Design and creation of a 3D virtual tour of the world heritage site of Petra, Jordan

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Abstract

The spatial documentation of cultural heritage sites using the technologies of laser scanning, aerial and close range photogrammetry, 360 degree panorama photography and conventional surveying methods has been well established as a means of digitally recording sites for conservation, restoration, site management, education and tourism purposes.

Currently the field of Virtual Heritage is trying to address the gap between the spatial data produced of heritage sites and the use of the data by interested parties. The reason for this gap is because data viewing platforms have not been adequately designed to allow the general user to view combinations of 3D spatial data in an easy manner and in a compelling and engaging 3D environment.

This paper describes the undertaking to assimilate spatial data into one seamless virtual tour, where a "virtual visitor" is able to view a wide variety of spatial data in a single interactive environment. The paper is based on the experiences of creating a 3D Virtual Tour of the UNESCO world heritage site of Petra using data the Zamani Project at the Geomatics Division, of the University of Cape Town, has generated in partnership with the Jordanian Department of Antiquities (DOA), ISPRA (The Institute for Environmental Protection and Research) and UNESCO under the framework of the Petra Siq Stability project.

1. Introduction

The Zamani Project, based at the University of Cape Town (UCT), has since 2005 been spatially documenting heritage sites in Africa and the Middle East. A large database of spatial material has been generated over this time. While this data has been widely used by heritage and conservation experts to manage and conserve these sites, it is less accessible to the general public without specialised knowledge (Stanco et al., 2011). The aim of this research is to investigate what types of spatial data exist for heritage sites, how this data is created and how it can be ultimately combined into an interactive 3D Virtual Tour. Individual spatial datasets, such as images of sites or 3D computer models, can easily be viewed or navigated on individuals' computers, but there are not

many options to inspect and work with different types of data in a single platform. Other fields using 3D data, such as computer gaming and the film industry have advanced significantly in displaying spatial data, while the field of heritage documentation lags behind, probably to a large extent due to the unavailability of funding (Roussou, 2002). Audiences are increasingly exposed to Virtual Reality environments in the media and have developed an expectation of what is possible in a Virtual Heritage environment. This expectation is extended to the interaction with digital data of heritage sites and Virtual Heritage needs to live up to these needs and expectations (Sanders, 2001).

The site chosen for this research is Petra in Jordan, a 2000 year old Nabataean/Roman site consisting of tombs, temples and dwellings carved into sand-stone as well as freestanding temples and other structures. The Zamani Project has been contracted by UNESCO to produce a number of spatial materials of Petra. These include a 3D model of the Siq (a 1.2 km narrow canyon leading to the ancient city of Petra), a consolidated GIS of the site, a DTM of the site, 3D computer models of chosen important structures and a 3D Virtual Tour (VT) of Petra.

The VT is designed to allow an interactive virtual walk-through of Petra, using the spatial data created by the Zamani Project. Individual 3D models of structures are incorporated into the tour as well as 360-degree panoramas, maps, plans, elevations, and other spatial data. The VT is designed as a stand-alone program, and will be accessible online. It is designed and created using Unity 3D (Unity 3D, 2014) gaming software usable on standard PC's and Laptops.

2. Virtual heritage

The term Virtual Heritage is derived from the terms Virtual Reality and Cultural Heritage (Granström, 2013).

Virtual reality environments are designed to convey to a user a sense of being in a real world that is in fact entirely simulated, and not real (this is opposed to augmented reality which is a combination of simulated reality and reality). The use of advanced technology such as head-mounted displays and motion sensing gloves is often employed to create a high level of navigability and interactivity in Virtual Reality systems (Granström, 2013).

According to the ICOMOS Ename Charter (ICOMOS, 2007), "Cultural Heritage site refers to a locality, natural landscape, settlement area, architectural complex, archaeological site, or standing structure that is recognised and often legally protected as a place of historical and cultural significance". There is now also a focus on intangible heritage, which is now included in the term cultural heritage, but obviously more difficult to represent in a virtual environment (Granström, 2013).

Virtual Heritage is then the incorporation of spatial cultural heritage data into Virtual Reality systems to create a simulated virtual environment (Roussou, 2002). The definition is somewhat

loosely defined and has, in the past, been used to refer to renderings, animations, or online virtual museums. However, for the purposes of this study it refers to a fully immersive 3D virtual space where a user is able to navigate interactively (Champion, 2008; Sanders, 2001).

2.1 Relevance of virtual heritage

Digital libraries have become prevalent in storing and displaying digital heritage data. Museums and libraries have collected vast quantities of digitised heritage data that can be accessed by the public and used as educational tools (Ott et al., 2010). Examples of this include the Musawwarat Graffiti Archive where users can view images of individual graffiti online (Musawwarat Graffiti Archive, 2011), The Trust for African Rock Art which hosts a large database of African Rock Art (TARA, 2014), and the Smithsonian X 3D archive where individual 3D models of heritage artefacts can be interactively viewed online (Smithsonian Institute, 2014).

Museums have come under pressure to make their collections more accessible to the public because of a need for better understanding of humanities history and heritage. Informal places of education such as museums, cultural centres, and the media can benefit greatly from Virtual Heritage which seeks to display digital heritage data and raise public awareness of heritage sites (Roussou, 2002).

Virtual reality has proven to be a valuable visualisation tool for spaces that cannot be easily accessed, or for structures that need to be examined from different perspectives. In a VT it is important to represent and display heritage data that is authentic and accurate, as this is what is expected by the public, in the same way as museums are expected to present data that is reliable. (Roussou, 2002; Sanders, 2001).

Another example of Virtual Heritage is The Hellenic Cosmos Cultural Theatre which offers visitors a fully 3D immersive environment in the virtual reality theatre. Visitors wearing 3D stereo-scopic glasses are able to take part in virtual travels, visiting cities and monuments that no longer exist (Foundation of the Hellenic World, 2014). Champion (2008) argues that "The primary aim of virtual heritage is to communicate the cultural significance of a site" and that this should be done via interaction (Champion, 2008).

Five target groups of users of Virtual Heritage content have been identified by Sanders (2001). These are: (1) archaeologists and historians who are interested in understanding the past, (2) museums and on-site interpretation centres, which the public visits to experience and learn from, (3) schools and education professionals, (4) experimenters who are individual testers or students, (5) the entertainment industry which includes computer games and the media (Sanders, 2001). To this another group can be added; conservators and restoration experts.

Virtual Heritage thus encompasses a wide audience and has a range of varied needs arising from different applications. One of these needs is the 3D Virtual Tour discussed in this paper. The following is a description of the VT concept.

2.2 Description of an ideal 3D virtual tour of heritage site

In an ideal scenario, the "visitor" is placed in the virtual environment of a 3D heritage site scene with a first-person perspective of the site's terrain, seeing the scene and its monuments as it would be seen in real life. The terrain should be of the highest detail with a high resolution texture. Using the keyboard and/or mouse, the visitor should be able to manipulate the view to create a sense of place and the atmosphere of walking through the scene (flying could also be incorporated). The visitor should then be free to "visit" 3D heritage structures, which in Petra comprise of tombs, caverns and buildings. When arriving at a structure the visitor should be able to view 360 degree photographic panoramas of the environment to add to the sense of reality. The visitor would then be able to explore the 3D model of the structure by entering and walking about. Information panels should pop up giving descriptions of the structure and videos of the structure could also be made available.

To further explore the site, the visitor can move on to further investigate other structures and the landscape. There should be a top-view mini-map window in the corner of the screen to indicate the visitor's present position on the site. On this map there should be clickable objects, allowing the visitor to move to new points of interest on the site. Layers of various map data should also be incorporated into this top view, allowing the visitor to choose varying combinations of these layers.

The goal is to make the tour simple, interesting, informative and attractive, and therefore it must be a "fun and immersive" experience. The data must be enticing enough for the user to want to explore and learn further. Additionally, video and audio narration should be available.

3. Phases of the 3D virtual tour creation

The VT creation can be divided into the following phases:

Phase 1: Research of current spatial documentation methods and data types, decisions on data to be incorporated and standards to be adhered to.

Phase 2: Data acquisition and processing. In the case of the Petra VT, which was documented to established standards and methods employed by the Zamani research project, an extensive data set comprising of a wide variety of spatial data was available.

Phase 3: The VT is conceptualised and designed and the spatial data is manipulated to be suitable for import into the VT. This stage requires familiarity with suitable software, such as Unity 3D, and developing programming skills. User feedback is also received.

Phase 4: Scientific analysis, interactive games, virtual tour guides, multiple users, and other techniques and technologies are incorporated into the VT.

3.1 Creating the 3D virtual tour

To create the 3D Virtual Tour a software package was chosen that is available at no cost, requires only a beginner level of programming skills and makes it possible to incorporate all the spatial data listed below. Important criteria in the choice of the software were the ability to create a first person perspective and user control and navigation capabilities.

The software chosen to create the virtual tour was Unity 3D. A number of available game engines, such as Unreal Tournament, Quest 3D and Morrowind, allow users to create their own Virtual Environments (Champion, 2008), but these were found to either be complex to use or limited in their ability, which lead to the choice of Unity 3D as the enabling platform. Also the Unity 3D community has 2.5 million registered developers and 500 000 active developers as of March 25th 2014, which would indicate that it is well accepted in the Virtual Reality community (Unity 3D, 2014).

Unity 3D is a software commonly used to create games for web-plugins, desktop platforms, consoles and mobile devices. It is a cross platform engine (meaning the output can be used on iOS, Mac, Android, Apple and others) with its own Integrated Development Environment (IDE). (Brodkin, 2013). There are two versions of the Software; Unity 3D which is free for non-commercial use, and Unity 3D Pro which has advanced features, such as advanced lighting and level of detail capabilities. All programming is done via scripts which are attached to objects in the game. The scripts are written either in Java or C++ (Unity 3D, 2014). There is an online forum where developers using Unity 3D can pose questions to other users and to Unity 3D creators. There is also a good user and document manual as well as many tutorials.

During the development of the VT it became obvious that the more detail (high polygon count models and high resolution images) imported into the VT the more processing power is needed for the end users' computer. Thus a compromise had to be found between high detail and efficient running speeds.

4. Data acquisition and processing

The spatial data of Petra was captured during four field campaigns to Petra between April 2011 and December 2013. Over 2000 laser scans, 450 panoramas, over one hundred RTK GPS measurements, and a few thousand images for texturing were captured. Extensive GIS datasets, available from previous research and documentation projects, were imported from multiple sources and merged with newly created data into a single GIS based on a common reference system, UTM 36N on WGS 84. There were also 15 aerial images of Petra which were used to create a DTM and orthophoto of the site. All newly captured data was processed by the Zamani Project team, which is described in detail by Rüther et al (2014), at UCT and combined into a 3D Virtual Tour. Most important for the VT is a point cloud of 3 km length which was created by registering all laser scan data together, thus creating a single point cloud which includes all major heritage structures as well

as the surrounding terrain. This point cloud was geo-referenced to the GPS points via points which could be identified in the point cloud and surveyed by GPS measurement. On screen digitising on an orthogonal projection of the point cloud also served to contribute topographic data and other features to the GIS.

The output of the processed data of Petra was thus:

- 3D models of 30 major structures, many of these textured
- 3D model of the 1.2 km long Siq (the access canyon to Petra)
- Plans, sections and elevations of each 3D model
- 450 panoramas in Panorama tours
- DTM and orthophoto of Petra and surrounds
- Comprehensive GIS with historical and current data

4.1 Petra topography in the virtual tour

The basis of the VT is the terrain that the user will be virtually walking across while exploring the site. The DTM of the terrain should be of a high resolution to provide maximum detail and textured with a high resolution aerial image to achieve a realistic appearing virtual environment.

A 1m grid of DTM points, covering an area of 30 square kilometres, was created from 15 aerial images and approximately 50 RTK GPS points. An orthophoto with a 20cm pixel resolution and a height map with a 1m raster grid was also created for the GIS.

The 3D model of the terrain was derived from the point cloud described above and indicated by the red area in figure 1. The point intervals of this point cloud varied from 1 to 30cm. The area covered by the laser scan 3D model was then cut out of the much larger area covered by the 1m-resolution aerial DTM and replaced by the laser-scanned DTM. The two DTMs were joined using a hole-filling meshing algorithm to achieve a seamless merge between the different resolutions (figure 2).
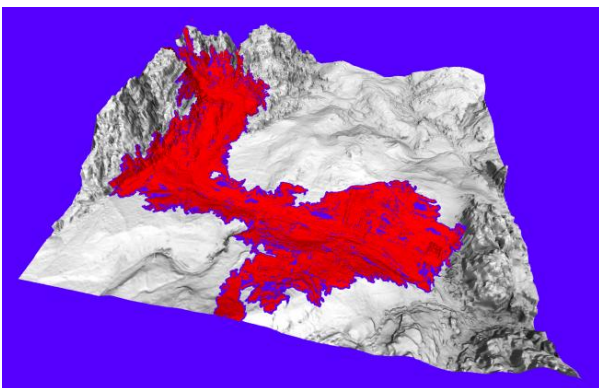

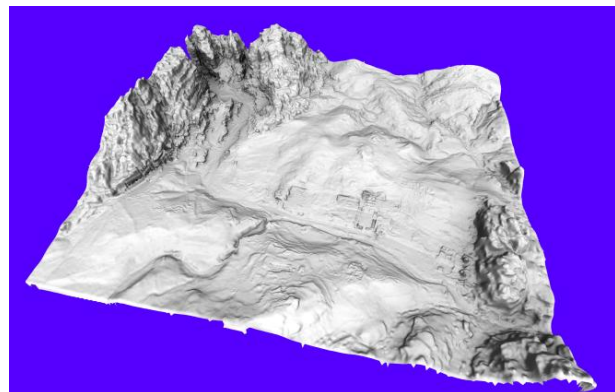Figure 1. Laser scan DTM shown in red. Aerial DTM in grey

Figure 2. Combined laser scan and aerial DTM

Unity 3D uses heightmaps to represent terrain. These are grey-scale images where the pixel intensity value represents a height value. The software has a built-in terrain editor where the extent, shape and texture of a terrain can be manually created and manipulated.

To import the Petra DTM, which was in a mesh format (a meshed surface represented by triangles (Rüther et al., 2012)), a tool had to be found to convert the mesh format to a terrain heightmap. Such a tool was available from the Unity 3D community (Haines, 2012). The most suitable resolution for importing the DTM into Unity 3D had to be a compromise between speed of display and displayed detail.

The 20cm orthophoto (figure 3) created from the aerial images was cut to the size of the DTM and used as a texture to colour the terrain (figure 4), and to form the backdrop of the mini-map of the site, which functions as a small-scale GIS.
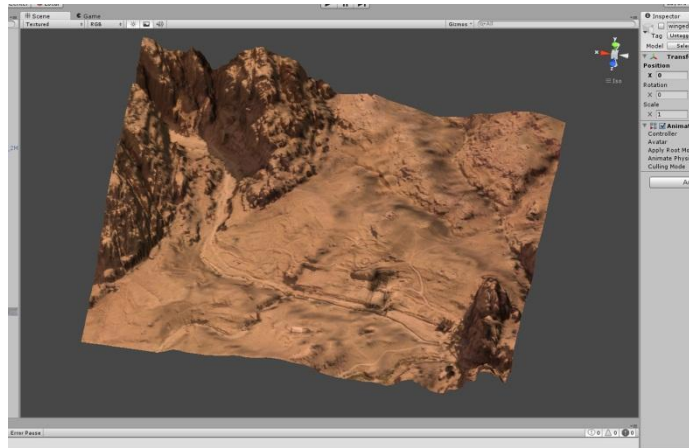

Figure 3: Orthophoto of Petra   Figure 4: Orthophoto draped over Petra terrain in Unity

4.2 3D models and texturing

Unity is able to import 3D models in .obj format (mesh format) with a polygon count of less than 65 000 polygons. If the model exceeds this count it is automatically split into segments of 65 000 polygons or less.

The more than thirty 3D models of Petra had to first be processed using a pipeline developed by the Zamani Project to create models with a uniform resolution of 1 - 2cm (Rüther et al., 2012). Some of the models were then textured using images taken on site. These models can run into very high polygons counts (over 20 million per structure) and need to be decimated to be displayable on a standard computer (see figure 5 and 6).

For the use of these 3D models in Unity 3D, the models have to be completely hole-filled as any holes in the model would enable the virtual visitor to see through these openings and thus through buildings and walls, which would be unrealistic, and if there are holes at ground level, the visitor

could 'fall' out of the model. Thus the models are artificially hole-filled to ensure that they are water-tight.

A limitation of the Unity 3D software which emerged during the creation of the VT is that individual structures should not have more than 500k polygons to guarantee quick loading and smooth running. This makes it necessary to decimate the polygon counts of models significantly from the original millions of polygons to not more than half a million, which reduces the displayed detail and causes the models to be visually unappealing. This was countered by texturing the decimated models wherever possible (see figures 6 and 7).

Texturing the 3D models posed significant challenges. Vertex based texturing was not appropriate since the models must be of high resolution for the texturing to look appealing (Rüther et al., 2012). It was therefore decided to use UV texture mapping, where a separate texture map is attached to the model and high quality textures are draped over low polygon models (Held, 2012). This significantly improves the appearance of low resolution models.
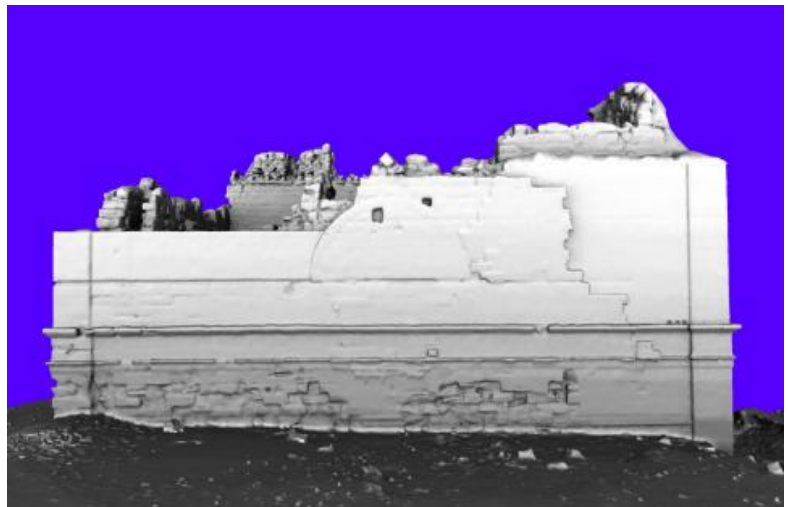
Figure 5: High resolution 3D model of Qasr al Bint, Petra

Initially panoramas, as opposed to standard images, were used for texturing the models as they covered a wider area. The panoramas were cubed (divided into 6 parts of a cube) and aligned to the model. After inspecting the textured model it was found that areas where two or more panoramas overlapped had a smeared appearance despite the use of filters which allocate weights to images as they are used for texturing. Weights are based on parameters such as distance from model, angle of incidence and distance to image border (Held, 2012). To reduce the smearing effect, images were masked, thus reducing the overlap to small areas at mask-edges. This resulted in a significant improvement and an approach was adopted in which models are textured with a minimum number of images thus avoiding or minimising overlaps and reducing the need for masking. The original policy to employ panoramas for texturing was therefore abandoned and individual images taken orthogonal to the surface to be textured preferred. All images were also manipulated to remove shadows and have similar base colours so that the texturing appeared seamless as can be seen in figure 7.

A complication arose when attempting to cover the large surface/wall areas of the various 3D models with a single UV texture map. UV maps in Unity 3D can comprise of a maximum of 4096 pixels which resulted in an unappealing, low resolution appearance for most and especially larger

models. Structures were thus generally textured using two or more UV maps, for example one map for the inside of the structure and one for the outside.

Figures 6, 7: Low resolution, and textured low res. 3D model of Qasr al Bint, Petra respectively

4.3 Panorama tours versus 3D virtual tours

Currently, the most widely employed method to view heritage sites virtually is by means of a panorama tour. A panorama tour, often, and somewhat misleadingly, referred to as a "virtual tour", typically displays a map layout of the site and next to this a window showing the panorama where the user can pan through 360 degrees from one spot. The map layout displays points marked where panoramas are situated and the user can jump between these positions and view the site from these spots. Although this is a suitable tool for a general impression of the site and its environment, it lacks full freedom to navigate the site as the user is confined to specific viewpoints. Moreover the panorama tour does not immerse the user into a true 3D environment. '

A number of panorama tours were created for Petra incorporating a total of 450 full-dome panoramas. The user can jump from one panorama to another and see each panoramas' location on a mini-map (Zamani Project, 2013). The VT was designed to provide the visitor with the panorama tour option in addition to the free navigation provided by the Unity 3D concept. The panoramas, as well as the panorama tour, were thus integrated into the VT to be called up by the visitor as required. To implement this panoramas were cubed, converted into the format used for Unity 3D and aligned to the Unity co-ordinate system, thus placing the visitor on entering the panorama into the same orientation as in the VT scene. Panorama positions appear as a clickable button in the scene as well as the mini-map.

4.4 GIS

The GIS created for Petra is extensive and includes over 150 layers. These include scan positions, satellite images, historical maps, outlines of the Siq and contours. Since GIS data is mostly in 2D form, a special window called the mini-map (Area 3, figure 8) was dedicated to the presentation of this data, with the user able to turn layers on and off. The base image of the mini-map was the orthophoto.

4.5 Virtual tour screen layout

The screen layout of the VT was divided into 3 areas. The side length of the square display areas of Area 2 and 3 are defined as equal to half the screen height. This is so that on any screen the size of 1, 2 and 3 will adjust accordingly to the screens dimensions (see Figure 8).
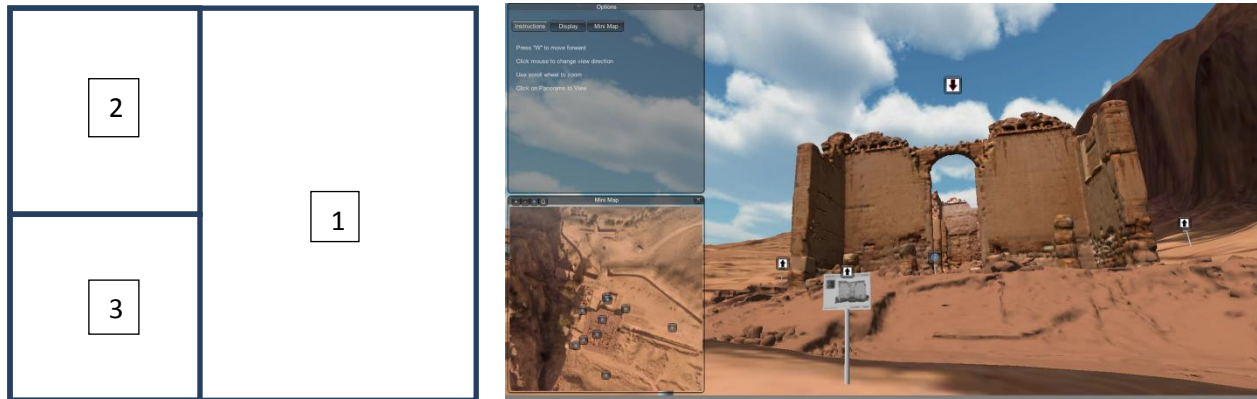

Figure 8 and 9: Screen layout of the VT and screenshot of the VT of Petra respectively

Area 1 is dedicated to the 3D virtual environment. The visitor is placed in a first person perspective view here. Clicking, holding and moving the mouse will change the direction of view. Pressing the up arrow or the letter "w" will move the visitor forward. Pressing "spacebar" will cause the visitor to jump, which is useful for climbing stairs or jumping onto higher objects or over walls. Area 2 and 3 can be minimised so that area 1 is full screen.

Area 2 is used to display data and provide options and information about the tour. This includes information on how to navigate. There are options to turn on and off data in the main VT window and mini-map (Area 1 and 3).

Area 3 is assigned to a mini-map of the entire landscape that the VT is covering, in this case the principal Wadis of Petra. The mini-map is a designed as a rudimentary GIS displayed against the backdrop of a top down orthographic representation of the site. The visitor will see the orthophoto of Petra and a green dot to show the location of the visitor in the middle of the displayed scene. When the visitor moves through the VT environment, the mini-map centre will follow. The mini-map may be zoomed in or out with the scroll wheel on the mouse or the use of the + and − buttons on the top left of the mini-map. Panning of the mini-map is done by clicking and dragging the left mouse button. The visitor can jump/teleport to any location on the mini-map by clicking on the desired location in the mini-map. The location of the panoramas is represented as blue dots on the mini-map. The visitor can click on the panorama to move the visitor to the panorama location and activate the panorama view.

In Area 1 the visitor will see icons with an up arrow at specific locations in the vicinity of 3D models of the structures. These icons are clickable and serve to call up elevations of the structures generated from the 3D model. An exit button at the top of the screen cancels the elevation image.

Above each structure hovers a down arrow icon. Clicking this icon transports the visitor to an invisible ledge above the 3D model providing a bird's eye view of the structure, which would not be possible for even a real site visit. The visitor can then "walk off the ledge" into the model and explore the 3D model and surrounds.

5. Conclusions

Virtual Heritage documentation and presentation has become increasingly possible and popular with the introduction of new technologies, equipment and software in addition to well established methods which have been employed in the field of heritage for decades. Currently spatial data are widely underused and their potential is not fully exploited (Rüther et al., 2012). Ways to make the access to spatial data more user friendly need to be found to enable the general public, which at present has little access to 3D models, GIS data and panoramas, to interact with this data. This paper has presented and discussed a solution to this problem in the form of 3D Virtual Tour. In the case of the VT of Petra, a variety of spatial data acquired and processed in co-operation with UNESCO, ISPRA and Jordanian partners was incorporated into the tour to provide virtual access to Petra for those who cannot visit the site in person, for visitors who want to prepare for travel to Petra or for those who wish the relive the experience after a visit. Other benefits arise for education, planning and site management.

Unity 3D was found to be a very suitable and flexible software for the creation of a VT. This project is on-going and it is proposed to add functionality to the tour to facilitate scientific analysis, interactive learning-oriented games, virtual tour guides, multiple users, and other applications. This will be dealt with in the next phase of the creation of the VT.

6. Acknowledgements

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