previous pilot projects, our study suggests that, first, the interest of students increases with the use of visual technologies [30]; second, a user-friendly software tool is necessary for learning 3D modelling [25]: and third, the close presence of a teacher is necessary for any Virtual Reality teaching methods to fulfil the high degree of adaptability and the dynamic individualisation of such methodologies [21, 26, 29]. Finally, the time spent in the virtual environment was not the same for all groups. It depended on their interest and the time spent in this room. The analysis of their learning rates showed that the longer they spent in the room, the more they learnt about Cultural Heritage topics.

6. Conclusions and future works

This study has shown that current state-of-the-art of graphic design and visualization technologies can generate flexible 3D semi-immersive platforms for the virtual recreation of Cultural Heritage monuments that are useful for the teaching of Cultural Heritage and its dissemination and interpretation. The platform comprised pre-existing software and hardware tools suitable for 3D modelling and 3D visualization. The

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software tools included 3D design software, such as Maya© and Blender, and Virtual Reality engines such as WorldViz and Ogre. The hardware media included a render farm, a workstation room and a semi-immersive 3D room. The positioning and the interface systems in the semi-immersive room included CCDs, Kinects, 3D glasses and datagloves, depending on the final application performed on the platform. A configuration based on Kinect equipment and 3 computers to split the acquisition process and the manipulation process between two machines appeared to be the best option for real-time interaction of 2 users simultaneously with semi-complex virtual environments and with the limited budgets that often constrain teaching activities.

Accurate integration and real-time rendering of the 3D models in the 3D Visualization Room was only possible with light 3D models of medium visual quality. This work also presented a modelling methodology especially suitable for this purpose. Although scanning and photogrammetric techniques may be used, they generate overly heavy 3D models of the building as it is today, which are very difficult to modify, in order to reconstruct the building at it was in the late Middle Ages. So, our new methodology was based on simplified 3D models and a multilayer texture application. One of the core elements of this methodology and also a highly time-consuming activity was the image texture preparation. The methodology was applied to the Church of the Charterhouse of Miraflores in Burgos, Spain. In this case study, the proposed methodology can decrease the 3D mesh size by a factor of 99% compared with a standard 3D mesh generated by a scanner, retaining the main visual characteristics of the 3D elements over a minimum threshold required for teaching purposes.

Finally, the main novelty of this research comes from the application of this virtual environment to a real teaching experience. Although young students pay more attention if the learning process includes Information Technologies, software and hardware tools will never in themselves ensure that teaching strategies are successful with these students. Ad-hoc methodologies need to be developed for such tasks that are optimized for the study modules that the students are following. The flexible platform has been tested with a real learning experience: a 40-minute teaching session during the Tenth Week of Science at the University of Burgos entitled "Virtual Reality applied to Cultural Heritage". This session introduced students to the historical and artistic significance of the medieval religious building and to fundamental concepts of Computer Graphics. The session was divided into four phases: a presentation of the virtual reconstruction of the building; a supervised practical exercise on the 3D Model; an interactive tour through the virtual reconstruction; and, a short evaluation of the teaching session by means of a survey. The surveys evaluated the strengths and weaknesses of this teaching methodology, in addition to levels of student understanding of historical and artistic meaning and the process of virtual recreation. The survey results showed that almost all of the students understood the main concepts related to history, art and computer science. They understood the meaning of the building as a holistic representation of the religious and social reality of the Late Middle-Ages. They demonstrated an understanding of the advantages and disadvantages of using 3D Virtual Reality for such reconstructions. The male students showed greater interest than the female students in creating a 3D Model by themselves. Finally, the time spent in the virtual environment depended on the level of interest of each group. The analysis of the learning rate in relation to Cultural Heritage topics showed that the longer they spent in the room, the more they learnt about these topics. These responses show the potential of such a flexible semi-immersive 3D platform, not only to teach concepts of a different nature, but also to enhance the interest of students in Cultural Heritage topics.

Further research will focus on expanding the use of this flexible platform to teach other disciplines to undergraduate students, such as, computer science students, to increase their interest in 3D Modelling and Animation, which represent two expected growth areas of specialist employment in Spain. Methodological improvements would also be of interest, so that the 3D Model and the multimedia material embedded in it could partially replace the presence of the teacher in the 3D environment, thereby reducing the human resources needed to perform this kind of teaching experience. Besides, the use of these teaching methodologies could also be tested in museum exhibitions, as a way of enhancing the

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interest of young people. Finally, the use of this platform to evaluate mechanical design and machine maintainability is an open issue that will also be tested in the near future.

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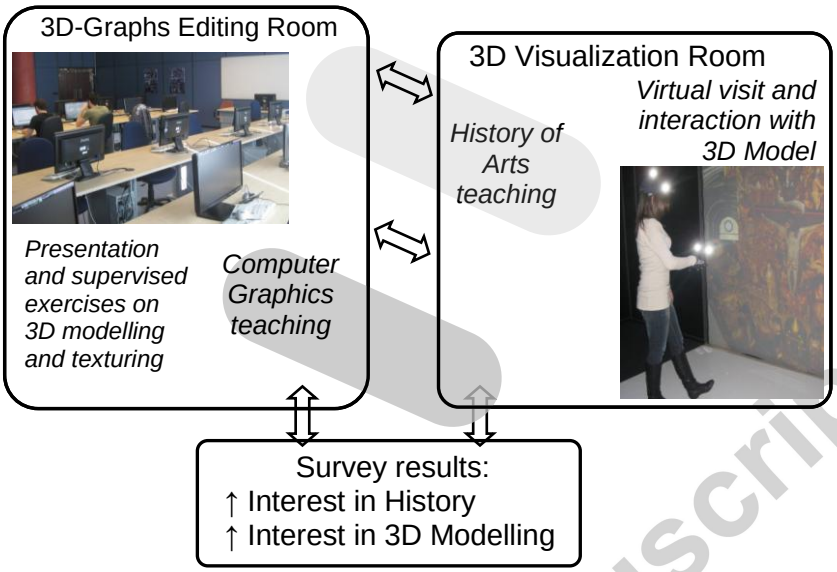
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Graphical Abstract (for review)

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Highlights

- A methodology to create light 3D models with Blender of Cultural Heritage items
- A methodology for short teaching experience in Virtual Environments
- Virtual Environment increases the interest of students in History
- Virtual Environment increases the interest of students in 3D Modelling

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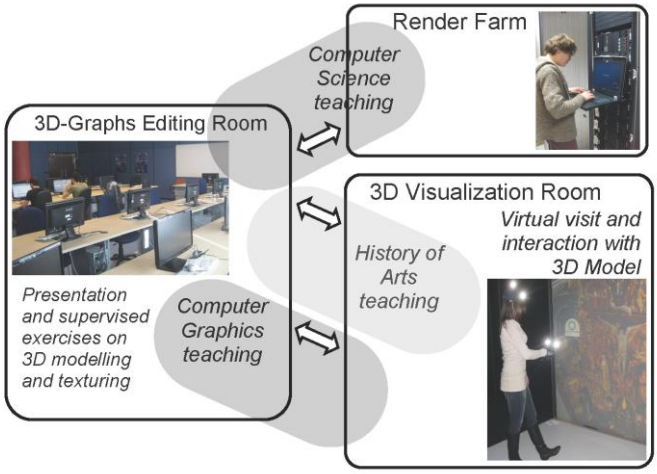


Fig.1 Main scheme of the new flexible platform



Fig.2 Interior view of the Church as it is nowadays



Fig.3 Comparison of mesh-generating systems for a Carthusian prayer group: original sculpture, mesh generated with the technique described above and mesh obtained with digital scanning

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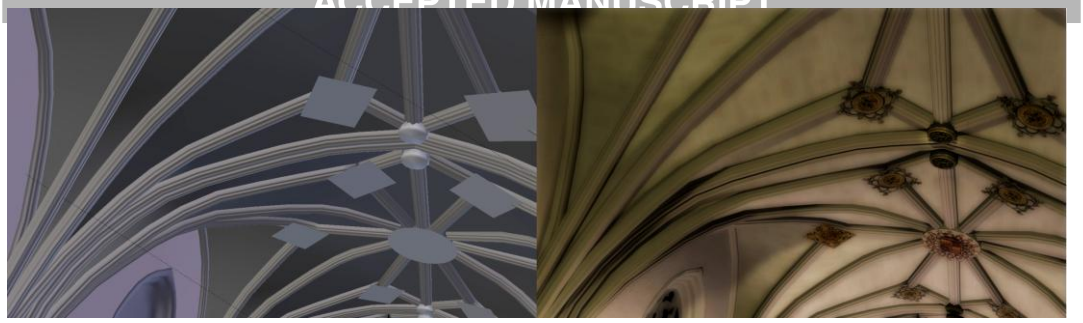


Fig.4 Shields without image texture and render of the shields with image texture using alpha channels



Fig.5 Projection of daylight through the windows on the opposite wall **(a);** Central view of the Church **(b)** and aerial view of the royal tomb **(c)**

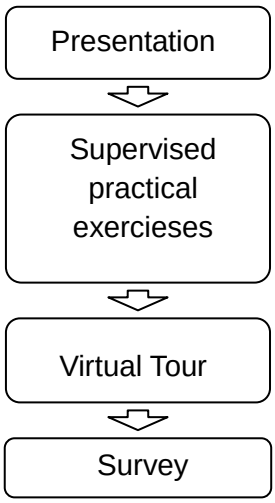


Fig.6 Stages of the teaching session



Fig.7 3D models the stained glass and final render and the lectern and final render

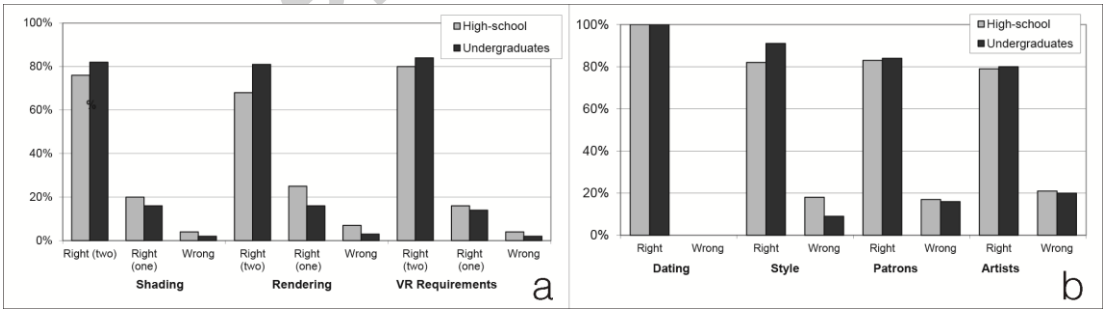


Fig.8 Student's knowledge of **(a)** the 3D modelling process and **(b)** Cultural Heritage topics after the teaching session

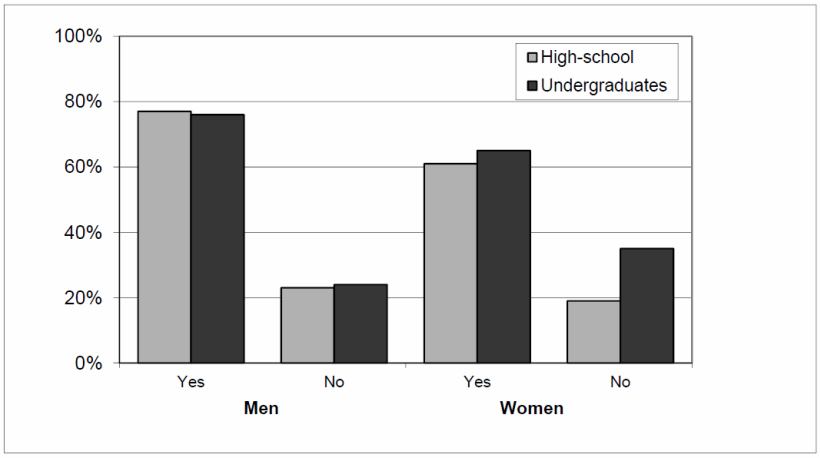


Fig.9 Willingness of students to create a 3D model by themselves

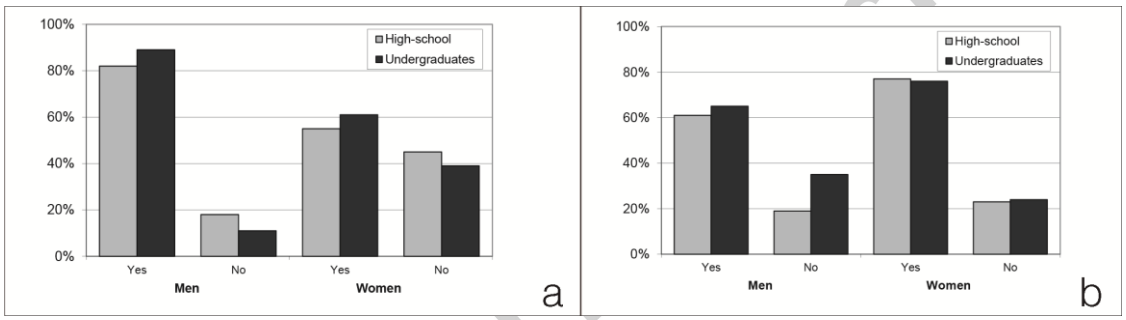


Fig.10 Interest in **(a)** Virtual Reality and **(b)** the Cultural Heritage Building after the teaching session

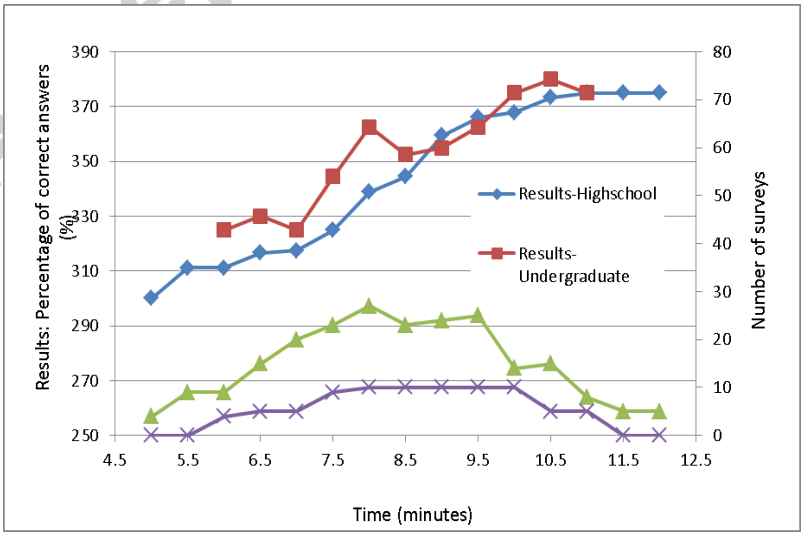


Fig.11. Learning rate of Cultural Heritage topics related to time spent in virtual environment