Utilising 3D Realistic Models in Serious Games for Cultural Heritage

Georgia Kontogianni, Christos Koutsaftis, Margarita Skamantzari, Andreas Georgopoulos, Laboratory of Photogrammetry, School of Rural and Surveying Engineering, National Technical University of Athens, Athens, Greece
Christina Chrysanthopoulou, Department of Fine Arts, Athens School of Fine Arts, Athens, Greece

ABSTRACT
In the cultural heritage field, many Serious Games applications have been developed whose goal is to educate players and users not particularly specialized or familiar with this field. On the other hand, 3D models of cultural heritage objects created with precise 3D modelling methods can be a very useful asset for these applications. In this paper a composite Serious Game for the Stoa of Attalos, a prominent monument in the Ancient Athens Agora, is developed and presented. 3D models are used, which were produced mainly with automated image based modelling techniques. The creation of the 3D models is described and presented along with the development of the application, which offers three options for the player. These options are: a quiz game, a 3D visual quiz and a virtual museum. The user interaction is described and, based on an evaluation questionnaire, the application is assessed by a group of people in the Cultural Heritage field.

Keywords: 3D Models, Cultural Heritage, Image-Based Modelling, Serious Games, Stoa of Attalos

INTRODUCTION

Nowadays, there are techniques available to create realistic 3D models of practically any object, among which are also cultural heritage assets. These 3D models can actually represent reality in extremely vivid ways. This can be very useful in many virtual reality applications. Realistic textured 3D models can be created using different methods. When based on 3D digitization, these methods may include laser scanning, digital imaging or a combination. In the cultural heritage domain, a 3D model can represent a whole building but also smaller objects, such as exhibits in museums, decorative elements, etc. They are very important media in *serious games* applications for cultural heritage, because they can help people that are not specialized in this scientific domain, such as tourists, school children, college students, museum visitors and others, to gain experience, expand their knowledge and stimulate their interest. The basic goal of this paper is to demonstrate and evaluate the usage of realistic 3D models created with 3D reconstruction techniques (mainly image-based) in a serious game developed for *the Stoa of Attalos* monument, in Athens Greece. The rest of the paper is organized as follows: in the next section an overview of the most important implementations of serious games in the cultural heritage domain is presented; then some basic thoughts concerning *geomatics and 3D modelling* are presented; in section 4 the creation of the 3D models of the objects used for the development of the "*Discovering the Stoa of Attalos*" application is presented and explained; next the development of the application is described in detail, highlighting the various decisions taken;

furthermore, the evaluation of the application is presented, and finally, some concluding remarks and the future perspectives of the project are introduced.

SERIOUS GAMES IN CULTURAL HERITAGE

During the last decade, many serious games applications have been developed in the cultural heritage field. The most representative ones have been selected and are briefly presented. The *Roma Nova* (Rome Reborn) project, whose main goal is the production of a high-resolution version of the city of Rome in 320 A.D. using procedural modelling techniques was developed a few years ago (Vourvopoulos, Liarokapis & Petridis, 2012). In the *Ancient Pompeii* (Maim et al., 2007) application the player tries to simulate a crowd of virtual Romans who exhibit realistic behavior in a specific district of Pompeii. Another interesting serious game application is the *virtual reality reconstruction of Otranto*, an Italian city during the middle ages (De Paolis, Aloisio Maria, Celentano, Oliva & Vecchio, 2011). *Virtual Egyptian temple* (Jacobson, Holden, Studios &Toronto, 2005; Troche & Jacobson, 2010) is a game about a hypothetical temple that does not exist in reality. The temple is a typical representation of the New Kingdom era and is divided into four areas, each one housing an instance of the High Priest. Also, each area represents a different feature from the architecture of the era of the representation. *Gate of Horus* (Jacobson, Handron & Holden, 2009) is an application based on an ancient Egyptian temple, in which students can learn through a virtual priest who challenges them to demonstrate knowledge. The Foundation of the Hellenic World (FHW) has developed the *Ancient Olympic Games* project, which includes a number of gaming applications related to the Olympic Games in Ancient Greece (Gaitatzes, Christopoulos & Papaioannou, 2004). A treasure hunt scenario for medieval objects located in and around the remains of Coventry's original Benedictine monastery, demolished by Henry VIII, is the theme of the *Priory Undercrofts* game (Doulamis, Liarokapis, Petridis & Miaoulis, 2012). A game that uses storytelling techniques and principles of modern videogames is the *Battle of Thermopylae* (Christopoulos, Mavridis, Andreadis & Karigiannis, 2011). In this game, the player learns many things about the battle and the associated legends. *THIATRO* (Froschauer, Arends, Goldfarb & Merkl, 2012; Froschauer, Merkl, Arends & Goldfarb, 2013) is a history of art serious game, in which the player can assume the role of a museum curator. The *Via Appia* application is an indirect augmented reality system, in which 1km of Via Appia Antica has been reconstructed in three different time periods and the user can explore the notion of narrative movements and travel across space and time in a cultural heritage context. Furthermore, it includes a quiz game with questions related to the information provided by the game (Liestol, 2014). A game, in which teenagers are able to construct the south portal of the Gothic cathedral of Amiens in France, is *Your Stone to the Building* (Leclet-Groux, Caron, Mouaddib & Anghour, 2013). *ICURA* is an application for intangible cultural heritage and especially for the Japanese culture and etiquette (Froschauer, Seidel, Gartner, Berger & Merkl, 2010). *MuseUs* is an attempt for developing an application to be used in museums that also runs as a smartphone application, in which the player is invited to create his/her own exhibition during a visit to a museum (Coenen, Mostmans & Naessens, 2013) for which it is available. *MyMuseum* is a serious game application, in which the players are able to experience and learn about the museum objects by creating their own virtual gallery space on Facebook (Goins, 2010). The *PLAYHIST* experiment is an attempt to develop a serious game, which will allow players to act and interact by posing as a historical character in a 3D environment, recreating one of the historical moments depicted in the Foundation of the Hellenic World

(FHW) and achieving a better knowledge about history (Perez-Valle, Aguirrezabal & Sillaurren, 2014). The main goal of *TouchBIM* application is to archive and educate the player on the Korean architectural heritage and its construction techniques (Lee, Kang, Kim, Lee & Goo, 2014). The main goal of the *Fort Ross Virtual Warehouse* serious game is to explore novel ways for archiving, disseminating and teaching cultural and historical information (Lercari, Mortara & Forte, 2013). The *i-Treasures* is a EU funded project whose first phase includes four novel game-like educational applications, which are: i) the Human Beat Box for traditional singing; ii) the popular Greek Tsamiko dance; iii) the art of making pottery and iv) the contemporary music composition (Dimitropoulos et al., 2014; Dagnino et al., 2015). The application of the *Medieval Craftsmen at Castle Waldenfels* in Austria (Kieu, Fershin & Angelo, 2015) has as main goal to teach the player about the medieval construction work. The application is divided into four levels including the recruitment of construction workers, the collection and processing of the materials, the operating construction devices and the completion of the medieval castle. The *Synthesis virtual museum* is a web-based virtual museum which relies and exploits the rich content of internal and external web cultural resources in order to encourage the users to create their own exhibitions with the use of cross-platforms gaming technologies (Kiourt, Koutsoudis, Markantonatou & Pavlidis. 2016). *DynaMus*[1] is the upgrade of *the Synthesis virtual museum* (Kiourt, Koutsoudis & Pavlidis, 2016). The Virtual Agora is a virtual heritage application in the Open Simulator environment which has as main goal to replicate daily life in the ancient Greek agora with the use of biologically-inspired motivation agents (Vosinakis & Avradinis, 2016). In another cultural heritage application the player has the opportunity to learn about the Cycladic sculpture by taking the role of a sculptor and progressively create a statue by selecting and applying the appropriate tools. The application is based on bare hand interactions supported by Leap Motion (Vosinakis, Koutsabasis, Makris & Sagia, 2016).

THE STOA OF ATTALOS & THE HISTORY OF THE MUSEUM

The history of the Stoa of Attalos museum is intertwined with the history of the reconstruction of the Stoa. Within a few years of the beginning of the excavations at the Agora, the Old Excavation House was no longer sufficient and plans for an on-site museum to present objects in their context were well underway even before the outbreak of World War II. The area west of the Areopagus seemed a suitable location for such a museum, and in 1946, preliminary excavation began there and sketches pf potential building plans were drawn up. The restoration of an ancient building was recommended by excavation director Homer A. Thomson when the excavations brought to light important features and finds. The Stoa of Attalos, built by King Attalos II Pergamon at 159-138 B.C was chosen because its form was suitable for museum gallery. The reconstruction was carried out with the generous financial support of John D. Rockefeller Jr. between 1953-1956.

Today the Stoa not only provides ample space for storage, research and the display of objects, but also allows the visitor to appreciate the function and form of this common type of ancient public building. It is an excellent example of the fully developed type of stoa. On each of its two stories a two-aisled colonnade was backed by a row of 21 rooms, which served chiefly as shops. In front, a broad terrace ran the entire length of the building. The main function of the Stoa was to provide a sheltered promenade for informal interaction which must also have assured its success as a shopping center.

[1] DynaMus, at http://dynamus.ceti.gr/tech.html

After undergoing various slight alteration in the course of four centuries, the Stoa shared in the destruction of 267 A.D. by the Herulian, a Germanic tribe. Note the effects of the fire on the inner face of the south end wall. A few years later was incorporated into the Post-Herulian Wall, at which time the façade and all the columns were dismantled for use in strengthening the rear part of the building. The back rooms continued to be used into Ottoman times. The survival of enough of the walls and architectural members made possible a detailed and certain restoration. Specimens of the various ancient members were added into the reconstruction, especially toward the south end of the building near the entrance. The restoration was carried south in the same materials as the original: marble for the façade, columns and interior trim; limestone for the walls and terracotta tiles for the roof. The upper floor and the roof are now supported on beams of reinforce concrete enclosed in wooden shells that reproduce exactly the spacing and dimensions of the original beams of solid wood. The design of the wooden doors was recovered from cuttings in the marble jambs and thresholds and from the analogy of surviving ancient tomb doors made of marble in imitation of wood. Through the reconstruction the visitor can understand the suitability of stoa as public gathering spaces, the spacious colonnades provided shelter for literally thousands of people protecting them from sun in summer and wind and rain in winter while allowing light and fresh air in abundance (Gawlinski, 2014).

GEOMATICS & 3D MODELLING

Protection and preservation of Cultural Heritage is nowadays the obligation of all civilized countries in the world, according to the numerous pertinent international conventions (UNESCO, 2003). According to the Charter of Venice (1964) the geometric documentation of a monument is imperative before any intervention. Hence specialized techniques have been developed over the years for the geometric documentation of monuments. Active and passive methods, image-based and range-based methods are some of the categories of such techniques, which are mostly based on recent technological advances, like the digital cameras, the automated total stations, laser scanning and the satellite data acquisition. In parallel, software development has helped a lot in that effort. Today, surveying, photogrammetry and laser scanning are the most prominent of the recent methodologies used for the raw data acquisition for the geometric documentation of monuments. They belong to the broader science of *Geomatics* or *Geoinformatics*, which, has lately joined forces with *Computer Vision* with spectacular results. These results include 2D and 3D documentation products mainly in digital form. Technological advances in the recent five or ten years enabled Geomatics engineers to produce high resolution 3D textured models of excellent quality and high accuracy. Initially, they have been used for visualization purposes, but gradually they served other purposes as well, like virtual restorations, virtual reconstructions (Valanis, Tapinaki, Georgopoulos & Ioannidis, 2009; Kontogianni, Georgopoulos, Saraga, Alexandraki & Tsogka, 2013) and production of tactile 3D copies using 3D printing for the benefit of visually impaired people. As these models are of very high quality and of great detail, it is only natural that they be considered as a valuable input to a serious game environment, in order to enhance the realism of the application and contribute to the arousing of the interest and edutainment. It is for this exact purpose that the development of serious games based and exploiting such high-resolution 3D models is considered worth attempting. In addition, Geoinformatics is able to interrelate and georeference any kind of information, thus building geodatabases. For that purpose, the representation of the 3D space is also necessary, which in turn may provide serious games with the important realistic environment for their development.

DEVELOPING THE 3D MODELS

This section describes the technical procedure of acquiring or creating the 3D models, which were used for the development of the application. These models include the monument of the Stoa of Attalos which was used in the virtual tour, the models of the museum exhibits that were used in the virtual museum and the southeast interior part of the Stoa, which was used in the 3D visual quiz mini game.

3D model of the Stoa of Attalos

The 3D model of the Stoa of Attalos, which was used in the virtual tour was taken from the *3D Warehouse library*[2]. Models taken from this website were developed in *Trimble Sketchup* software[3], with which the users can easily create a 3D model of an object based on its horizontal plans and then texture it with images that they have acquired even with their own camera or through the Web. When the 3D model is ready, the user can upload it to the website of the 3D Warehouse to be freely available to other users for further exploitation in other applications. Figure 1 illustrates the 3D model of the Stoa of Attalos from the 3D Warehouse library. The advantage of using a freely available model from 3D Warehouse is firstly that it is ready made, secondly that it is optimized (it is not a 'heavy' model) and thirdly that it is usually quite realistic. Since the Stoa of Attalos has not yet been 3D documented (range-based or image-based reconstruction) it was decided that its model be retrieved from the 3D Warehouse library for the purposes of the game.

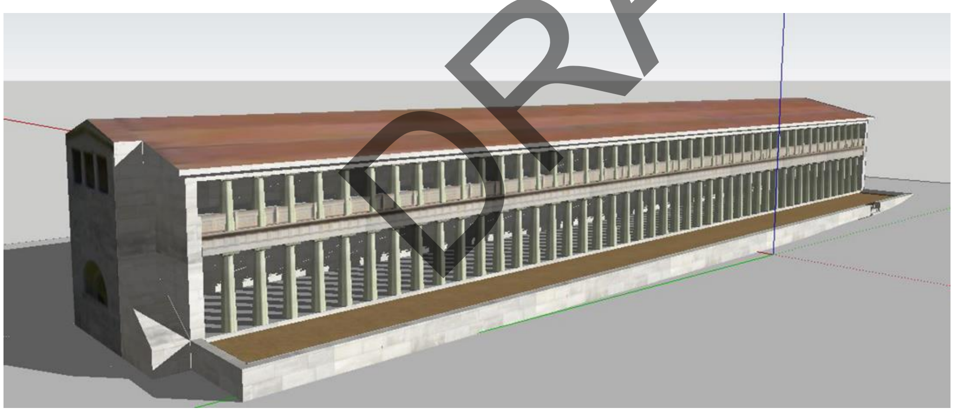

Figure 1: 3D model of the Stoa of Attalos

Exhibits of the Virtual Museum

The 3D models of the selected artifacts from the museum of the Stoa of Attalos were created with image-based reconstruction techniques. The purpose of their reconstruction was to be converted into exhibits of the virtual museum of the Stoa of Attalos. The image-based 3D

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[2] 3D Warehouse library, at https://3dwarehouse.sketchup.com/
[3] Trimble Sketchup, at http://www.sketchup.com/

reconstruction techniques usually require a large number of digital images to produce the 3D textured models for the artifacts. For the necessary data acquisition a 24 Mpixel Nikon D3200 DSLR camera with a APS-C CMOS sensor was used, equipped with a NIKKOR AF-S DX 18-55mm zoom lens and f/3.5-5.6 aperture values respectively. In addition, a special photographic tripod, a collapsible light reflector, a steel ruler with 4 pre-marked targets for scaling the models and a ladder were used. The number of images for each artifact varied according to its size and complexity. 1208 images were taken in total for all of them in 11 hours. Most of the images were taken with the tripod for stability. The average number of images for the artifacts was 60-90, while some of them needed more (100-120) and some significantly less (30-45) images depending on the artifact's size and details. The steel ruler was placed next to each exhibit so as to appear in at least 3 consecutive images in order to scale the exhibit later during the process of the 3D reconstruction (Skamantzari & Georgopoulos, 2016).

Agisoft Photoscan Professional[4] was utilized for processing the images and producing the 3D models of the sculptures. It is an automated image-based 3D reconstruction software that implements the *Structure from Motion* technique coupled with multiple-view dense 3D reconstruction and allows the users *some control* over the whole process. The software applies computer vision and photogrammetric algorithms to automate the process of forming 3D models. Initially, it applies a feature point detector, similar to SIFT, in order to identify characteristic points on each image. This is performed with the use of Gaussian scale space pyramids. Also it uses features that are invariant to image scale, rotation and translation, and are partially invariant to illumination changes, affine projections and image noise (Lowe, 1999; Lowe 2004). These features are described by a vector, called *feature descriptor*. The basic steps of the algorithm are:

1. Image pyramids are created with the use of a Gaussian kernel in order to achieve the scale invariance. Key points are detected as extrema in different of Gaussians. The DoG pyramid is created by subtracting adjacent images in every pyramid level.
2. In each DoG pyramid every pixel is compared with its 8 neighboring pixels in the current image and with 9 neighbors in the adjacent scales. Points that differ significantly from their neighbors are described as points of interest.
3. The next step is the calculation of the scale and orientation of each point of interest. Consequently, a histogram of the gradient orientation of the image is created within a region around the point and the orientation of each point is given by histogram peaks.
4. The feature point descriptor is created in order to ensure that the points of interest are not affected by alterations of image orientation and radiometry.

These points are related to their counterparts in the adjacent images with the use of image matching techniques and especially the feature-based matching method. In this method the feature points extracted are compared, taking into consideration the feature's neighborhood. During matching the features are compared and considered to form a homologous pair if and only if the distance between their attributes is minimum. The feature-based matching consists of two phases: in the first phase, an initial set of correspondences is created that is based on matching criteria and other assumptions, in order to restrict the search space; in the second phase for each point, all the correspondences are checked for consistency and the best are chosen after comparison (Baltsavias, 1991). After the image matching technique, the relative orientation is taking place to determine the relative position (alignment) of the images in space With the use of

[4] Agisoft, http://www.agisoft.com/

Bundle Adjustment, the last step of every reconstruction method, a sparse set of 3D points, in this case the feature points, is created (Figure 2).

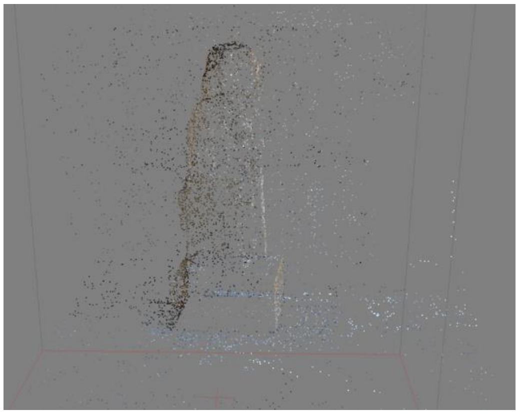

Figure 2: Sparse point cloud

Next step is the creation of the dense point cloud by applying dense image-matching techniques, practically up to every pixel. The user has rather limited possibilities of intervention, which requires extreme caution. In this case, the precision needs are not extremely high, but the realistic result is crucial, so the parameters on every step of the 3D modelling for our case, were chosen to be of *low* or *medium* quality. The software in *Ultra high* quality setting is processing the original photos, while each following step (high, medium, low, lowest) implies preprocessing image size downscaling by factor of four, two times of each side.[5]

For the production of the dense point cloud, based on the estimated camera positions the required quality was decided to be medium and the depth filtering parameter was disabled. The dense point cloud was checked and edited in order to delete the unnecessary points and reduce the noise (Figure 3).

Figure 3: The dense point cloud before and after reducing the noise.

Next, the software reconstructs a 3D triangular mesh that represents the object's surface based on the dense point cloud (Figure 4). Finally, after the geometry was reconstructed and checked, the mesh was textured. Since the 3D meshes of the artifacts in our case were created with the *Arbitrary* option, the texturing phase was performed with the *Generic* mapping mode. The *Blending* mode determines the way that the images will be combined. The *Mosaic* option which was selected, implies a two-step approach: Firstly it blends the low frequency component

[5] Agisoft Photoscan manual, at http://www.agisoft.com/pdf/photoscan-pro_1_2_en.pdf

for overlapping images to avoid seamline problem, while the high frequency component is taken from a single image. The one that presents good resolution for the area of interest.[5]

Figure 4: The 3D polygonal mesh on the left and the textured 3D mesh on the right part of the image.

Table 1 presents the quality setting that was chosen for every step of the 3D reconstruction process of each artifact, the number of images taken, the number of points and faces of the dense cloud and mesh respectively, as well as the file size for each final 3D model.

Table 1 Quantitative details of the 3D models of the exhibits

Artifact	Dimensions LxWxH (m)	Number of Images	Quality	Number of points (million)	3D Model Faces (thousand)	File Size (MB)
Statue of Apollo Patroos	0.9x0.5x3.2	178	Low	1.5	28.4	37.38
Statue base	1.2x0.5x0.8	71	Low	0.9	16.4	26.69
Architectural Element	0.8x0.4x0.4	65	Mediu m	3.7	223	50.22
Architectural Element	0.8x0.2x0.4	54	Mediu m	3.8	193.3	48.41
Architectural Element	0.6x0.4x0.4	41	Low	0.6	13.5	23.29
Ionic Column	0.8x0.6x1.7	155	Low	1.5	28.3	36.25
Ionic Column	1.2x0.7x1.9	88	Low	0.7	16.4	28.98
Inscribed base	0.9x0.8x0.7	33	Low	0.6	17.1	24.96
Inscribed base	0.7x0.5x2.3	101	Low	2	38.6	38.99
Inscribed base	0.6x0.4x2.1	86	Low	1.5	28.3	36.06
Statue of Godness Aphrodite Hegemone	0.8x0.5x2.1	66	Mediu m	5.1	313.6	60.63

Artifact	Dimensions LxWxH (m)	Number of Images	Quality	Number of points (million)	3D Model Faces (thousand)	File Size (MB)
Boundary Stone	0.3x0.2x1.3	39	Medium	1.6	107.4	32.37
Boundary Stone	0.3x0.2x1.3	42	Low	0.4	16.4	21.30
Hermes	0.3x0.2x1.5	88	Low	3.7	219	52.99
Statue of Woman	0.6x0.3x1.8	60	Medium	1.4	27305	30.53
Hermes	0.4x0.2x1.3	41	Medium	1.4	69466	30.30

Southeastern interior of the Stoa

The southeastern part of the Stoa of Attalos was created with the use of image-based 3D reconstruction techniques, just as the exhibits of the Virtual Museum. Some parts of this area of the building were created with a methodology similar to the one used for the artifacts, which is subsequently described. The equipment used for the image collection was the Canon EOS 1Ds, MK III DSLR camera with a CMOS full frame sensor in combination with the Canon EF 50mm f/1.2 USM L lens and the Pentax K-5 DSLR camera with a CMOS sensor of 15.7x23.7 mm paired with the Pentax SMC DA 18-55mm f/3.5-5.6 AL WR lens. *Agisoft Photoscan* was also used in this case for the creation of 3D models of the interior Ionic colonnade, the internal façade of the southern wall as well as the part of the eastern façade, the first eight rooms, stores as they are called. The floor and the roof of the model were created with the use of the open source 3D modelling software *Blender*[6]. Especially the surface of the beam roof, which is poorly illuminated and multi-faceted, was very difficult to capture and it was decided to be modeled with Blender using measurements from the archival drawings of the building, which are openly available. It was also proven difficult to generate acceptable meshes for the terrazzo-tiled floor because of the reflective nature of the material (Figure 5). The model of the Stoa of Attalos taken from the 3D Warehouse library was used to give scale to the 3D model of this part. Finally some of the exhibits from the virtual museum were also added in the virtual scene.

[6] Blender, https://www.blender.org/

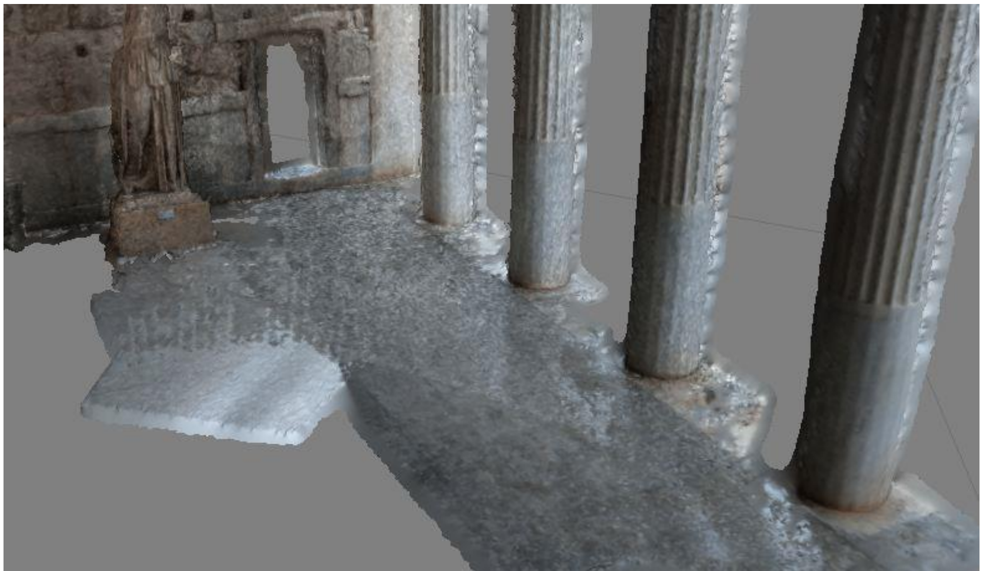

Figure 5: Problematic mesh of the terrazzo-tiled floor

In order to guarantee sufficient coverage of all the surfaces while simultaneously keeping the number of pictures as low as possible, a couple of specific image taking strategies were tested. Firstly, the capturing trajectory followed a cross pattern of diagonal orientation thus yielding a smaller number of pictures, but the results were not visually sufficient and presented a number of lacunae, that resulted in holes of the produced mesh. The preferred shooting method employed a camera movement parallel to the walls according to the recommendations of the Agisoft Photoscan manual. The captured data were divided into subgroups, the so-called chunks and the processing was executed separately for each chunk.

The procedure that was followed uses the same settings as in the case of the exhibits described above until up to the stage of the dense point cloud creation. The Mesh Generation step proved significantly time consuming and due to its automated nature, produced results with many problematic areas. This implies the existence of holes or wrong texture at a later stage or, even, inadequate surface description (Figure 6).

Figure 6: An example of problematic surface

Photoscan lacks efficient tools for repairing such areas. The basic objective was faster procedures and cleaner meshes. *Geomagic Studio* software[7] was used for the meshing of the dense point cloud. Photoscan can export the dense point cloud in a number of formats; in this project the ASCII format was selected. Within Geomagic, the editing procedure of the point cloud includes selecting and deleting disconnected components and outliers, removing noise and resampling the points. The creation of the 3D polygonal mesh was the next step, while mesh editing followed. The solution for the correction of all the faulty parts of the mesh was the *Mesh doctor*, a tool which automatically detects and corrects errors in the 3D polygonal mesh. A common mesh inconsistency was the formation of holes, which usually required utilization of the specialized *Close Holes* tool (Lerma, Genechten & Quintero, 2008).

The result was exported using the Wavefront (.obj) format and reimported in Photoscan for generation and application of the texture. The texture of the mesh was realized with the *Building Texture* step such as the exhibits. An important step needed to avoid repeating the *Align Cameras* step is to export the camera position parameters as an .xml file from the original Photoscan project and reimport them to the new one in the chunk containing the edited mesh. In order to align the several chunks 33 markers were used. The final result has a polygon count of 2903381 faces and is based on data from 679 images (Figure 7).

[7] Geomagic Studio, http://www.geomagic.com/en/

Figure 7: 3D texture model of the interior of the Stoa

The number of images used for creating the 3D model was 679 and the selected quality was medium. The dense point cloud has about 1.8 million points and the faces in the 3D model are about 2.9 million. The final file size is about 216 MB.

The preferred output format for the application development is the .fbx file format because of the smaller file size, compared to the Wavefront format, and the incorporation of textures. However, the resulted model was proven exceptionally cumbersome for *Unity 3D game engine*[8], the software where the game design took place. Drastic simplification of the mesh was needed and the retopology approach was selected. This method regards the creation of a model of simplified geometry, consisting mainly of quadrangular faces as opposed to the triangular high-poly original model. The simplified geometry is superimposed on the high-poly model. To achieve the same visual result as the original model, the simplified geometry uses *normal maps*, a mapping of the vectors that represent the angles of light reflection for every vertex of the triangular mesh, from baking operations to texture from high-poly models (Troiano, Moro, Merlo & Vidal, 2014). Retopology is a technique that can be performed within a variety of commercial and freeware software solutions. Two different pipelines were experimented which are described below.

In the first pipeline *Autodesk Maya*[9] was used, a comprehensive software solution for 3D animation. Maya boasts an advanced and efficient toolbox and powerful baking, the process where an aspect of the mesh or a material characteristic of a 3D model is recorded as an image feature. The high poly mesh was assigned as a *make live surface*, a setting that allows for fast snapping of the low-poly mesh on the original. Several other tools were used for the refinement and finalization of the low-poly mesh. The *transfer maps* feature was used for transferring the texture on the simplified geometry. In addition, *diffuse* and *normal maps* were created. Two models were retopologized, the Ionic column and the two walls of the Stoa. The initial mesh of the Ionic column was around 100K polygons, while the simplified result was 11266. The high resolution wall model with 2.9M polygons was lowered to around 35K polygons (Figure 8). However, the texture of the retopologized model of the walls had significant visual

[8] https://unity3d.com/

[9] http://www.autodesk.com/products/maya/overview

inconsistencies that could not allow us to use it the game design stage. In certain visible areas of the mesh, the generated texture presented unidentifiable patterns and discolorations that where obstructing and affected the realistic quality of the mesh. Furthermore, the 3D model of the Ionic colonnade was duplicated in order to create the inner colonnade of the Stoa.

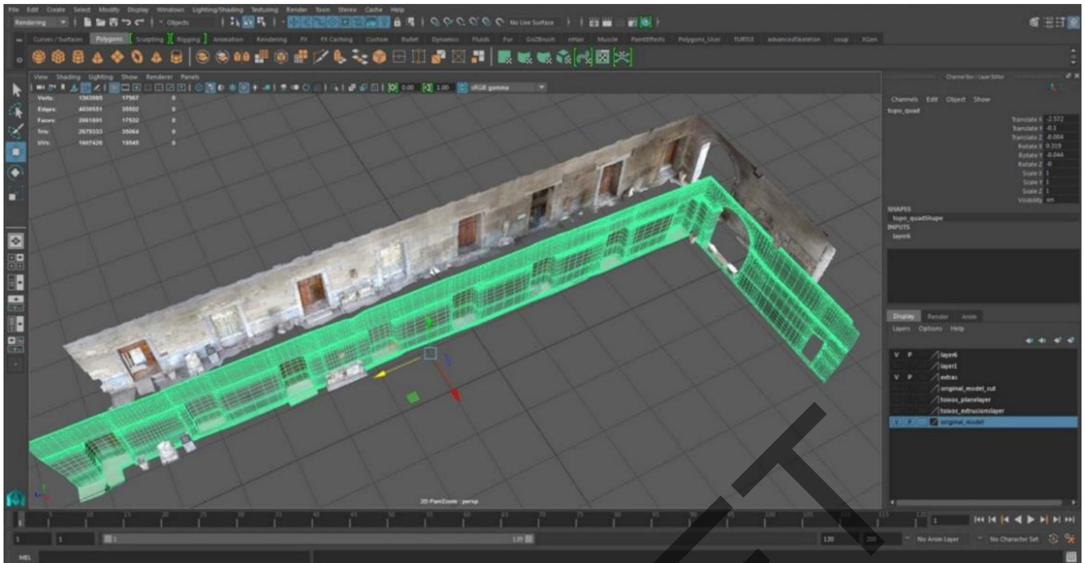

Figure 8: High poly mesh and the retopologised result in Maya environment.

In order to reach a visually acceptable and light enough model for Unity, a second pipeline was tried. The high resolution Photoscan model was initially decimated using the *Autodesk Remake*[10], formerly known as Autodesk Memento, a freeware, end-to-end solution for converting any captured reality input, photos or scans, into 3D meshes that can be cleaned up, fixed, and optimized for the Web, mobile or 3D printing. The specific software has an option of rebaking the texture in the export menu where the decimation is also applied. So, while the mesh is simplified, the texture is recalculated and applied again. A mesh with a polygon count of 1469421 was produced but the result was still unmanageable for Unity. The decimated mesh was then locally simplified using the freeware *MeshMixer*[11], a mesh editing, procedural retopology tool, focused on 3D printing (Schmidt & Singh, 2010). Meshmixer's *brush tool* can alter the number of mesh triangles or the mesh itself as a sculpting tool would do. Most importantly, while discarding geometry details, it keeps the UV mapping intact, therefore allowing the preservation of the model's original texture and not altering it, a fact that seemed to cause all the visual problems in the texture produced in the previous pipeline. This laborious method is performed manually, allowing for the necessary constant visual check, to avoid oversimplification or distortion of the geometrical features of the model. Finally, the result's count of the polygon faces was reduced to 1026335 and the total file size was 39.83 MB, while a detailed textured map was retained. This model was proven manageable within Unity game engine.

[10] Autodesk Remake, https://remake.autodesk.com/about
[11] MeshMixer, http://www.meshmixer.com/

DISCOVERING THE STOA OF ATTALOS

The Virtual Reality (VR) application was developed with *Unity 3D Personal edition*. Unity was chosen among other similar freely available engines, like e.g. Unreal, CryEngine (Kiourt et al., 2015) because apart from the fact that it has all the necessary tools for developing the application, we had already extensive experience with its use and in addition it is very easy to develop small scripts for the application.

First step was the creation of the terrain on which the 3D model of the Stoa was placed. The terrain was created with the use of a raster DSM image and the corresponding orthoimage (Figure 9) of the areas with a GSD of 50 cm which were made available from the National Cadastre and Mapping Agency S.A[12].

Figure 9: Orthoimage of the Ancient Agora (left) and its raster DSM (right)

Initially an empty terrain was created in Unity software, which had the same resolution as the DSM image. The DSM image was in 32-bit format, which is not manageable by the software. So it was converted to a raw 16-bit format with the use of the commercial image processing software *Adobe Photoshop*. The first time the raw image was inserted into the game environment, the terrain seemed to appear as a mirror reflection, due to the fact that Photoshop and Unity have different coordinate systems. So the DSM image was flipped vertically in Photoshop in order to be inserted correctly in Unity. Nevertheless, this problem was taken care of in more recent editions of Unity. The terrain was smoothed with tools available by Unity, because there were many abrupt variations due to numerous trees and buildings in the area. Finally, the terrain was textured (Figure 10) using the corresponding orthoimage that ought to have the same dimensions with the untextured terrain (Kontogianni & Georgopoulos, 2015a; Kontogianni, 2016).

[12] National Cadastre and Mapping Agency, http://www.ktimatologio.gr/

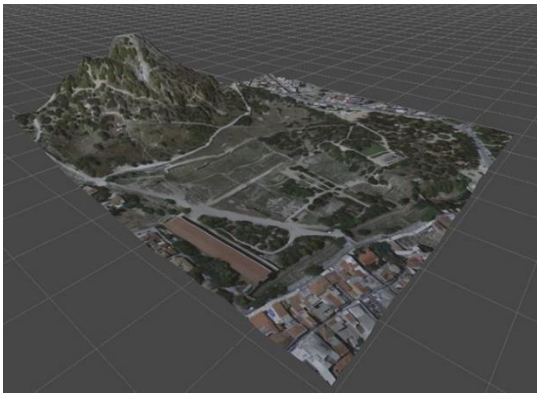

Figure 10: Textured terrain

Then the 3D model of the Stoa of Attalos was placed in its right position on the terrain in order to create the virtual tour in the environment. The virtual tour was realized with the use of the *First-Person Controller*, a tool available by Unity. Furthermore, a mini map was added in order to help the players easily recognize their location and navigate in the virtual environment. This was realized by adding a new orthographic camera in the scene above the terrain. In order to follow the *First-Person Controller*, a script in C# was attached to the camera. During the virtual tour of the Stoa of Attalos elementary historical and architectural information about the monument is offered to the user with the use of a GUI window that is presented to the player during the virtual tour (Figure 11).

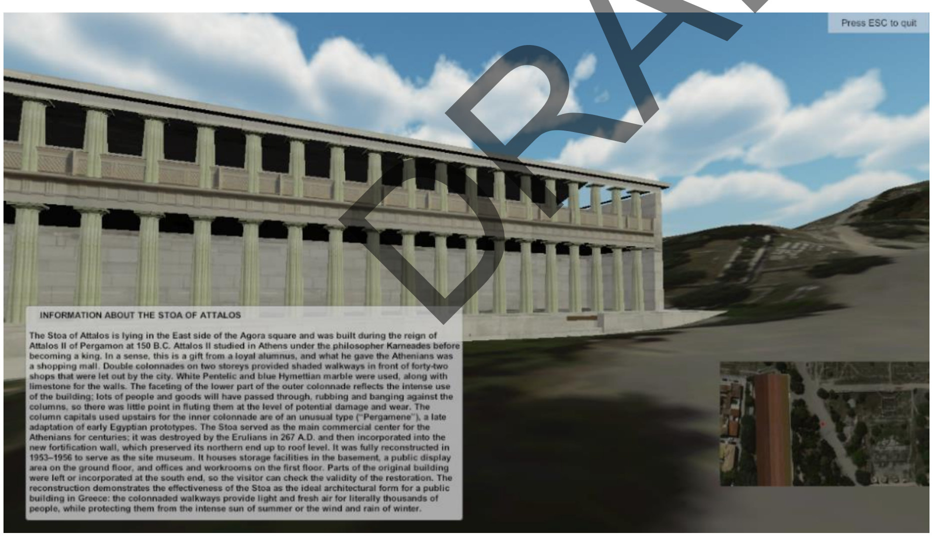

Figure 11: The virtual tour with some textual information and the mini map

As the player approaches the monument of the Stoa of Attalos, a GUI menu provides with three applications (Figure 12). The first application is a quiz game relating with basic historic and architectural facts about the monument. The second application is an advanced quiz game integrated into a virtual tour of the southeast wing of the Stoa, in which the player is asked to distinguish parts of the Stoa that belong to the original construction, while providing the player with information on the various construction periods. The third application leads the player to a virtual visit of the museum of the Stoa, where the real exhibits may be closely examined, giving thus the opportunity to learn all the necessary historical and architectural information about the monument (Kontogianni, Koutsaftis, Skamantzari, Georgopoulos & Chrysanthopoulou, 2016). These applications are described in more detail in the following paragraphs.

Figure 12: GUI menu with the three options

Quiz Game

The first application is a quiz game realized in different scenes. Each scene includes the question and the explanation of the correct answer. The questions are based on the informative text which the player can read during the virtual tour. The player has to provide a correct answer to continue with the next question. In case the player is wrong then a new window with the explanation of the correct answer appears (Figure 13) (Kontogianni & Georgopoulos, 2015b; Kontogianni, 2016).

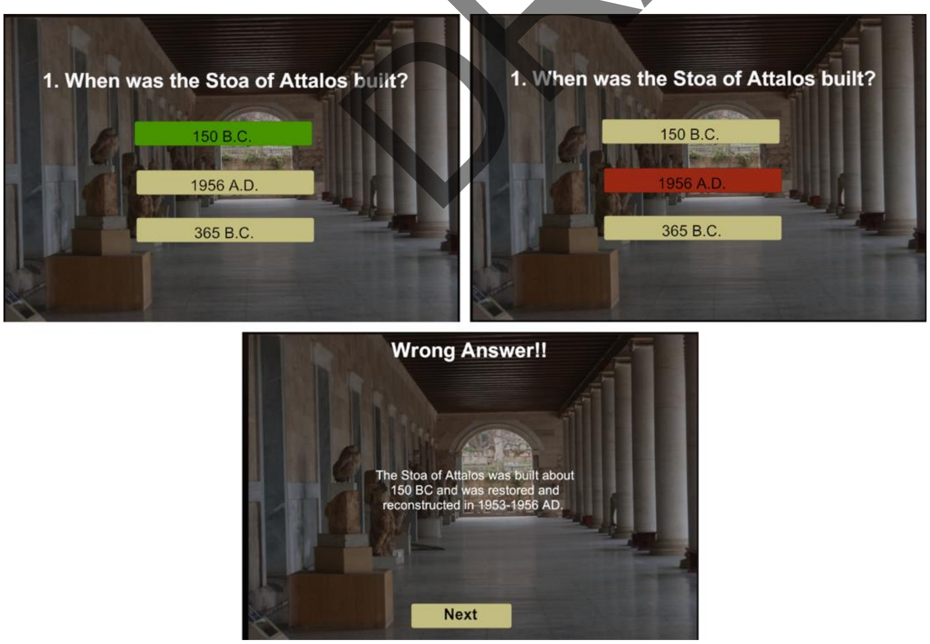

Figure 13: An overview of the quiz game

The User Interface (UI) tool was used to create the scenes of the quiz game. The possible answers were realized with the use of UI buttons, which were developed with the use of a simple script in C# language to provide the player with the proper scene navigation.

3D Visual Quiz

The scene, with all the assets properly arranged, was imported as an .fbx file in Unity. Generic assets and scripts, such as *First-Person Controller* were utilized for basic player movement in the virtual space. *Colliders* were set up for emulating physical objects as barriers in the player's movement. On the 3D scene there have been selected ten (10) regions of interest (hotspots) which were used as interaction of the player between two game objects: firstly, a child object of the First Person Character called *Trigger Camera*, a rectangular and oblong collider, marked as a trigger; secondly, the objects *Real and Fake Triggers*, also box colliders marked as triggers, which correspond to structure areas that are part of the quiz game (Koutsaftis & Georgopoulos, 2015; Koutsaftis, 2016). The interaction between the two triggers activates a series of game mechanisms and the area in question is highlighted. If it is part of a wall, a child object, i.e. a stressed red outline of the area in question is activated and additionally a GUI quiz dialog appears with the question, the answer and the additional info (Figure 14). A series of standard and custom scripts, written in C# programming language govern the relations between actions and events following the gameplay described.

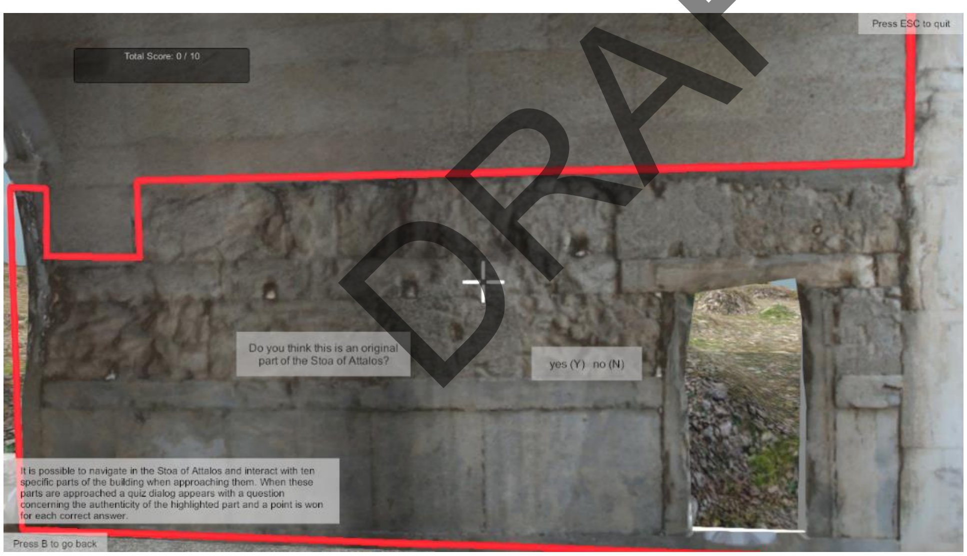

Figure 14: Highlighted part with the question

The question always concerns the originality of the highlighted part. In this serious game application, the player wins a point in case of a correct answer; after answering, the player is provided with an explanation and additional information (pictures) in the form of pop-up windows (Figure 15).

Figure 15: Explanation of the correct answer

Virtual Museum

For the development of the virtual environment of the exhibits, for every .obj and .tiff file that was imported, a corresponding documentation material was added to describe every 3D model. It is important to mention that the *Shader* of each material was chosen to be *Unlit/Texture* so that every 3D model appears exactly as it was exported from Photoscan. Every exhibit had a higher entity in the hierarchy, an empty *GameObject* was placed to the center of the 3D model and then, both as one object were properly placed in the virtual museum. This was an important step for the manipulation and rotation of the exhibits. As far as the *Main Camera* is concerned, the components that were added, adjusted the ambience and the depth of field to provide a more clear and realistic view of the exhibits. Furthermore, the proper scripts, written in C# language, were added as components to every exhibit to enable the manipulation and rotation of them around their center of mass as well as the appearance of textual information when the visitor selects each exhibit (Skamantzari & Georgopoulos, 2016). Particular attention was given to the formation and design of the panel which displays the instructions of the virtual museum at the beginning of the virtual experience so as to guide and help the visitor move around and explore the environment (Figure 16). Furthermore, a mini map accompanies users in the virtual museum for their convenience and better orientation in the environment.

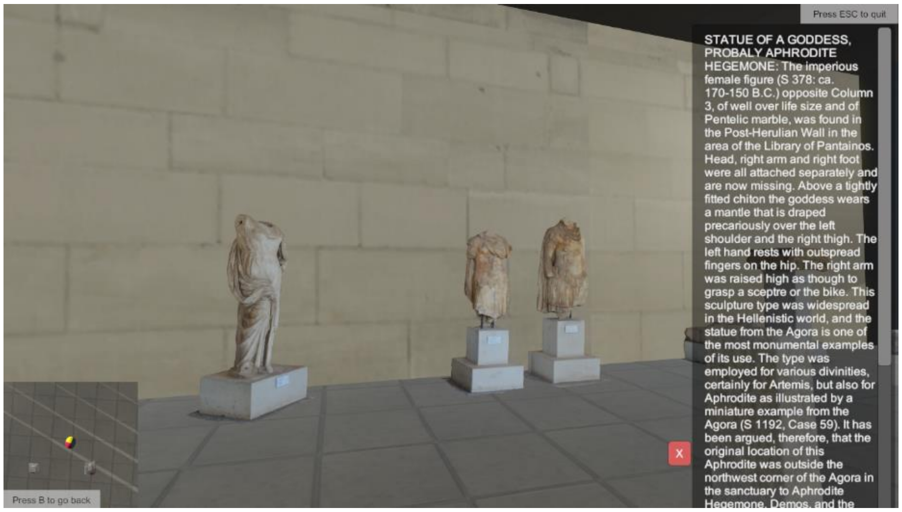

Figure 16: The virtual museum with all the elements included (exhibits, mini-map and information).

The three previously described applications combined, form an integral adventure for a potential user to come into terms with the Athenian Agora, its monuments and its history in a pleasant way and, hopefully, to feel motivated to plan a visit in person. Engagement and attraction to the original site were the ultimate goals of the application developed and this is the reason for experimenting with realistic models of the objects involved.

EVALUATION

An evaluation of the application was scheduled to be realized so that different players use the application and then express their opinion through a questionnaire specially created with the online survey tool Google forms[13]. The evaluation was performed by a group of people experienced in Cultural Heritage because it was considered preferable a specialized application in a scientific field to be evaluated by related experts. Players who participated in the evaluation should first use the application and then answer the online questionnaire to evaluate the serious game approach. Data collection is in the form of self-administered questionnaires which focus on user experience and follow the general form of a Usability and Learning Outcomes questionnaire (Barak, Herscoviz, Kaberman & Dori, 2009). User experience is measured in terms of attractiveness, fun experience, knowledge gain, learning goals achieved, ease of use and reliability. A flawed game design would cause frustration to the gamer and would influence negatively both motivation and engagement. The questionnaire was grouped in items under each one of these categories of usability and it consisted of 7 parts including several questions: the first part was about basic demographic data about the players; the next five parts include questions concerning the individual applications and specifically about the realism of the models, the virtual tour, the quizzes and all the other game elements; the last part of the questionnaire is about the general experience of the player playing the integrated application.

A group of 19 people experienced in Cultural Heritage field took part and evaluated the application. From the participants 10 were men and 9 women, with the majority of them in the age range of 19-30, with only few of them in the age range of 31-45. As far as the educational

[13] Google Forms, https://www.google.com/forms/about/

background of the players is concerned, 16 of them have a master’s degree, 2 of them have a bachelor’s degree and only 1 finished some college and has no degree. Since the target group of the survey was people that are experienced in Cultural Heritage, most of them (84.2%) study or work in the field of applied sciences and only 3 of the participants in the field of social sciences. It is important to mention that 11 of the participants have actually visited the site of the Stoa of Attalos in the Ancient Agora of Athens and from those 7 are women between 19-30 years.

In the section of the questionnaire concerned with the virtual tour application and the Quiz Game about the site of the Stoa of Attalos, 95% of the participants found the presented information about the monument *interesting* during the virtual tour and all of them found the questions of the Quiz Game interesting. Most of the players (84.2%) answered that the questions were *relatively easy*, 5% of them thought they were *easy* and 10.5% of the players found the questions *somewhat difficult* (Figure 17).

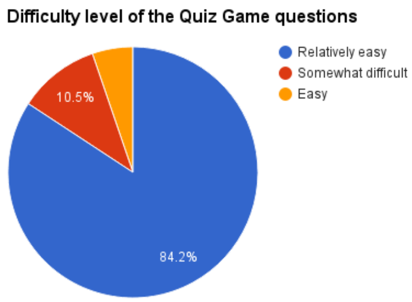

Figure 17: Pie chart regarding the difficulty of the Quiz Game questions.

During the 3D Visual Quiz the players were asked to search for the original parts of the Stoa of Attalos. According to the survey, 84.2% of the participants found the challenge enjoyable and most of them scored 5-7 out of the 10 points as it is presented in Figure 18. Moreover, all of the participants agreed to the fact that the game helped them understand that the Stoa of Attalos is actually a reconstruction.

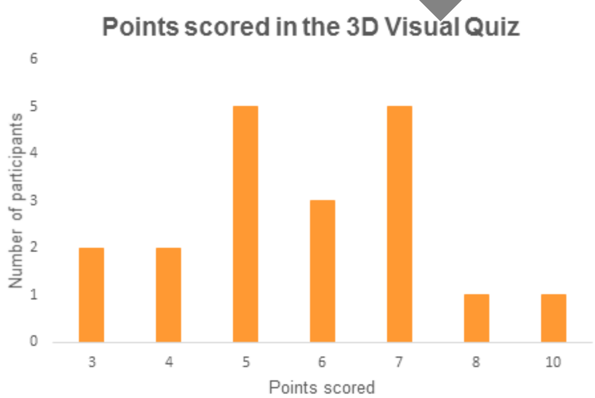

Figure 18: Bar graph of points scored in the 3D Visual Quiz.

As far as the Virtual Museum is concerned 84% of the participants found the information provided for each exhibit adequate and only 3 of the participants expected more information. Moreover 18 out of the 19 participants found the 3D models of the exhibits *realistic*. To the question whether they prefer to rotate the exhibits in different directions a percentage of 52.6% answered negatively and 47.4% of them answered that they would like to have this possibility (Figure 19).

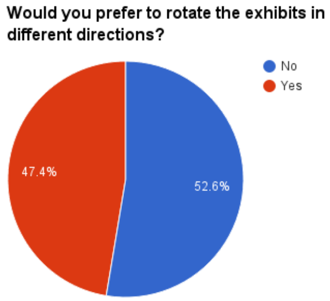

Figure 19: Pie chart on whether rotating the exhibits in different directions would be appealing.

In general the majority of the participants (79%) found the application user friendly and 58% of them did not experience any technical difficulties when playing the game. However, 8 of the players experienced difficulties and made useful comments for the tested game in order for the application to be improved in the future. Many of the participants mentioned that in the 3D visual Quiz, it was very difficult to find the 10 hotspots in order to answer the questions. They mentioned that these parts should be highlighted to be more easily identifiable for them.

The questionnaire focused on the realism of the 3D models and the virtual environment since this was the main concern and goal of the project. A percentage of 73.7% of the participants found the navigation and the content of the Virtual Tour application *somewhat realistic*, while 15.8% found it *very realistic*. Only 2 participants thought that it is was a *little realistic* (too graphical). As far as the 3D Visual Quiz is concerned 21.1% of the players found the virtual experience *very realistic*, 52.6% *somewhat realistic* and 26.3% of them found it a *little realistic* (too graphical). Finally, in the Virtual Museum application 42.1% of the participants answered that the virtual environment and content was *very realistic*, 52.6% found it *somewhat realistic* and only 1 participant found it a *little realistic* (too graphical). The results of these questions are presented in Figure 20.

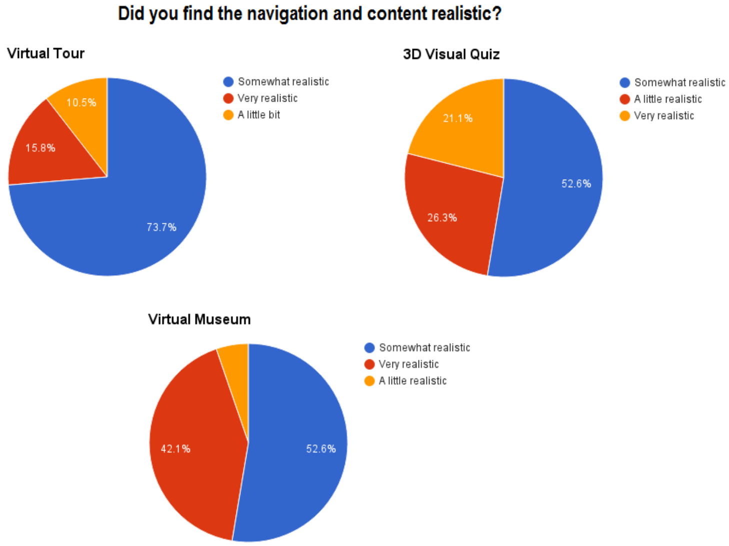

Figure 20: Pie charts concerning the realism of the applications.

According to the survey, 84.2% of the participants would recommend the game to a friend and 94.8% of them would visit the actual site in the Ancient Agora of Athens after playing the serious game *"Discovering the Stoa of Attalos"*, which is a great impact and result. Furthermore, 94.8% of the participants would like to try an immersive VR version of the game (Figure 21).

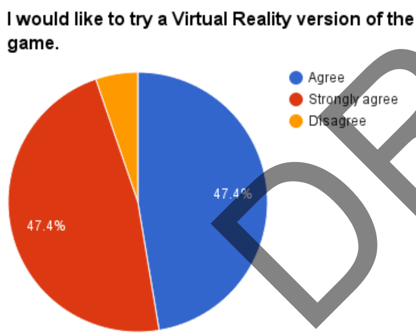

Figure 21: Pie chart on whether an immersive VR version of the game would be appealing.

CONCLUDING REMARKS

The main scope of the project described in this paper was to investigate the effectiveness of exploiting 3D textured models of reconstructed cultural heritage in creating serious games applications from a user perspective. For that purpose a serious game was developed for the Stoa of Attalos monument, titled "Discovering the Stoa of Attalos". The 3D textured models were created with image-based 3D reconstruction, a method that can provide realistic results. This is because visual realism is recognized as a very important fact for educational applications.

In the case of the usage of the 3D virtual exhibits in the game engine, the 3D models are easily manageable and no special procedures have to be followed. On the other side, in the case of the southeastern interior part of the Stoa, due to the large number of polygons, there where issues in importing and manipulating the model within the game engine. As a rule of thumb, in such cases it is advisable to lower the level of detail of the model, but, of course, only to a level that will not affect realism, which is a prerequisite for the educational purposes initially set.

Besides the development of the application and the programming process, the 3D modelling of monuments was also a rather challenging and complicated process, which required detail and precision. During the data acquisition there were certain factors that should be taken into consideration, like the lighting conditions on site, the access to every object from all sides, the size, complexity and details of each object and many more (Pavlidis, Koutsoudis, Arnaoutoglou, Tsioukas & Chamzas, 2007).

Last but not least, the programming process of the virtual environment and the game mechanics were rather challenging, as many factors should be taken into consideration about the transition to each application, the options given to the player, the instructions of the game as well as all the main and complementary elements of the game in general. The results of the survey were quite enlightening on this matter and pointed out all the problems and technical difficulties that were not taken into consideration at the beginning.

FUTURE PERSPECTIVES

The project is currently under redevelopment to be implemented as an immersive VR application. The targeted platform is Windows / MacOSX, and it will make use of a VR headset, earphones and a game controller. The revision needed to provide a fully immersive experience, without compromising the educational character of the application, regards the reevaluation and redesign of the gameplay as well as the reconstruction of the meshes that have resulted from the image-based 3D reconstruction.

The application will be improved according to the evaluation and will be enhanced and extended to include other monuments of the Ancient Athenian Agora. An important improvement is the addition of highlights in the 3D visual quiz to enable the players to see the parts of interest of the monument. As far as the gameplay is concerned, the additions that need to be implemented serve the purpose of making the application possibly more immersive while creating a comfortable experience for the user. Such changes include, to begin with, the conversion of text into audio information, not only to facilitate the user, as it is more challenging to read large texts while using a VR headset, but to also enrich the immersive experience as the audio plays the role of a short narration. Moreover, the displacement of the player constitutes a challenge to the success of the application, as the virtual space is too large to be navigated (while walking through it) by means of sensors provided by the current commercial VR headsets. Such an approach could be possible if other sensors were to be used, a motion capture system such as the Optitrack, multiple motion sensing devices such as the Kinect etc. Therefore, the most suitable approach is to either use the pad button of a controller to let users cover large distances, or to construct points of interests that teleport users if they focus on them for more than a predetermined amount of time, while allowing users to walk for small distances to examine more closely the structure and exhibits. As far as the interactions are concerned, the ideal type of controller would be a motion and orientation detection controller, which would be extremely useful especially in the “Virtual Museum”, where the user is able to examine the statues up close while rotating them.

Regarding the meshes, for the immersive VR version of the application, it is mandatory to reconstruct the models that consist of a large number of polygons. To obtain an accurate yet VR optimized model, the original mesh is used as a base. For this procedure, modeling software such as Autodesk Maya give the possibility to create “live surfaces”, on which the vertices of other meshes can snap accurately and the low poly model can be either constructed quad by quad or modeled as a whole, allowing for the vertices to snap on the original mesh. With this technique, the low poly model will be geometrically accurate and will include all the morphological characteristics of the original. Finally, the diffuse and normal map of the original is baked on the low poly model, preserving the texture information and adding the remaining details to the final mesh.

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