

Virtual Museums for all: Employing Game Technology for Edutainment

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Abstract. Museums have started to realise the potential of new technologies for the development of edutainment content and services for their visitors. Virtual reality technologies promise to offer a vivid, enjoyable experience to the museums guests, but the cost in time, effort and resources can prove to be overwhelming. In this paper, we propose the use of 3D game technologies for the purpose of developing affordable, easy to use and pleasing virtual environments. To this end, we present a case study based on an already developed version of a virtual museum and a newly implemented version that uses game technologies. The informal assessment indicates that game technologies can offer a prominent and viable solution to the need for affordable desktop virtual reality systems.

Keywords: *Virtual Museums, Desktop VR, 3D Game technologies*

Introduction

Museums host exhibitions in order to convey their message to their visitors. In the museum's context this is achieved by combining exhibits and information in a carefully designed order and presentation style. New technologies such as multimedia, 3D graphics and Virtual Reality can be used to enhance the presentation, offering a more vivid and enjoyable experience. A number of museums make use of images, sounds and video aiming to complement existing presentations and to create a memorable exhibition. In addition to this, during the past years a shift has taken place in the museums' identity, from simple holders of cultural objects to educative and at the same time entertaining institutions. Hands-on exhibitions allow their visitors, usually children, to interact with exhibits and to learn while they play with them [1].

However, this type of exhibitions, need careful planning in order to achieve their full potential and have to change in rather frequent time intervals to keep the visitors' interest. Furthermore, as any other type of exhibition they set a key prerequisite: visitor's physical presence. Although some museums have created interactive media that the visitors can acquire and use at their home, the overall experience cannot be compared to the one gained at the museum. To this end, virtual reality techniques could provide a plausible solution, but a variety of reasons hinder this approach.

In the rest of the paper we will describe some of these reasons supporting the rationale for more "affordable" (in terms of both development and hardware) virtual

reality implementations, discuss possible solutions to this problem and give useful insight to the development of virtual museums with game technologies and conclude with an informal assessment of this approach.

The Need for Affordable VR

Virtual reality technology can help museums overcome a number of limitations they face [2]. Virtual reality can help display exhibits the museum cannot present either due to lack of space or due to their fragility and their need for special handling. It can also help in cases when there is a need for visualising and simulating environments, constructions or objects that no longer exist, be partially preserved or cannot be easily visited [3].

The previously mentioned advantages can be coupled with the potential of virtual reality for more vivid and realistic experience in comparison to simple multimedia presentations. In a virtual environment exhibits can be observed from different viewpoints or even manipulated. Technologies such as haptic feedback may enable visitors to touch and feel valuable objects, or it may allow people with vision problems to sense an exhibit.

Especially in the case of museums that offer education through entertainment, otherwise known as edutainment [4], virtual reality can help create an environment where users will be able to learn by exploring, to get acquainted with the use of objects, guided by virtual agents through an exhibit's history or even assemble and disassemble it to pieces. So far, a number of research efforts have focused on the applications of virtual reality to museums and science centres. Pratt & Whitney exploited virtual reality to enable both students and visitors to get acquainted with the fundamentals of jet engines [5]. The Smithsonian Institution's National Museum of American History (NMAH), in partnership with Digital Artefacts and the University of Iowa have commenced a research project to evaluate the usability and potential applications for virtual environments in a museum setting [6]. Spalter et al. discuss issues encountered in the creation of an Immersive Virtual Reality -based educational project that aims to exploit Virtual Reality technology to enable the interaction with visualizations of abstract concepts [7], while Chen et al., present MUVEES, a PC-based multi-user learning environment with digitised museum resources, which targets middle school students aiming to enhance their motivation in learning about science [8]. In [9] Alison et al. present an immersive virtual environment that lets students immerse themselves in a gorilla habitat, assume the persona of an adolescent gorilla, and interact as part of a gorilla family unit. The Canadian Museum of Civilization and the Institute for Information Technology at the National Research Council of Canada (NRC) have produced an online VR museum of Inuit culture [10]. In [11], Mine presents some of the lessons learned during development of location-based entertainment attractions for Disney's indoor interactive theme park. For an overview of virtual reality museums, categorised according to the technologies employed one may also view [12].

So far, only a small number of museums have tried and exploited virtual reality technologies. Probably the main reason for the small infiltration is the affordability of

both the development of a virtual environment and of its execution. The development of a virtual environment is a difficult and time-consuming process especially when viewed in comparison to traditional information systems, since it requires the cooperation of a group of people with a variety of expertise in different areas. As with all information systems a system programmer and probably a user interface designer are necessary for the programming of devices and the development of interaction. Apart from these experts, an architect will be valuable for the design of the virtual space, a domain expert (e.g. archaeologist for archaeological museums, a zoologist for zoological museums etc) will be of the essence for the selection of objects to be digitised, their classification and the preparation of accompanying material. A graphic designer should also be required for the digitisation and optimisation of digitised objects. All these experts have to cooperate and work closely together in order to implement a user friendly, easy to use virtual environment.

On the other hand, experience with the development of virtual environments is scarce, far less than that of ordinary information systems. Design and implementation of virtual environment systems has started to advance and find application only during the last ten or so years and, to this end, research on various aspects of the design and implementation is needed. This results in a lack of guidelines and methodologies and a subsequent extension in the development effort and time for new virtual reality systems.

Execution of virtual environments is also an issue. Traditionally, virtual reality systems require a high-end system with a graphics accelerator card and special input and display devices. Usually such a state-of-the-art system is costly to build and maintain. In addition, peripherals such as 3D input devices, haptic devices, etc. are sometimes experimental and most often sensitive to frequent and/or hard usage, rendering them inappropriate for use in a museum.

For virtual environments to be successfully exploited in the context of edutainment in museums, these impediments have to be removed or at least minimised. For the development of virtual environments, the processes of creating the virtual space, programming interaction, interfacing devices and populating the space with digitised objects have to be facilitated and the cost of this phase has to be reduced. The requirements of the execution environment have also to be reduced to less 'exotic' standards, if virtual reality technologies are to be adopted by museums. These barriers became more evident in the deployment and maintenance phases of the "Virtual Museums" project (discussed in the next section), during which museums were reluctant to withstand the (considerable) cost of buying the development environment, while at the same time prospective visitors would have to own extravagant hardware to be able to use the virtual environment in their homes.

The "Virtual Museums" Project

"Virtual Museums" [13] was a project implemented in the framework of EPET-II, a Greek Secretariat of Research funded programme. Virtual Museums aimed to explore the use of virtual reality technologies in the premises of museums, to help both researchers and the general public in visualising artefacts, learning their use and in

viewing exhibits that were not usually displayed. The project created two systems: one with a high-end configuration, with support for Head Mounted Displays and trackers for use by researchers and a small number of individuals, and a desktop version that was targeted for use by the open public. For the design and implementation of these virtual museums, the following tasks were carried out:

1. *Exhibit selection*: museum curators select the most appropriate exhibits, taking into account the exhibit significance, the *message* that the virtual museum must communicate and the profile of the visitors.
2. *Exhibition space design*. During this phase, the exhibition space is designed, usually comprised of halls, foyers and corridors. The exhibition space must be appropriate for the exhibits selected, while its structure may allow for different levels of *movement freedom*: linear hall sequences direct visitors through a predetermined path, while foyers with entrances to different wings permit a more flexible choice of route within the museum.
3. *Selection of presentation methods*. For each exhibit, the most prominent presentation methods are chosen. This may include any combination of 2D photos, 3D photos, audio, video, 3D models, textual descriptions, etc.
4. *Interaction design*. At this stage, the allowable interactions with each exhibit are specified. Certain exhibits may be only viewed; others may be rotated, moved or even decomposed and reassembled. Interaction design should be correlated with presentation methods, since some presentation methods are inherently more restrictive than others (e.g. 3D photos allow less interaction than 3D models).
5. *Exhibit digitisation*. Once the presentation and interaction requirements for each exhibit have been determined, digital representations for each exhibit are created.
6. *Placement of exhibits within the exhibition space*. During this phase the digital representations of the exhibits are placed in appropriate locations within the exhibition space.
7. *Interaction programming*. Within this step the necessary actions for delivering the specified interaction capabilities are performed. These actions may range from simply defining hotspots or animation sequences to writing complex, custom code, depending on the desired interaction capabilities and the facilities offered by the development environment.

These steps are usually taken sequentially (some of them can be actually performed in parallel, e.g. exhibition space design and selection of exhibit presentation methods), while iterations may be introduced to improve decisions taken in previous steps.

It has to be pointed out that the work performed within some of these steps is dependent on the platform through which the Virtual Museum will be accessible to the users. For instance, an environment offering an extensive library of built-in interaction methods will greatly reduce the effort required for attaining the desired interaction levels. Exhibit digitisation may also be facilitated if the chosen environment provides support for popular data formats, such as 3D Studio or VRML models. Lack for such support may influence the presentation methods that will finally be available in the VR-museum. Finally, the environment capabilities may impact the exhibition space design: some engines become sluggish and unresponsive if the overall virtual world is large. The solution to this can be to segment the virtual museum into smaller areas, which will be loaded/unloaded when the user crosses

certain spots, this however can introduce delays and degrade user experience. Thus an engine capable of handling large virtual worlds efficiently is preferable.

The platform used for the implementation of the systems was Sense8's World Toolkit (WTK) for the high-end version and Sense8's World Up (WUP) for the desktop version. Although successful, the program re-established what was anticipated: the cost in effort, time and resources for developing and maintaining a virtual museum was overwhelming for most small or medium-size museums, so, despite their willingness to develop and maintain virtual environments, this was not possible. A more viable solution would require fewer resources in the tasks associated with the creation of the virtual museum and the necessary infrastructure, minimising the requirements on the following factors, which are –generally– the most demanding in terms of resources:

- *Hardware and software infrastructure.* The development platform software (World Up) has a significant acquisition cost, and imposes certain requirements on the hardware platform. The selection of a less costly and less demanding platform, which would deliver all the necessary functionality, would be highly desirable.
- *Interaction programming.* Interaction programming has a significant impact on the overall cost for virtual museum development, since -being a specialised technique- requires high expertise and corresponding resources. Reducing thus the need for interaction programming would significantly decrease the overall costs associated with museum development.
- *Exhibit digitisation.* Although the costs associated with exhibit digitisation may seem orthogonal to other tasks or the development environment, it is worth noting that certain development environments place very strict requirements on the specifications of the exhibits to be imported, encumbering thus the digitisation process and increasing the cost associated with this task.
- *Placement of exhibits within the exhibition space.* The effort and resources required for this task may range from little to substantial, depending on the tools employed. Visual editors allowing for interactive object placement and examination reduce the overall resource consumption, compared to non-graphical interfaces, or authoring environments where objects are placed using one tool and the virtual world is viewed using another. Similar remarks hold for other items within the virtual world, such as lights, sounds, animations etc.

Games Engines: a Solution

Taking into account the issues outlined in the previous section, and since the digitisation of a sufficient number of the participating museum exhibits had already taken place, it was considered a good opportunity to investigate the feasibility of implementing a virtual reality museum with the use of 3D game technologies. Such an alternative would allow users to view and navigate in a virtual world, even in the location of their home, without noticeable compromise in the overall quality. Furthermore, the interaction style of game applications in non-game domains can be compelling, as suggested in [14]. This solution to the need for affordable VR is offered by from the game software industry, which, during the past few years, has

followed hardware evolution, and from simple sprite graphics (i.e. a small rectangle of pixels depicting a virtual character, usually in games) has come to offer colourful, crisp and life-like 3D graphics. Game technology has managed to develop systems that on the one hand exploit computer's potential to the maximum and on the other offer the user a sophisticated, interactive environment with 3D graphics and in some cases immersion capabilities that can be enjoyed at even a moderate home computer. As Lewis and Jacobson [15] point out:

"While precise multimodal VE simulations such as those required for remote surgery will continue to demand custom solutions, for most VE applications a game engine can add value by performing 3D bookkeeping, providing networking and synchronization, or driving high-fidelity hardware accelerated graphics. "

The idea of employing a game engine for non-game applications is not new. 3D game engines have found their way to a number of non-game applications ranging from CAVE™ installations to simulating context-aware services. Freudenberg et al., describe a Virtual Reconstruction of the buildings discovered in an archaeological excavation, presented in a spherical projection chamber employing the real-time rendering capabilities of a game engine [16]. Jacobson describes CaveUT, an extension to Unreal Tournament™ game engine that allows the implementation of immersive large displays. [17]. Rhyne [18] discusses applications of games engines for scientific visualization, while Chao [19] presents a novel interface for system administration, which is based on the Doom game engine. Cummins [20] discusses applications of games into the e-commerce area, presenting arguments for designing e-commerce interactive systems that install into games. Bylund and Espinoza [21] present QuakeSim, a system based on Quake III Arena™ that is used to evaluate and demonstrate context-aware services. Finally, Cavazza et al [22], describe a system that is developed on top of the Unreal Tournament™ game engine and which implements interactive storytelling functionality.

3D game engines offer a number of features that cannot easily be disregarded. From the user's point of view they offer a customisable environment that can be adapted to both their needs and to a large degree to their home computer specification, since most of the 3D games support a variety of peripherals, graphic cards and screen resolution. From the developer's point of view these games offer a robust, well-tested environment that implements an efficient graphics engine. Some of these environments include their own development tools that can be used to extend or alter the system, while they also comprise of a number of pre-made functions and code, reducing the effort needed for development of new games. Fig. 1 and Fig. 2, illustrate two popular 3D games, namely Unreal™ and Quake™. Both systems offer a wealth of features, typical for a game of this type. The user is able to navigate in a 3D environment, play either stand-alone or connect and compete with other players, to choose the avatar that will represent her in the environment and with which other users will identify her, to download new levels, avatars, etc.



Fig. 1. Screenshot from Quake™



Fig. 2. Screenshot from Unreal Tournament™

To this end, a small survey was carried out and the platform of Unreal Tournament™ was selected as the testing platform, because it offered functionality and advantages considered to be useful:

- *Extensible environment.* The engine of the Unreal Tournament™ was highly extensible and configurable, allowing it to be tailored to the requirements of creating virtual exhibitions.
- *Small execution requirements.* The Unreal Tournament™ engine runs smoothly on low-end PCs, equipped with a 233 MHz processor, 32 MBytes of RAM and a graphics card with 4 MBytes of RAM, presenting an adequate level of detail. For higher levels of detail and/or more complex virtual worlds, these requirements scale up to a 300 MHz processor, 64 MBytes of RAM and a graphics card with 8 MBytes of RAM and an entry-level graphics accelerator, which are quite typical in modern PCs.
- *Design tools.* The Unreal™ Engine comes complete with an editor for designing virtual worlds, the *Unreal Editor*. This editor is quite intuitive and easy to use, and many users have already employed it to create new levels, avatars, weapons etc for the Unreal Tournament. The Unreal editor provides also tools for importing spaces and exhibits from many popular 3D modelling tools, including LightWave [22], 3D Studio Max [23] and Maya [24]. For 2D exhibits and animation sequences the Unreal engine suite directly supports common graphics formats, such as JPG, PCX and animated GIFs, while for audible content all the most commonly used formats (e.g. WAV, MP3, OGG, MID, RMI) can be converted to the natively supported UMX and UAX formats through the Music Browser tool included in the Unreal engine suite.
- *Support for immersion and VR.* The Unreal™ Engine directly supports a number of configurations for immersive VR environments, such as stereo displays, 3D glasses etc., without imposing needs for significantly better hardware.

All the above features, coupled with extensive built-in libraries for interaction, smooth scrolling of the virtual world (even for large and complex virtual spaces) and support for high levels of interactivity, led to the choice of the Unreal™ suite for building the experimental virtual museum.

Applying 3D Game Technology to VR Museums

Application of game technology to virtual reality museums involves the mapping of tasks that have to be performed in the context of a virtual reality museum to respective tasks that take place within a 3D game. Moving is directly mapped, although some moves (e.g. jumping) may have to be restricted since they are not useful in a VR museum. Regarding object (exhibit) examination and manipulation, this may be mapped to actions that users may perform on objects they find within a game, including rotation for examination purposes, viewing of help messages (usually textual descriptions) and moving or carrying. Under certain circumstances, performing an action on an object causes the object to be replaced by some other object –or a set of objects. This feature comes in very handy for implementing exhibit decomposition and composition, where decomposition may be modelled by replacing an object with a set of other objects representing its components, while assembly can be represented by substituting the components with the whole object. Finally, actions on objects may trigger the reproduction of audible media, video, or animation sequences. This set of interaction elements is adequate to implement most user activities needed in the context of a virtual museum, thus the need for interaction programming is minimised: implementing the required interaction is reduced to the specification of the respective properties on the appropriate object, using the Unreal editor.

For the development of the exhibition space, first a sketch of the Virtual Museum was drawn depicting the overall space and the placement of each individual exhibit as presented in Fig. 3. As depicted in the figure, exhibits were arranged into collections in separate rooms, one for each collection. Important exhibits were presented in separate rooms.

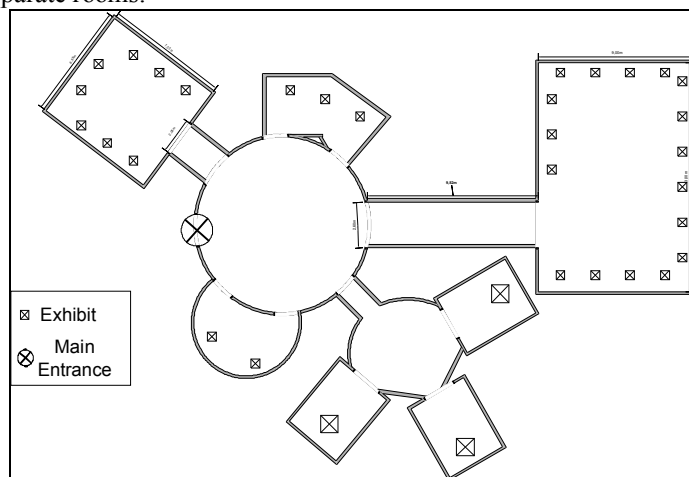


Fig. 3. Topographical map of the Virtual Museum

Consequently, 3D Studio Max™ was used to create the 3D space, and the results were initially exported in the ASE format (ASCII Scene Export) and then converted to T3D format, using the ASEtoT3D utility. Then, the exhibition space was imported

to the Unreal editor and an appropriate surface was applied. Fig. 4 shows an exhibition space in the Unreal editor; on the left, only the mesh (3D layout) is displayed, while on the right an aspect of this exhibition space is displayed, after a surface has been applied.

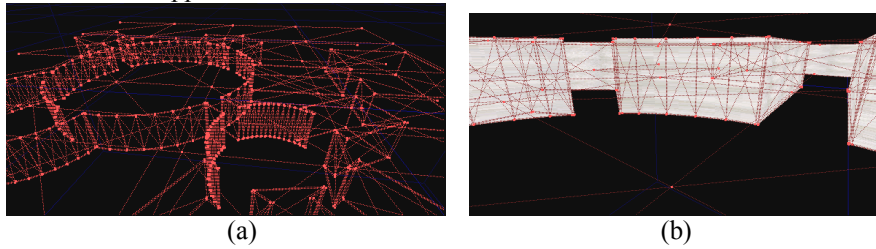


Fig. 4. (a) Exhibition space mesh (b) Exhibition space with surface applied

Once the exhibition space has been imported into the Unreal™ Editor (**Fig. 5**), the exhibit placement phase may commence. Initially, a preparatory step is required to create a file structure (directories and certain files); this step is automated and can be bundled into the execution of a program, which reads from the user the museum name and arranges for the proper directories and files to be created. Then, the digital representations of the exhibits need to be installed in the appropriate location in this directory structure, after they have been converted into the appropriate format (the native 3D object format for the Unreal suite is the UNR format). In the developed museum, 3D exhibits were created using the 3D Studio Max environment, and the conversion and the installation of the exhibits were performed in a single step using the *3ds2unr* [25] tool. Similar tools exist for 3D models in other formats, while most major 3D development packages support exporting to the 3D Studio format, thus the *3ds2unr* tool is adequate for all conversions. Once the 3D exhibits have been converted and installed in the proper directories, they can be viewed using the *Mesh browser*, integrated into the Unreal Editor and then placed into the exhibition space. An exhibit viewed using the Mesh Browser is depicted in **Fig. 6**.

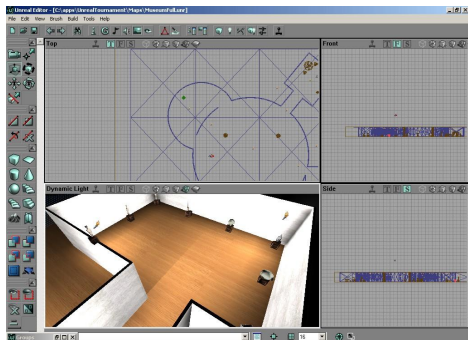


Fig. 5. Screenshot of the Unreal Editor

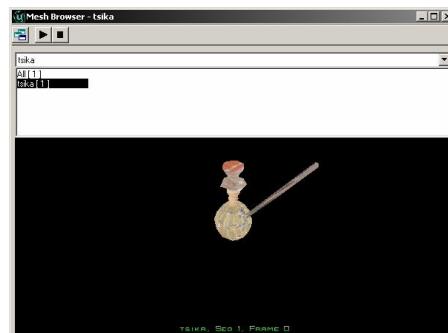


Fig. 6. 3D exhibit in the Unreal Editor's Mesh Browser

Once the exhibition space has been set up and the exhibits are in place, a number of activities for enhancing the user experience may commence, such as selection of

background music, assignment of sounds to certain events, definition and tuning of light sources, presentation of area maps upon user request etc. All these activities are performed through the Unreal Editor.

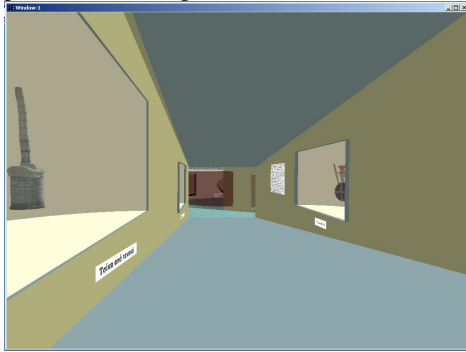


Fig. 7. Exhibit hall from the original version



Fig. 8. Exhibit hall from the game version

The game version of the museum was developed as part of an internal research project. A record of the necessary development steps along with problems that occurred and solutions explored (in a Design Rationale form) was kept. Since the game version of the museums followed the same basic principles as with the original version, no museum curator was actively involved in the project.

Game version assessment

In order to evaluate the suitability of a game platform as a system for implementing a virtual museum for a generic audience, one has to assess the effort and resources needed for its development, the requirements set for the execution environment as well as the users' opinion of the system. Although user satisfaction is and should be the primary objective, resources for the development and requirements set for the execution also are of significance.

Development effort

The time spent and the effort required for the development of the virtual museum using game technologies can be evaluated against the effort spent for development of the original version of the virtual museums. The first phases of the development procedure are common for both implementation approaches. That is, the resources dedicated for the selection of exhibits, the design of the exhibition space, the selection of presentation methods and the design of interaction are the same for both approaches. The differentiation starts with the actual implementation phase of the virtual museum. As described in the previous section, some extra effort was needed for the conversion of digitised objects into the format read by the Unreal graphics engine. Time needed for exporting objects in the Unreal format cannot be regarded as

a development overhead, because comparable effort had been given during the creation of the exhibits in the native format required for the original version of the virtual museums. Moreover, both tasks can be semi-automated, minimising thus user involvement in the whole process.

Overall, importing spaces and objects into the game environment was rather straightforward. The virtual environment editor, which was bundled with the game software featured functionality comparable to that of most 3D designer packages, making the placement of exhibits in the museum space and the construction of the virtual exhibition easy.

In contrast to the development of the original version of the virtual museums where effort was put in writing code handling the interaction of users in the environment, in the game-based version, more effort seemed to be devoted to learning the new application-programming interface (API) and to customising its object classes to fit the interaction design. That was due to the fact that most of the functionality needed was already built-in the platform. On the other hand there was a lack of detailed documentation, which often resulted in spending a lot of time to discover simple features. This was somewhat anticipated, since this was primarily a game software and whatever programming documentation was intended for users who wanted to create their own game levels and not for programmers who wanted to extend the API. It has to be pointed out that the customisations needed to be performed have now been documented in detail, thus the process of building a new virtual museum in the Unreal suite runs now smoothly, without the need for locating extra information on customisations or techniques.

For the development of the virtual museum the programmer has to customise the environment and alter some of the game-based functionality. First of all, the programmer has to disable opponent computer-controlled avatars and to hide the weapons and the health-status bar. Secondly, the system menus have to be modified to enable the user to easily select the museum space she wants to visit. It has to be pointed out that the system can be configured so as to directly load a museum upon starting, but for the requirements of this case study, it was thought better to keep the look and feel of the game environment, where the user selects the 'level' she wants to load.

Some of the game functionality proved to be useful. The system could display, without the need of extra programming effort, a 2D map of the virtual space. This was considered to be an important feature, especially for large museum spaces, because it could be used as a navigational aid for the user [26]. Other features offered by the system, such as teleporting or the ability to save the 'game' were also useful. The first of them can be used to move the user to a predefined position. The system supports two variations of teleporting: one where the environment designer creates 'shortcuts' between points in the virtual space and marks them accordingly, and a second where the user can set a bookmark at point of interest and be transported to it afterwards. Storing an instance of the navigation can be practical in cases where the virtual space is large or the user wants to quit navigation and continue at a later time.

In total, taking into consideration the time spent for learning to use the development environment, it required almost half the effort to build the environment with game technologies than with 'traditional' tools, mainly due to the functionality that was built-in the game engine and was readily available for use.

Execution environment requirements

Requirements set by the virtual museum for its execution environment are of key importance, especially if the application is to be experienced by users at their desktop computer at home. Usually virtual reality systems require a high-end computer and often it may demand even more 'exotic' for the average user technologies. As pointed out earlier, 3D games have managed to operate efficiently in small, common personal computers. Both versions, the original desktop version and the game-technology version, were tested on two different configurations, one high-end and one medium. The first was a PC with an AMD Athlon at 1GHz, 512 MBs of RAM, an Oxygen GVX420 graphics card at 1024x768@100 Hz with a 21" monitor, while the second was a PC with an Intel Pentium III at 450 MHz, 256 MBs of RAM and an Elsa Erazor III LT graphics card running at 800x600@100 Hz with a 17" monitor. The original version of the virtual museum ran without problems on the high-end PC, but had problems on the medium configuration computer, namely the system's response and animation were very slow. The game version of the virtual museum operated smoothly on both PCs.

It has also to be noted that the medium configuration computer supported the use of shutter glasses, offering the possibility of having a semi-immersive system with low-cost. Performance was not optimum but the user could get a good sense of perspective and depth as described in the interaction assessment section.

Interaction evaluation

Both systems were comparatively evaluated by a small group of users. Due to the small number of participants (10 persons) this was more of an informal study rather than a controlled experiment. However, the results indicate where the strong points of each version of the virtual museums lie. Evaluation participants were undergraduate and postgraduate students who volunteered to test both environments. Their age varied from 20 to 29 years, all of the users had prior experience with computers, while only three out of ten claimed prior experience with computer games. About two thirds of the participants had a computer at home, which they used mainly for activities related to their academic responsibilities. Half of the participants were men.

Evaluation comprised of three distinct phases. During the first phase, participants were briefed by an instructor on the aim of the evaluation, the two systems configuration and were introduced to navigation in the virtual environment and manipulation of exhibits. During the second phase of the evaluation participants had a chance to use each one of the configurations. Participants tried in random order, the high end PC and the low end, with both versions of the virtual museum. At the end of the second phase participants had a chance to try the low end PC with shutter glasses. A joystick was used as an input device for both systems and software versions. Actions with the Joystick were configured to be identical for the two versions. There was also an effort to calibrate the Joystick to perform equivalently in both systems, but for the low-end machine the Joystick response in the two systems (original and game technology based) was not identical. When users tried to move at a fast pace, the original version of the system became sluggish and interaction deteriorated.

During this phase the instructor was present and kept notes of the users' interaction with the systems. The instructor also aided the users whenever they had problems with the navigation or manipulation of exhibits. Although participants were free to wander in the virtual space and there was no predetermined path of navigation, the instructor encouraged them in performing actions in order to be able to better assess the system. For example, the instructor might encourage the user to grab and rotate an exhibit or to read a sign. The average time a user spent in each configuration was ten minutes, but if a user preferred to spend less or more time in the museum she could.

During the last phase the participants completed a questionnaire. The questionnaire consisted of questions regarding the participants' profile and their experience. Participants were asked to rate the four configurations according to whether it was easy to navigate and manipulate, enjoyable and pleasing, stimulating, if the quality of the graphics was good, if the refresh rate and animation scrolling were adequate, etc. Participants could also make some general comments and remarks regarding their experience, things they liked or they disliked. In the next figure (Fig. 9), the part of the questionnaire that addresses the user experience is being presented. Table 1 summarises the users' responses. Since the number of subjects was small there was no additional statistical processing of the data, in terms of statistical significance tests.

1. The software was:								
	1	2	3	4	5			0
terrible						wonderful	NA	
2. The software was:								
	1	2	3	4	5			0
difficult						easy	NA	
3. The software was:								
	1	2	3	4	5			0
frustrating						satisfying	NA	
4. The software had:								
	1	2	3	4	5			0
inadequate power						adequate power	NA	
5. The software was:								
	1	2	3	4	5			0
dull						stimulating	NA	
6. The software was:								
	1	2	3	4	5			0
rigid						flexible	NA	
7. Reading characters on the screen was:								
	1	2	3	4	5			0
hard						easy	NA	
8. Image quality was:								
	1	2	3	4	5			0
bad						very good	NA	
9. Animation was:								
	1	2	3	4	5			0
slow						very good	NA	
10. Sense of depth was:								
	1	2	3	4	5			0
bad						very good	NA	
11. I felt I was really in the Virtual Environment:								
	1	2	3	4	5			0
Not true						true	NA	

Fig. 9. Questions regarding user Questionnaire

Table 1. Quantitative data for the above questions

Question No.	Game version				Original version			
	Low-end Conf		High-end Conf		Low-end Conf		High-end Conf	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1.	4.1	0.74	4.5	0.53	2.2	0.92	3.9	0.88
2.	3.3	1.16	3.9	0.99	3.2	0.63	3.4	1.17
3.	3.4	0.70	3	0.94	2.1	0.74	3.6	0.70

Question No.	Game version				Original version			
	Low-end Conf		High-end Conf		Low-end Conf		High-end Conf	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
4.	3.4	0.70	3.5	1.18	3.1	0.99	3.9	0.32
5.	3.8	0.79	3.8	1.03	2.1	0.57	3.7	0.67
6.	3.9	0.99	3.5	0.85	2.2	0.79	3.8	0.92
7.	3.0	1.10	3.2	0.88	3.4	1.23	3.7	1.26
8.	3.7	0.82	3.8	1.14	3.2	0.79	3.9	0.74
9.	3.6	0.70	3.8	1.14	3.2	1.32	3.4	0.84
10.	2	0.94	2.4	0.84	2.1	0.74	3.1	0.99
11.	2.4	0.84	3.1	0.99	1.8	0.63	3.3	0.67

- *Rating of overall experience (questions 1, 3, 5, 6).* Most users found their experience of both systems in the high-end configuration and of the game version in the low-end configuration pleasing and enjoyable. On the other hand, participants rated negatively the original version of the system that ran on the low-end configuration. Most of them found this system and configuration annoying and were disappointed by the overall experience.
- *Ease of use (question 2).* All of the versions in all configurations were found easy to use. Again the rating for the original in the low-end configuration was rated lower than the other three. Some of the participants complained that the game version with shutter glasses running at the low-end system was tiring after some use.
- *Animation scrolling (questions 4, 9).* The original version was rated as the poorest, while the game version on the high-end configuration was unanimously rated to have the smoothest animation scrolling.
- *Image quality (questions 7, 8).* All configurations and systems were rated high in the image quality and detail. The best rating was for the original version of the museum on the high-end configuration. The lower rating for the game version could be attributed to some technical problems in the process of importing images in the game environment.
- *Sense of presence (questions 10, 11).* The versions without shutter glasses that ran on the low-end configuration were rated as *weak* in the sense of presence. The game version on the low-end configuration with shutter glasses was rated as offering a medium sense of presence by the majority of participants. Participants' opinion on the high-end configuration was divided between weak and medium, probably due to wider screen monitor. Four of the participants also wanted to try the original version at the high-end configuration and with shutter glasses. They claimed to have a good sense of presence and all agreed that they felt “they could reach and touch objects”.

It has to be noted that from the group of participants, those who had played with 3D games before, commented that the environment was familiar, easy to use and stimulating. Additionally, two of the participants suggested that the detail and quality of the 3D exhibits in the game version could be inadequate for research purposes.

Finally, four of the participants suggested that for all the environments there was a need for a better sense of objects' size.

Conclusions - Future Work

In this paper we presented our on-going work on desktop virtual reality systems for museums and edutainment institutions and particularly that of exploiting 3D games technology for the development of virtual museums. The informal study and assessment of this approach indicates that use of these technologies in the context of edutainment is prominent. These technologies deliver adequate quality for the majority of the target audience of a virtual museum with the extra advantage of the reduced need for development and system resources. The exocentric view provided by most game engines may be used to aid users in acquiring a better sense of the exhibits' size in the virtual environment and to help them in their visual search tasks [27]. However, researchers have commented that these technologies sacrifice some detail, which may prove valuable for a thorough study. In such cases the extra effort in development and resources required can be well justified.

Future work will include a detailed evaluation of the suitability of game technologies with special focus on the users' sense of presence and immersion, the use game-bots as exhibition guides in the virtual museum and the exploitation of multiplayer functionality for collaborative activities in the virtual environment.

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