Virtual Reality for Immersive Visualisation of Turkish Cultural Heritages

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Abstract

Technological advances in Virtual Reality (VR) in recent years have the potential to have an ever-increasing impact on our everyday lives. VR makes it possible to explore a digital world in an immersive experience through a Head Mounted Display (HMD). Combined with tools for 3D documentation, modelling and software for creating interactive virtual worlds, VR has the potential to play an important role in the preservation and visualisation of cultural heritage for museums, educational institutions and other cultural sectors. It opens up a new form of scientific communication that can benefit historical and cultural heritage objects that are either damaged, destroyed or too far away from an interested visitor. This article presents a review of three virtual reality projects carried out in collaboration between BİMTAŞ, a company affiliated with the Greater Municipality of Istanbul, Turkey, and the Photogrammetry & Laser Scanning Laboratory of the HafenCity University Hamburg, Germany. The objective of this collaborative endeavour was to exemplify an immersive and interactive visualisation of three historical Turkish monuments (Selimiye Mosque in Edirne, the Rumeli Hisarı fortress in Istanbul, and the Istanbul Çatalca İnceğiz Caves) using the recently developed virtual reality system, HTC Vive. The objective of the projects was to create a virtual reality (VR) representation of the monuments, allowing users to interactively explore them from a first-person perspective.

1. Introduction

The growing importance and popularity of Virtual Reality (VR) in a variety of fields such as industry, construction, architecture, medicine and scientific research is a phenomenon that cannot be ignored. As a result of the accelerated development of VR technology, the financial outlay required for the necessary hardware is decreasing, allowing greater accessibility to a wider demographic. VR applications offer a wealth of opportunities to present and visualise a wide range of subjects in an informative and innovative way.

Virtual reality (VR) applications are now an indispensable tool in the field of digital reconstruction and visualisation of historical buildings and monuments. VR applications allow us to create, explore and experience virtual environments in an immersive way (Dörner et al., 2019). The use of virtual reality (VR) provides a valuable opportunity to document culturally significant objects and monuments, thereby facilitating their preservation and conservation despite the destructive forces of war, vandalism and natural disasters. In particular, cultural heritage objects that no longer exist or only exist in plans and drawings can and will be visualised. The virtual environment can and will come very close to reality, offering a wide range of different representations. New VR technologies allow users to feel as though they are part of an artificial environment. Kersten et al. (2020) delineate the evolution and deployment of a novel approach to knowledge transfer based on interactivity within a VR system. The particular use case under discussion is a VR application centred on the fourmasted barque (ship) Peking.

This paper presents a review of three Turkish VR projects that were realised in collaboration between BİMTAŞ, a company affiliated with the Greater Municipality of Istanbul, Turkey, and the Photogrammetry & Laser Scanning Laboratory of the HafenCity University Hamburg, Germany. The objective of these projects was to present the historical and culturally significant objects and monuments in Turkey to a broad and interested public in the form of interactive and immersive experiences. Chapter 2 provides a summary of previous work that has employed virtual reality (VR) to explore historical objects. Chapter 3 briefly outlines the workflow used in the BİMTAŞ and HCU Hamburg projects, while Chapter 4 describes the three Turkish VR projects. Chapter 5 presents the implementation of the VR projects. Finally, Chapter 6 offers a conclusion and outlook.

2. Related Work

Virtual reality (VR) plays a significant role in the advancement of the field of virtual cultural heritage. It facilitates a novel form of public and scientific communication, particularly for historical artefacts and monuments that are either damaged, destroyed or situated at a distance from potential visitors (Addison, 2000; Sone & Ojika, 2005; Affleck & Thomas, 2005). In a research study conducted by Zhang (2021), the experiences of end users exploring a virtually reconstructed model were investigated. The objective was to identify the aspects influencing cultural learning in a virtual cultural heritage environment. The results indicate that a combination of information design, content creation, user experience and guidance system should be considered when developing virtual cultural heritage applications.

In their 2020 study, Medyńska-Gulij and Zagata examine the impact of virtual immersion in a historical-geographical context on experts and players. The fortress in Ostrów Lednicki (Poland) is employed as a case study. In their 2020 publication, Bożorghi and Lischer-Katz present the Virtual Ganjali Khan Project. This is an ongoing research initiative that employs the use of 3D and VR technologies with the objective of facilitating the preservation of the cultural heritage of the Ganjali Khan complex. The complex is an important historical site in the Iranian city of Kerman, situated in the desert. Edler et al. (2019) describe the use of virtual reality (VR) technology to support the development of a neighbourhood in an area that has undergone industrial restructuring. The VR model of the former industrial area of Zeche Holland in Bochum-Wattenscheid is used as a representative example of a similar area in the Ruhr region. In a recent study, Janovský et al. (2022) presented a 3D visualisation of the historic Vltava river valley, which they created using both procedural and CAD modelling techniques. They then used the outcomes of this process to establish a virtual reality (VR) application in the Unreal Engine software.

A number of virtual reality applications have been developed at HafenCity University Hamburg, with a particular focus on historic architecture. One such example is the Bad Segeberg museum, situated in a townhouse from the sixteenth century, which has been digitally reconstructed in four dimensions (3D model including six construction phases from 1541 until 1963) for virtual reality immersion using the HTC Vive Pro (Kersten et al., 2017b). Furthermore, three historical German cities and their surrounding areas have been developed as virtual reality experiences. Duisburg in 1566 (Tschirschwitz et al., 2019b), Segeberg in 1600 (Deggim et al., 2017a), and Stade in 1620 (Walmsley and Kersten, 2019). Moreover, virtual reality experiences of cultural and religious sites are available, including a wooden replica of Solomon's Temple (Kersten et al., 2018b) and the imperial cathedral in Königslutter, Germany, which employs 360° panorama photographs to create an immersive real-time visualisation (Walmsley and Kersten, 2020). Furthermore, a virtual reality application has been developed for the fortress Al Zubarah in Qatar (Kersten et al., 2021). In a recent publication, Kersten et al. (2024) describe the development of a VR application for the "Villa Michaelsen" in Hamburg. The villa was designed and built in 1923 by the architect Karl Schneider, who was a representative of the New Building Movement. The VR app offers the opportunity to view a variety of information, historic and panoramic photos, as well as construction phases and drafts.

Articles on VR applications and museums of Turkish culturally significant monuments have also been published in the literature. Döker and Kırlangıçoğlu (2018) present the development of a 3D virtual museum application of Hagia Sophia to promote cultural heritages through a virtual museum platform. Güleç et al. (2021) promote digital storytelling on a virtual heritage museum with believable agents aiming to teach individuals the Turkish horror culture by experiencing them in a realistic environment with various different stories in a virtual reality-based gamified system including different scenarios. Günay (2022) investigates the different visualization techniques and tools for lost architectural heritage examples in post-conflict societies with limited available data, focusing on the VR mobile applications and their implementations using lost architectural heritage buildings in Izmir, Turkey and Thessaloniki, Greece. Apan and Özdemir (2024) investigate in the Educational role of virtual museums in cultural transfer focusing on Ottoman artefacts.

3. The Workflow

The following workflow was developed with the objective of generating a detailed virtual 3D model for immersive visualisation (Figure 1): (1) data acquisition by terrestrial laser scanning, digital photogrammetry or other sources, (2) 3D solid modelling with AutoCAD, ArchiCAD, SketchUp or other software using segmented point clouds, (3) texture mapping of polygon models using 3ds Max, Blender, Cinema 4D, Substance Painter or other software, (4) data conversion for import into the game engine (Unity or Unreal), including integration of motion control and interactions, and (5) immersive and interactive visualisation in VR systems (e.g. HTC Vive Pro, Pico 4 or others) using Steam VR as an interface between the game engine and the head-mounted display (HMD).

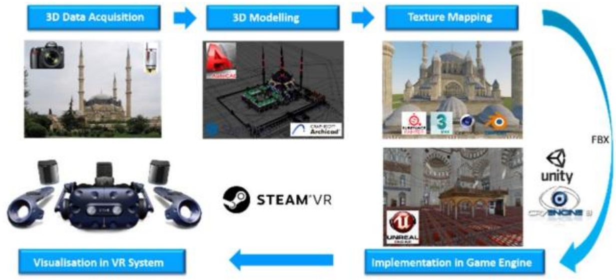

Figure 1. Workflow for the development of virtual reality (VR) applications.

4. The Turkish VR Projects

Three projects have been conducted in collaboration between BİMTAŞ and the Photogrammetry & Laser Scanning Laboratory of the HafenCity University Hamburg. The objective of this joint endeavour was to exemplify an immersive and interactive visualisation of historic Turkish monuments utilising the virtual reality system and head-mounted display HTC Vive.

4.1 Selimiye Mosque

The initial project was the development of a virtual reality (VR) application for the Selimiye Mosque (Figure 2), situated in the city of Edirne in Turkey. This project is described in detail by Kersten et al. (2017a) and summarized in the following. In 2011, the Ottoman imperial mosque was inscribed on the UNESCO World Heritage List. The mosque is distinguished by four pencilshaped minarets, which are the tallest ever constructed, reaching a height of 71 metres from ground level to the top.

Figure 2. The Selimiye Mosque of Edirne, Turkey.

The scanning of the mosque and its surrounding environment was conducted over the course of approximately one month in 2012, utilising a single terrestrial laser scanning system, the Riegl VZ400, and a team of three personnel from BİMTAŞ. In total, 110 scans of the interior and 447 scans of the exterior of the mosque were acquired, with an average scan density of six points per cm^2. Subsequently, in order to facilitate the subsequent colourisation of the laser scanning point clouds, an integrated Nikon D700 camera with a 20 mm lens was positioned on top of the Riegl scanner (Figure 3). In order to create a three-dimensional model of the mosque, a point cloud comprising 3.5 billion laser points was utilised (Figure 4). The geo-referenced point clouds were imported into Autodesk Recap and Geomagic Studio (for the generation of smaller details) for the generation of 3D meshes, which were used as the basis for solid modelling in the program 3ds Max to derive CAD drawings and the 3D model. Subsequently, photographs were taken using the Nikon D90 cameras during the field campaign for the purpose of texture mapping the solid 3D model of the mosque. These images were then radiometrically enhanced in Photoshop prior to texture mapping. The 3D modelling of the mosque required 24 personweeks.

Figure 3. Terrestrial laser scanning (TLS) of the Selimiye Mosque using the integrated DLSR camera Nikon D700 on top.

Figure 4. Part of the coloured TLS point cloud of the Edirne mosque – overview (left) and detail (right).

Figure 5. The coloured object parts of the Mosque show all objects with polygons reduced (left) and textured entrance of the Mosque model (right)

The final CAD model of the Selimiye Mosque comprised 6.5 million polygons, which was too large for an acceptable performance of the virtual reality (VR) application in the game engine. Therefore, the number of polygons were significantly reduced to 901.133 (Figure 5) to ensure smooth performance during the motion in and interaction with the virtual 3D model using the VR system HTC Vive.

Figure 6. Rumeli Hisarı, the historic Ottoman fortress at the Bosporus in Istanbul, Turkey (Courtesy of Şirin Akıncı Mimarlık Bürosu).

4.2 Rumeli Hisarı

The second project involved the generation of a virtual 3D model of Rumeli Hisarı, an Ottoman fortress situated on the Bosporus in Istanbul, Turkey (Figure 6), and its subsequent processing for the purpose of integrating the data into the game engine Unity. A detailed description of this project can be found in the paper of Tschirschwitz et al. (2019a), while a summary can be found below. Rumeli Hisarı, located on the European side of the Bosporus in the Istanbul district of Sarıyer opposite Anadolu Hisarı, was constructed in 1452 by Fatih Sultan Mehmed II (the Conqueror) with the objective of controlling the passage of ships entering the Bosporus through a narrow strait measuring only 700 m in width.

In February and March 2017, the entire fortress and its surrounding area were subjected to a comprehensive scanning process spanning approximately four weeks. This was conducted by the staff members of Solvotek, the subcontractor of BİMTAŞ, who utilised three terrestrial laser scanning systems, namely the IMAGER 5010c, IMAGER 5010x and IMAGER 5006h, produced by Zoller + Fröhlich (Figure 7). Subsequently, the Z+F IMAGER 5010x and 5010c were used to capture parallax-free 360° HDR colour imagery, utilising a DLSR camera (Canon Rebel T6) with a Canon 8mm fisheye lens mounted on the nodal Ninja MKII panoramic head following each scan of the IMAGER 5006. This was achieved through the use of the integrated i-Cam. The registration of 1480 scans, which was conducted by two operators, required approximately 30 days. The 3D modelling process employed in the point cloud was analogous to that used in the Selimiye Mosque project. The 3D modelling of the fortress in 3ds Max, which was carried out by two operators, took 3.5 months to complete and resulted in a polygon model with textures and 659,000 polygons, as depicted in Figure 8. For the texture mapping of the 3D fortress model 800 photos were taken by two persons in one week using a Canon EOS 50D camera with zoom lens 18-55mm.

Figure 7. The terrestrial laser scanning system Z+F IMAGER 5010 at the fortress Rumeli Hisarı (Courtesy of Solvotek Mühendislik) (left) and coloured point cloud (right).

Figure 8. The fortress as a polygon model with textures after solid modelling in 3ds Max.

4.3 Istanbul Çatalca İnceğiz Caves

The third project was the development of a virtual reality (VR) application for the Istanbul Çatalca İnceğiz Caves, which are located in the Çatalca District on the European side of Istanbul. This project is described in detail by Büyüksalih et al. (2020) and summarized in the following. The caves were carved out of the rocks in the Karasu valley. The cave structure, which covers an area of approximately 3500 m^2, was scanned in July 2018 using a Riegl VZ-400 terrestrial laser scanning system and four staff members from BİMTAŞ. In total, 46 scans of the interior and 50 scans of the exterior of the cave were acquired using a scanning density of 4 mm at a distance of 50 m. As with the previous projects, the 3D modelling was conducted in a similar manner. For the texture mapping of the solid 3D model of the cave, 300 photographs were taken using a DSLR camera Canon EOS 50D with an 18–55 mm zoom lens by two people in 3 days. In Figure 10 a panorama and a part of the interior model of the cave are illustraded.

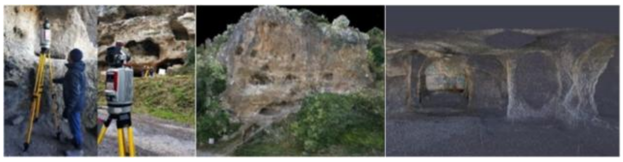

Figure 9. Terrestrial laser scanning using the Riegl VZ-400 inside and outside the cave (left) and the colourised point cloud data outside (left) and inside the cave (right).

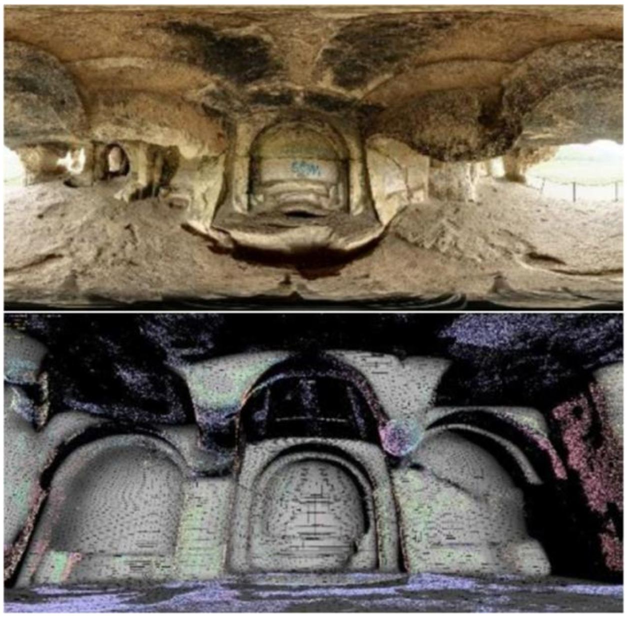

Figure 10. Gigapixel panorama of the cave indoor (top) and 3D interior model generated from the point cloud in 3ds max (bottom).

5. The VR Implementation

The scanning, modelling and texture mapping of the monuments was conducted by BİMTAŞ, while the VR implementation was undertaken by the Photogrammetry & Laser Scanning Laboratory of HCU Hamburg. The virtual reality applications of the three monuments were developed using the game engine Unity. The two textured CAD models and the meshed model of the cave, all generated in 3ds Max, were imported into Unity using the file format FBX. The virtual reality experience offers the possibility of visiting the monuments from a realistic firstperson perspective and employs intuitive interactions. The field of virtual reality also encompasses research into the mechanics of movement within this context. In his study, McCaffrey (2017) provides an overview of the various locomotion methods that have been developed and their implementation in Unreal Engine 4. The movement feature was implemented using the SteamVR package, which was downloaded from the Unity asset store. It was thus determined that the user should be able to move freely in the virtual object space, as opposed to via a series of viewpoints. In order to traverse long distances in the virtual space, a teleportation function was incorporated for the fortress and cave, whereas for the mosque, the user can select between teleportation and flight mode as a means of locomotion.

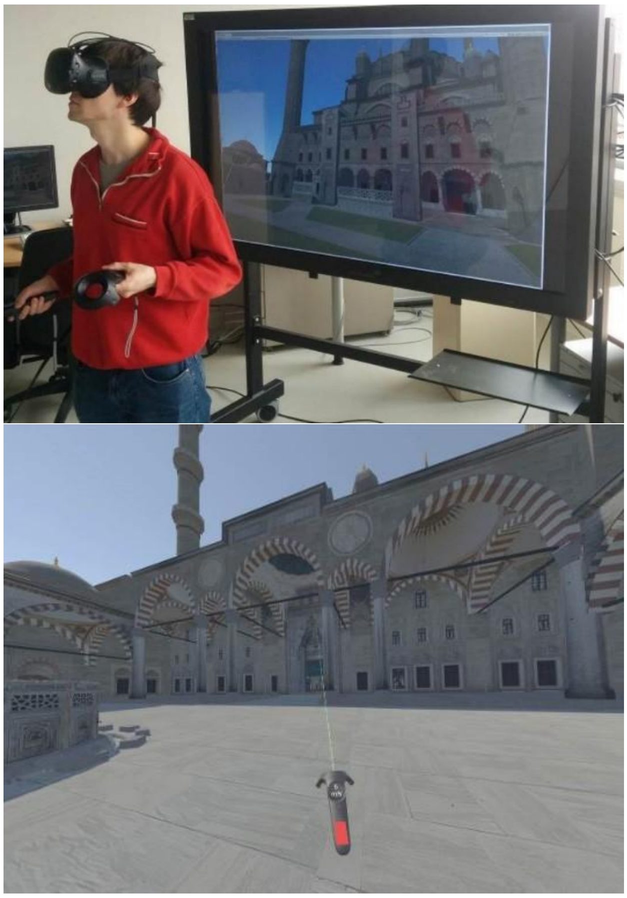

Figure 11. The Virtual Reality System HTC Vive in action using the controllers for interacting in the environment (top) and flight mode as locomotion using the controller in the Selimiye Mosque of Edirne (bottom).

In an interactive world, the user's view can't just be limited to the immediate surroundings. Therefore, the real environment of the fortress was visualised based on the 3D city model of Istanbul. The 1m resolution digital terrain model was used for the landscape in a TIN representation with approximately 430,000 faces. The terrain is textured with an ortho image of 0.25 m GSD and the dimensions of 8192 pixels squared. For the surrounding buildings, LoD 2 data was placed into the scenery as a block model with a standard roof structure. In order to contrast the highly detailed model of the fortress with the surrounding city, the LoD 2 dataset was coloured only in grey for the buildings and in orange for the roofs. Specific buildings such as the Fatih Sultan Mehmet Bridge are clearly visible to the informed user of the VR application (Figure 12).

Figure 12. VR application of the Istanbul Çatalca İnceğiz Caves.

Figure 13. Two perspective views of the fortress in the VR application (Unity) from the interior (top) and with the 3D city model of Istanbul in the right background (bottom).

The following figures illustrate the implementation of the VR application, which provides a virtual representation of the Selimiye Mosque of Edirne (Figure 11), the historic Ottoman fortress Rumeli Hisarı (Figure 13), and Istanbul Çatalca İnceğiz Caves (Figure 12).

The VR system permits users to enter, explore and analyse the virtual environment, thereby providing a high level of visual and corporeal immersion without the necessity for users to visit the sites in person. The challenge of the projects was to achieve a balance between the level of detail in the 3D data and the speed at which the 3D scenes were rendered in real time, in order to provide a smooth experience and to avoid the occurrence of motion sickness.

Virtual reality using an HMD is by definition a solitary task, as all external senses are muted to enhance immersion and therefore the experience. To create a more social experience, multiple users can participate in the experience, exploring the virtual object together as avatars while each user is in a different real-world location with an HMD. The Photon (Photon Unity Networking) independent networking solution is used to synchronise the movements of multiple users. Speech is captured by the HMD's built-in microphone and replayed for all users with respect to the speaker's position (spatialised audio). Photon also provides the server infrastructure and is free of charge for a moderate number of users.

Figure 14. Multi-user feature of the Virtual Reality System HTC Vive presenting two avatars with controllers.

The multi-user functionality was tested between Hamburg and Istanbul on 14 February 2017, when four users simultaneously visited the virtual model of the Selimiye Mosque as avatars to discuss and check the geometric quality of the modelled 3D data of the during the VR visualisation. During the joint virtual visit, the users communicated with each other via microphone. As the user groups were based in two different locations, Hamburg and Istanbul, travel costs could be avoided.

6. Conclusions and Outlook

This contribution presents the digital workflow, from data acquisition to the generation of an immersive visualisation of the three monuments in Turkey as a review. A virtual reality visit to the three sites was developed utilising the Virtual Reality System HTC Vive Pro, based on the 3D data that had been modelled from 3D point clouds of terrestrial laser scanning and textured using photos of DSLR cameras in the game engine Unity. The VR system provides a truly immersive experience, enabling users to step inside a virtual building environment, such as the mosque and the cave, without having ever seen the building in real life. The multi-user functionality offers new capabilities for interested parties to hold interactive discussions about aspects such as the architecture, structural analysis, building history and virtual restoration of a monument or a building. Furthermore, the VR application enables geometric quality checking of the modelled 3D data during the VR visualisation.

It is becoming increasingly evident that a purely immersive visualisation of the geometry of monuments of cultural significance will no longer be sufficient in the future. The advent of virtual reality (VR) has the potential to revolutionize the way knowledge is transferred. The utilisation of so-called 'serious games' within a virtual environment enables the acquisition of knowledge in a manner that is perceived as enjoyable by younger age groups in particular. The use of storytelling can facilitate the acquisition of background information on historical objects, thereby enabling users to gain a deeper understanding of the environment. Furthermore, the incorporation of individuals (dressed in historical attire, as exemplified in Stade 1620, Walmsley & Kersten, 2019) and animals can enhance the immersive quality of the virtual environment.

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