Virtual Reality Experience of Sarajevo War Heritage

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Abstract

Sarajevo War Tunnel can not be visited any more. It was closed just after the war due to the airport runway security. A small part (20m) can be seen in the Tunnel Museum. The only way to experience passing through this object, crucial for Sarajevo survival during the war, is Virtual Reality (VR). The paper describes the Sarajevo War Tunnel VR project, a virtual cultural heritage application combining VR storytelling about the Sarajevo siege with the VR simulation of the tunnel crossing. The user experience evaluation shows the potential of VR technologies in presentation of dark heritage.

CCS Concepts

*•**Human-centered computing** → HCI design and evaluation methods; •**Computing methodologies** → Virtual reality; •**Applied computing** → Education;*

1. Introduction

Digital technologies make time travel possible. Nowadays we can virtually visit the cultural monuments in their original appearance and experience the life of their inhabitants, learning from history the valuable lessons for our present. Digital storytelling breaths life into cultural heritage virtual reconstructions [Riz17] . The bare geometry, as realistic as it might be, is not enough for users to immerse in the past of cultural monuments and feel as they are really there. VR storytelling increases the immersion providing the possibility to look around while watching the stories.

The real value of Virtual Reality (VR) shows when presenting something that can not be experienced in reality. This is the case of Sarajevo War Tunnel. It saved the city during the siege (1992-1996) and provided the minimum of food, medical supplies and weapons to 500 000 citizens without water, electricity, heating and exposed to the constant shelling and sniper fire. Today only 20m of this object is open for public within the Tunnel museum, while the rest is closed due to the airport runway security.

This paper presents the VR application aimed to introduce the users with the Sarajevo siege and enable them to experience the Tunnel crossing at that time. It is an extension of the [JCIK19] paper, where we presented only the Tunnel crossing simulation part. In this paper we present the whole project, where the simulation is expanded with storytelling about the historical content of Sarajevo siege and details on the Tunnel construction. The application is set up in the Tunnel museum and available for free download online.

We consider as the main contribution of this research to the state-of-the-art in digital heritage the methodology of presenting the war experience to the users through interactive digital storytelling in virtual reality, immersing them in the past and teaching them about historical events in an attractive way. The educational aspect of the application is ensured through the conditioning the access to VR simulation by passing the quiz where the knowledge gained through VR stories is evaluated.

The paper has the following structure: Section 2 presents related work on VR cultural heritage experiences with particular emphasis on dark heritage; Section 3 describes the project with its historical background, application structure and web implementation; Section 4 shows how we conducted the user experience (UX) evaluation and what results were obtained and Section 5 offers our conclusions.

2. Related Work

Similar projects in VR and dark heritage are described in this section. In this paper we will use war and dark heritage as synonyms.

2.1. VR experience

Since the development and usage of VR are in steady growth and considering the popularity of VR technology, there is a lot of research considering this topic, including many applications treating historical and cultural heritage using immersive VR experience. Of particular importance is that, as Roussou states in [Rou99], usage of VR allows users to travel through space and time without stepping out of the museum building, or in broader case, without leaving the place VR setup is placed. This is particularly important in case of destroyed or unreachable cultural or historical artifacts and monuments [JCIK19].

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In [RIL*15], Rende et al. presented the usage of VR for the Exploitation of Underwater Cultural Heritage. The project iMARECULTURE [SAB*16] explores the same topic of using immersive virtual reality techniques for presenting European underwater cultural heritage, which is physically inaccessible to the majority. Having the same motivation of showing inaccessible monument and impossible to feel emotions, we are using similar methods.

In [SRH*18] Selmanovic et al. presented how VR can provide a means by which to explore and investigate intangible cultural heritage sites. In this project, among 360 degree videos and storytelling, Mostar Bridge diving is offered to users in VR simulation. Authors conclude that "for preservation, it is not only important to document the heritage, but to transfer the intangible part which can include feelings, perception, drive and motives."

What we find as an advantage of the methods used in Selmanovic et al. [SRH*18], is that the intangible heritage is being presented and preserved. What we consider a con in the mentioned work is that too much information is being given in narrative form without interaction, instead of focusing on the realism of the simulation and embedding information in simulation.

Also, it is important to mention State-of-the-Art work by Bekele et al. [BPF*18] where authors gave a very detailed overview and have discussed the AR and VR application in Cultural Heritage projects.

2.2. War Heritage

As Fisher and Schoemann discuss in [FS18], there are many ethical questions raised in the VR representation of dark heritage. These questions could be the reason why there are not more VR applications considering the dark heritage. In this part, we shall describe some of the dark heritage projects similar to ours.

A project that also deals with the theme of Sarajevo siege is Sarajevo Survival Tools Virtual Museum [RSHK12]. In this virtual museum, users can learn about the lives of people in Sarajevo during the siege through interactive digital storytelling and 3d models of objects used for everyday survival. Another similarity to our project is that the authors have made a user evaluation with a focus on the user's emotions during the museum visit. Our project can be considered as an extension of this project so that the users can have a wholesome experience of Sarajevo siege.

Another project where the user can experience life in captivity is VR Secret Annex of Anne Frank Museum [Fra19]. The project consists of a virtual museum and VR application for the Oculus HMD. This project was created because the real Secret Annex is empty and too small to admit a massive number of visitors so, in this way, everyone can visit it.

The Last Goodbye [Goo17] is a VR experience of the testimony of Majdanek Nazi concentration camp survivor. The authors have filmed the survivor in front of a green screen and put him in a virtual environment (VE) made with photogrammetry. They wanted the user to feel emotionally connected to the survivor's stories and place. Like in our project, the VR application was made for HTC VIVE Head Mounted Display (HMD), and it has interactivity and emotional factor.

On the other hand, a project that aims to show the humanity of combatants of both sides in war is The Enemy [Ene17]. Both VR and AR applications are made for this project. The user is put between two combatants of opposing sites in the VE. The combatants tell their experiences, feelings, fears, and hopes, so the user can get a full grasp of how it is to fight in a war.

The project The Great War in Raversyde [Rav19] is VR application where user can walk inside the VE of German coastal defense system in Raversyde, Belgium during the first World War and experience the life inside bunkers. This project differs from ours because it does not use HMD but joysticks for user interaction. Because users cannot enter real bunkers, in this way, they can see and learn how the ammunition was loaded into cannons and other similar experiences. This project could be more immersive if it were made for the HMD.

3. The Tunnel project

3.1. Historical background

The siege of Sarajevo started on 4th April 1992 and it continued for 1425 days. Units of the former Yugoslav National Army and Serb paramilitary forces surrounded the city and launched an unprecedented campaign of terror against its 500,000 residents. Water and power supply were cut and the gas supply was reduced. The city started to run out of food. The aggressor fired at the city from all the weapons in its arsenal. Snipers located at the surrounding hills fired mercilessly at pedestrians crossing street intersections. In June 1992, the United Nations assumed control over the Sarajevo Airport. Instead of terminating the siege immediately, they started delivering humanitarian aid under the principle: half to the aggressor, half to the victim [Sar10].

In order to survive and obtain at least the minimal amount of food, medical supplies and ammunition, the Sarajevo citizens have built a tunnel under the airport runway. After a few unsuccessful attempts to cease the siege of Sarajevo, and all of them ending in huge human losses, the construction of the tunnel seemed at that moment as the last straw for a change of the extremely difficult situation in the city, but also in the entire territory where the battles for liberation were led.

The work on the tunnel started at the beginning of 1993. Consequently, the tunnel was dug by hand, with shovels and picks, and wheelbarrows were used to carry 1,200 cubic meters of detritus away. The tunnel was dug 24-hours a day, with workers working in 8-hour shifts digging from opposite ends. Its construction was supported by the BH State, the Army, and the City of Sarajevo. The workers were paid with one packet of cigarettes per day, an item that was in high demand and a prized bartering possession. The construction of the tunnel was completed on 30 June 1993, when the two tunnels met in the middle. Use of the tunnel began the following day on 1 July 1993 [JCIK19].

After the end of the siege and the cessation of the need for communication under the runway, the tunnel was abandoned. The airport authorities claimed it was a threat to the runway security. It began its decline. Without regular maintenance, it was quickly flooded with water. Today only the first 20 meters are accessible to the public within the Tunnel Museum.

Figure 1: *The map of Sarajevo siege with the position of the Tunnel, photograph from the Tunnel Museum*

microphones (Sennheiser ew 100 ENG G3 Wireless Microphone Combo System) and an audio recording device (Tascam DR40).

Figure 3: *Screenshot from the first VE*

3.2. Application structure

The VR application was developed in Unity game engine. It consists of three parts: stories about the Sarajevo War Tunnel, Quiz with the questions about the Tunnel and simulation of walking through the Tunnel. The structure of the application is shown in the figure: 2. Because this application is made for HTC Vive HMD, everything is in 360-degrees: the stories, the user interface, the quiz, and the simulation.

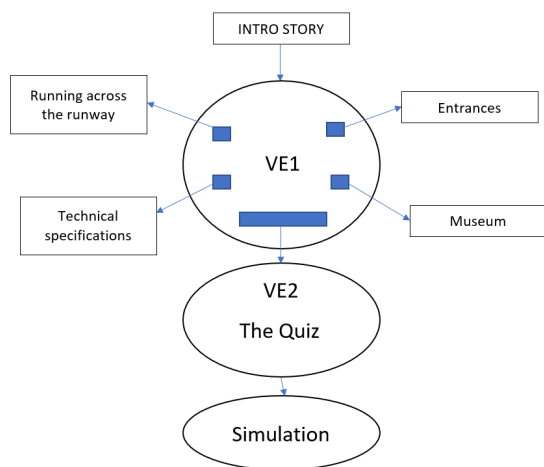In the first part, the user has to watch all five stories so they can

Figure 2: *The structure of the Sarajevo War tunnel application*

Figure 4: *Screenshot from the story about technical specifications*

When completed the watching of the videos in Virtual environment 1, the user is transferred to Virtual environment 2, where he accesses the quiz about the Sarajevo War Tunnel as shown in figure 5. The quiz has six questions, all of them abstracted from previously seen videos. User has to answer at least four questions correctly in order to finish the quiz successfully.

After finishing the quiz successfully, the user gains access to the

Figure 5: *Screenshot from the Quiz VE*

walk through the Tunnel as a reward. The introduction story offers an overview of the state citizens of Sarajevo were in during the siege and the reason why the Tunnel was necessary. After that, the user is transferred to Tunnel Museum VE (shown in figure 3, and they can choose the order of four stories that are left. These stories are about crossing the runway, technical details of the Tunnel, the entrances from and into Sarajevo, and the Museum. Edis Kolar, the curator of the Museum is the narrator in these stories (shown in figure 4). All VR videos have been recorded by a Garmin VIRB 360 Action Camera. The sound was recorded separately with two

Sarajevo War Tunnel VR experience as a reward. VR experience consists of the simulation of the walk through the Tunnel during

the siege of Sarajevo. The user finds itself on the entrance of the Tunnel and has to walk to the other side, to leave the occupied city. During its walk, the user is encountering obstacles, including blackouts, rising water level, and passing the man walking in an opposite direction.

The idea of making any simulation in VR is not easy, because the main problem is how to make all the actual reality aspects seem realistic in the virtual world. So to make the experience of the simulation as realistic as possible, a lot of effects that will increase the users' sensation have been used, involving audio effects like the storm in the background, bomb explosions, bullets and shot sounds, also visual effects including light flickering and blackouts, as well as the model of the tunnel itself with all the accompanying textures and materials.

The 3D model of the Tunnel was created manually, based on the blueprints of the construction project and observations/recordings of the part open for public within the Tunnel museum. Tunnel model was made in Blender, in respect to actual architectural drawing, and materials and textures are corresponding to real-life images., together with suggestions from the Museum curators and people who passed through during the siege. [JCIK19] Then the model was imported to Unity, and animations of flood, light flickering and walking were added. Every object has its own collider, so there are no flaws and possibilities for unrealistic movement. Also, some objects may be picked up. When it comes to lightning, blinking point lights were used, in order to achieve realism and represent possible situations at the time when the tunnel was still active. All of the scripts used in our project were written in C. The application was then adjusted to use HTC VIVE Head Mounted Display. The preview of what a user sees when entering the simulation is shown in figure 6.

In order to move through the tunnel, the user uses controllers, making hand gestures while holding the triggers. When experiencing a collision with the walls or another obstacle, the user's movement is limited in order not to step out of the tunnel. When the user steps in the flooded part of the tunnel, it's movement becomes slower and harder.

The challenge about this particular model was that the real tunnel had varying height so at some places it was higher and the average sized person could walk normally, yet on other places it was really low so the person had to bend. To achieve this effect in the application, the exact same varying height had to be simulated using colliders on the ceiling. Furthermore, the tunnel was narrow and two persons could barely go by each other, so to simulate that, a man that is pushing a wagon with supplies in the opposite direction was added, and the user has to move to the side in order to make him pass.

During rain storms the tunnel was often flooded, sometimes to the point that it had to be closed, so the animation of the water level rising was added, in order give the users insight on how would that look to be in a narrow space and with no exit near you. Because the tunnel was dark and the lights that were mounted in it could not always help illuminate it, as the result of blackouts due to electricity shortage, a lantern was added so the users can navigate even if it is pitch black. All the aspects crucial for realism and

Figure 6: *In-game preview*

immersion were added in order to produce a mix of feelings like fear, anxiety and concern yet in the end safety and relief.

3.3. Web implementation

Because not everybody can come and see the Tunnel Museum, and we wanted to attract potential visitors to the Museum, we have chosen to make this application available online [Sar19] similar to [SRH*18]. The web version is made in the Unity game engine, and it uses WebGL API and HTML as in our previous projects, [SRH*18] and [RBOS17]. Alongside these technologies, in the [RBOS17] we have used AngularJS Web framework also. The application structure is the same as HTC Vive application (Figure 2). The only difference is user interaction. The user can move and interact in the application using the keyboard and mouse. We had to make some adjustments, we have omitted SteamVR and VRTK, and used FirstPlayerCharacter Asset for user representation, and made custom scripts for user movement and interaction.

4. User Experience Evaluation

Approaches in evaluating user experience (UX) are primary determined by the goal of the study. Broad classification of evaluation goals according [LFH10] is:

- Exploration to understand novel problems,
- Explanation of a context of technology use,
- Description of a context of technology use,
- Demonstration of novel tools.

Common feature of these different evaluation goals is informative feedback to designers and developers, with substantial qualitative component. We have decided for qualitative evaluation, with users being observed during the experiment and guided through two user experience surveys. The experiment involved usage of the VR application, and was conducted at the Graphics Lab at the University of Sarajevo. Users were recruited by invitation, representing different user types. In order to establish validity of survey responses we included questions for relevant demographic data: age, gender, personal experience related to the Sarajevo war tunnel and the Museum, experience with the VR environments [LFH10]. . The evaluation involved 14 participants each of them being engaged in individual session. Participants were informed about the experiment procedure and their tasks before conducting the experiment. Users watched digital stories and answered the first survey aimed to collect data linked to the digital stories experience. After answering the quiz users were engaged with the Sarajevo war tunnel virtual environment, and finally answered the second survey measuring perceived emotional experience.

The evaluation of digital stories was based on rating the set of 7-point Likert items, where users had to complete a statement choosing between the opposite endings, as in the following: "Digital stories improved my knowledge about the Sarajevo War Tunnel: very much ——- very little". Users appreciated the information learned through the IDS application, but emotional dimension of the stories is reflected in near average rating for the statements related to the concentration and complexity.

In order to capture emotional experience of the participants passing through the Sarajevo War Tunnel; we have offered them open questions asking for their feelings and comments. In addition to open questions we asked participants to rate our list of 25 different emotions. Users rated emotions on a 5-point Likert scale.

The open answers were analysed to identify key themes linked to the user experience. The most frequent themes have been identified as: Anxiety, Fear, Sorrow, Memory, Adventurous. The list of the themes identified from the open questions are shown in the word cloud diagram depicting their frequency, see figure 7.

The highest rated emotions from predefined list of 25 were: Mystic, Dark, Attractive, Sorrow, Anxious, Adventurous, Winner, Tragic, Strong, and Focused. It is interesting to notice compliance between the open question answers and the highest rated emotions from the list. It is illustrating that users emotional response were in compliance with an intended empathetic connection provided by the VR application.

5. Feedback

Sarajevo War Tunnel VR project was expected with anticipation even during the work in progress. Since the first announcement the media and general public were following the implementation with great attention. The promotion of the project was held in the Tunnel Museum where the VR setup became a part of the permanent exhibition. It created a media uproar. All TV stations and news portals have published the news. Several TV stations made live transmissions of the VR experience demo. The general impression was a huge appreciation of the work and opportunity
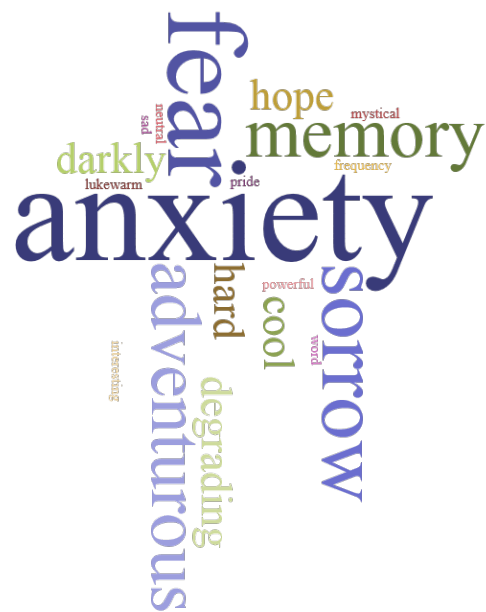

Figure 7: *Word cloud illustrating the frequency of words used to describe feelings of passing through the Sarajevo War Tunnel*

it creates to experience the Tunnel crossing not anymore possible in reality. Particularly important were comments of war veterans who were involved in building the Tunnel. All of them claim that we succeeded in recreating the realism of the actual crossing. The visitors of the Museum were very excited and looking forward to try the VR setup.

We assume that this kind of feedback was caused by the fact that war heritage carries on a special emotion, not usual for other cultural heritage sites and objects. People emphasise with war victims and horrors that survivors experienced and feel the need to contribute by experiencing the same at least in a virtual way. The storytelling of the Sarajevo War Tunnel VR project contains enough historical facts to convey the essential information on Sarajevo siege and the Tunnel to the users, not overburdening them with data so they would give up on watching. At the same time, it includes also some comical stories about various crossing experiences that were also a part of our war reality and helped us to preserve our sanity in that extremely difficult period. The introduction of the quiz makes a difference between our storytelling and a game-like VR simulation creating commitment to the viewers to pay attention to the information told in the stories. It adds educational dimension we find compulsory in virtual presentations of war heritage.

6. Conclusions

The Sarajevo War Tunnel VR project shows the potential of VR technology to recreate the experience of war heritage objects and events. Horrors of war need to be remembered in order to be prevented from happening again. VR experiences use computer graphics, sound and storytelling to transport the users in another world and to make them understand how fortunate they are to experience those horrors only virtually. Combination of VR storytelling and 3D virtual environments is a natural way to achieve the maximum immersion and edutainment.

The project is now upgraded with the third virtual environment containing the stories about the UN official position towards the Tunnel, bomb threats, the oil and explosive transfers, massacres, Tunnel building material, problems with water, communication, ventilation, black marketing and attacks of the aggressor against the Tunnel. We plan to add also testimonies of Sarajevo defense commanders, Tunnel engineers and other persons crucial for the Tunnel building and maintenance. After this addition we plan to conduct a more detailed user experience evaluation.

References

[BPF*18] BEKELE M. K., PIERDICCA R., FRONTONI E., MALINVERNI E. S., GAIN J.: A survey of augmented, virtual, and mixed reality for cultural heritage. *JOCCH 11* (2018), 7:1–7:36. 2

[Ene17] The enemy is here. http://theenemyishere.org/, 2017. Accessed: 2019-06-14. 2

[Fra19] The anne frank house in vr. https://www.annefrank.org/en/about-us/what-we-do/publications/anne-frank-house-virtual-reality/, 2019. Accessed: 2019-06-14. 2

[FS18] FISHER J. A., SCHOEMANN S.: Toward an ethics of interactive storytelling at dark tourism sites in virtual reality. In *Interactive Storytelling* (Cham, 2018), Rouse R., Koenitz H., Haahr M., (Eds.), Springer International Publishing, pp. 577–590. 2

[Goo17] The last goodbye. https://www.wired.com/2017/04/vr-holocaust-history-preservation/, 2017. Accessed: 2019-06-14. 2

[JCIK19] JAJCANIN A., CHAHIN T., IVKOVIC-KIHIC I.: Sarajevo war tunnel vr experience. *Proceedings of Central European Seminar on Computer Graphics* (2019). 1, 2, 4

[LFH10] LAZAR J., FENG J. H., HOCHHEISER H.: *Research Methods in Human-Computer Interaction*. Wiley Publishing, 2010. 4, 5

[Rav19] The great war at raversyde. https://thegreatwararaversyde.wordpress.com/, 2019. Accessed: 2019-06-14. 2

[RBOS17] RIZVIC S., BOSKOVIC D., OKANOVIC V., SLJIVO S.: Kyrenia - Hyper Storytelling Pilot Application. In *Eurographics Workshop on Graphics and Cultural Heritage* (2017), Schreck T., Weyrich T., Sablatnig R., Stular B., (Eds.), The Eurographics Association. 4

[RIL*15] RENDE F. S., IRVING A. D., LAGUDI A., BRUNO F., SCALISE S., CAPPA P., MONTEFALCONE M., BACCI T., PENNA M., TRABUCCO B., ET AL.: Pilot application of 3d underwater imaging techniques for mapping posidonia oceanica (l.) delile meadows. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 40*, 5 (2015), 177. 2

[Riz17] RIZVIC S.: How to breathe life into cultural heritage 3d reconstructions. *European Review 25*, 1 (2017), 39âĂŞ50. doi:10.1017/S106279871600034X. 1

[Rou99] ROUSSOU M.: Incorporating immersive projection-based virtual reality in public spaces. In *Proceedings of 3rd International Immerse Projection Technology Workshop* (1999), Citeseer, pp. 33–39. 1

[RSHK12] RIZVIC S., SADZAK A., HULUSIC V., KARAHASANOVIC A.: Interactive digital storytelling in the sarajevo survival tools virtual environment. In *Proceedings of the 28th Spring Conference on Computer Graphics* (New York, NY, USA, 2012), SCCG '12, ACM, pp. 109–116. 2

[SAB*16] SKARLATOS D., AGRAFIOTIS P., BALOGH T., BRUNO F., CASTRO F., PETRIAGGI B. D., DEMESTICHA S., DOULAMIS A., DRAP P., GEORGOPOULOS A., ET AL.: Project imareculture: advanced vr, immersive serious games and augmented reality as tools to raise awareness and access to european underwater cultural heritage. In *Euro-Mediterranean Conference* (2016), Springer, pp. 805–813. 2

[Sar10] SARAJEVO GRAPHICS GROUP: Sarajevo survival tools virtual museum. http://h.etf.unsa.ba/srp/, 2010. 2

[Sar19] SARAJEVO GRAPHICS GROUP: Sarajevo war tunnel vr. http://h.etf.unsa.ba/tunel-spasa/, 2019. 4

[SRH*18] SELMANOVIC E., RIZVIC S., HARVEY C., BOSKOVIC D., HULUSIC V., CHAHIN M., SLJIVO S.: Vr video storytelling for intangible cultural heritage preservation. 2, 4