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VISUALISATION OF ARCHAEOLOGICAL HERITAGE INTERPRETATIONS IN VIRTUAL AND AUGMENTED REALITY

Abstract. Digital heritage finally provided methodology and technology enabling archaeologists to visualize their interpretations of cultural heritage objects and sites. High fidelity 3D reconstructions, Virtual and Augmented Reality applications and other digital heritage outputs are opening the world of archaeology to the general public through digital contents in museum exhibitions and online. In this paper, we present the work of the Sarajevo Graphics Group Laboratory from University of Sarajevo in digitization and digital presentation of cultural heritage of Bosnia and Herzegovina, Serbia, Montenegro, Albania, Greece, Cyprus and Italy. The presented projects will show successful interdisciplinary collaborations and elaborate challenges and lessons learned. User Experience study's results will prove user immersion and edutainment of developed applications.

Key words: archaeological heritage, Virtual (Augmented) Reality, immersive technologies, virtual archaeology, interactive digital storytelling

INTRODUCTION

Digital technologies are since long time entwined with our everyday lives. The significant amount of our time is spent online. Due to unfortunate pandemic circumstances, we are getting used to virtual movement and communication. The announced development of metaverse as „a shared online space that incorporated 3D graphics, either on a screen or in Virtual Reality,[1] foresees growth in popularity of Virtual Reality environments.

This technological development advances in many areas, including cultural heritage preservation and presentation. It gives archaeologists new opportunities to visualize their assumptions about cultural monuments and sites and their original appearances. Although some of them are still reluctant to claim something they cannot be sure about, many are embracing these tools and methods and find them very useful in their research. There is no doubt that digital heritage has huge potential in the popularisation of heritage itself and attracts people to museums and heritage sites, offering them context information and interaction with exhibits, as well as virtual travel to the past.

[1] Sparkes 2021, 18.

Interactive digital storytelling is a methodology that becomes often used in digital cultural heritage applications. It is defined as narrative entertainment that reaches the audience via digital technology and media.[2] It uses the fact that humans have been communicating by telling stories since the beginning of mankind, only this time storytelling becomes digital and interactive. Within the H2020 project iMARECULTURE, researchers from the Sarajevo Graphics Group Laboratory at the University of Sarajevo – Faculty of Electrical Engineering, established the Guidelines for Interactive Digital Storytelling[3] based on inputs from interdisciplinary experts. These guidelines provide directions for creating educational and attractive digital stories and implementing interaction possibilities.

We used this methodology in numerous digital cultural heritage projects, some of which will be presented in this paper. We will introduce the common workflow of interactive digital cultural heritage applications, with particular emphasis on collaboration with archaeologists. We will show how different archaeological sites and cultural heritage objects can be revived using digital technologies and made more attractive to visitors.

In Section 2 we will introduce the workflow of a typical digital cultural heritage application. Section 3 will overview case studies of Tašlihan, Bijela tabija, Kyrenia, Baia, and Roman heritage in the Balkans. Section 4 will present users' impressions and in Conclusion we will offer lessons learned and solutions for the challenges we encountered.

1. The workflow

Regardless of whether the final application will be in Virtual Reality (VR), Augmented Reality (AR), desktop VR, or mobile platforms, we use the same workflow to create it. We engage the interdisciplinary team of professionals which includes archaeologists, historians, screenplay writers, music composers, sound designers, graphics designers, set designers, make-up artists, UX designers, and computer scientists to design, develop and implement digital cultural heritage applications. Only such a team can produce something that will be historically accurate, entertaining, and educational at the same time. The workflow of a typical interactive digital storytelling application is shown in **Figure 1**.

Fig. 1. The workflow

1.1. Collecting historical information

The first step in the production process is collecting historical information on cultural monuments or sites. We contact the archaeologists and/or historians who are experts

[2] Miller 2019.

[3] Rizvic et. al. 2017a.

for that site or historical period and they provide us with the selection of relevant information needed for creating the scenario. In many cases they are not familiar with VR or AR, so we make a demo of our applications using VR headsets and mobile devices to show them what they can expect from the application. Only after that demo they grasp the potential of digital technologies and get ideas what aspects of a cultural monument can be presented in this way.

It is very important that the historical information is not too detailed and only the most significant parts are extracted, as the attention span of users is very short nowadays and we need to divide the information in a hierarchical structure that would make them interested to go deeper and discover more in the process.

We always ask for sketches or assumptions people who study the site could have about its original appearance, so we could create 3D reconstruction. For some sites it is not difficult, as there are historical photos or blueprints, but for many sites, it is impossible to get any material describing the original shape of the monument. In that case, we rely on assumptions of archaeologists/historians based on some typical objects from that particular period.

On a few occasions, we encountered difficulties when archaeologists were not keen to have their assumptions visualized, claiming that they cannot be sure if the assumptions were correct. We explained to them that we always put disclaimers related to the presented reconstruction, which inform the viewers that there is uncertainty that needs to be taken into account. We are guided by the fact that it is better to present even an uncertain reconstruction of the cultural monument that can attract visitors and make them learn about its history, than not presenting anything at all.

Aside from materials for 3D reconstruction of cultural monuments or sites, we always seek information about intangible heritage aspects of the selected object, in order to be able to present life in that historical period through the appearance of our actors/narrators. We look for historical events, legends, customs and other elements that can be used for tailoring the storytelling.

1.2. Filming locations in 360 video

360 video is a new video format that positions the viewer in the center of the shot. Unlike the classical video we watch on the screen, this video gives us a feeling of immersion and makes us believe that we are really in the place where it was recorded. 360 video can be watched on a computer or mobile device screen, but the most immersive experience is watching it on VR headset. Another feature of this video format is interaction, as the viewer can turn around and see the recorded environment in 6 degrees of freedom (6dof).

We use 360 videos to record the cultural heritage sites and transform them into their historical appearances using computer animation. Recorded video enables the user to virtually travel to the selected location and experience its presence. Then, in computer-animated transition, the location transforms into its past and 3D reconstructions pop out from the existing remains.

Recording in 360 videos has its challenges. For example, the film crew can not be visible in the shot, so we always need a place to hide while recording. For the projects we mention in this paper we used Garmin VIRB 360 camera. This camera has a Wi-fi connection to the mobile device, where the operator can follow the recording (**Fig.2**). We recorded in 5.6K video quality.

1.3. **Photogrammetry**

Another exciting feature of digital cultural heritage is that it offers the users possibility of interacting with exhibits. In real museums is unthinkable to touch the exhibits, while in digital applications we can take the exhibits and explore them from all sides. That is particularly attractive for very small exhibits, where we can see all the tiny details in the 3D model.

Fig. 2. Filming 360 video

We create digital replicas of museum exhibits using photogrammetry. It is the technique of obtaining 3D models from a large set of photographs. We record the object from all sides and import the photographs into the software which aligns them and creates e 3D model with authentic texture. For smaller objects we use a light box setup with the rotatable platform (**Fig. 3**). The object is placed on the platform and the camera is connected with it and a mobile phone using wi-fi. Through mobile application we record a sequence of pictures, while the platform rotates for every picture, offering a different view of the object.

Fig. 3. Photogrammetry of small objects

Fig. 4. Photogrammetry of large objects

When the object is too big to fit into the light box, or it is located outside and cannot be moved, we make a large set of photos from all sides (**Fig. 4**). There are several challenges in this process, such as the light conditions (uneven light, shadows on the object, change of illumination),the position of objects (obstacles to approaching it, other objects too close) etc. Sometimes we need to cut the grass around the object in order to approach it, sometimes it is completely impossible. For larger objects in the exterior, we use drone photogrammetry.

Regardless of how we obtained the photographs, they are loaded into the software for photogrammetry to create the 3D model. We use Reality Capture software, one of the

most appreciated in the industry. The pictures are aligned and after several steps, the polygonal model and the texture files can be exported. We usually export the models in obj files which can be imported in the Unity 3D game engine for completing the application.

1.4. Costumes design

Interactive digital storytelling applications include actors-narrators telling stories to the users. Our experience shows that the users much more appreciate human narrators than 3D characters/avatars.[4] According to our user experience evaluations, the reason is that for humans it is easier to empathize with another human. As our applications present certain historical periods, the narrators need to be dressed accordingly. Our collaborators from archaeology and history instruct our costume designers on the target appearance of the characters.

Costume designers work in the same way as for theatre or film production. The only limitation is in using green color, as the actors who will be recorded against the green screen should not wear any green, because it will look transparent after postproduction. In **Figure 5** are presented 8 different costumes from the Underground project.[5]

Fig. 5. Costumes from Underground project

1.5. Set design

Sometimes in our applications, we have scenes recorded in physical space. In order to show selected historical periods, we create sets that we use for filming. These sets are created in the same way as for theatre or movie production. The main difference is that they need to have the possibility to hide the microphones and lights, as in 360 videos no film equipment can be visible. Therefore, we use practical lights for the illumination of the scene and record the sound using boom microphones attached to actors. In Figure 6 is presented the set for a scene from WWII for the Battle on Neretva VR project. There we enable the users to experience one of the most important battles from WWII that happened in Jablanica, Bosnia and Herzegovina. The scene is a part of storytelling in which the user receives instructions from partisan commander how to destroy the bridge and save the wounded.

1.6. Composing music

Music and sound are very important elements of VR/AR experience. As in every movie production, the sound consists of the narrator's voice, background music and an environment sound called folly. Music needs to be composed with special attention to the historical period we are presenting, so we also here rely on the inputs from archaeologists/historians.

[4] Rizvić 2017.

[5] Underground 2021.

In VR production a particular challenge is encountered: the sound has to be 3D. We cannot have actor speaking from the right side of the user and his voice coming from the left side. It means that the music and sound need to be spatialized. Sound spatialization is not trivial, as the background music needs to be headlocked, meaning that it should not change with the position of the user. Only sounds related with physical positions in the VR environments need to follow the movement of the user. We described this complicated sound production process in.[6]

1.7. Filming the actors on green screen

The actors-narrators need to be recorded against the green screen background, to provide the possibility for removing the green and superimposing them into computer animations or adding them in game engine as parts of the application. Green screen recording is performed in a special studio that has evenly illuminated green background, in form of cloth, screen or painted wall. The actors should not wear anything in green colour, as in postproduction holes appear in that places. The sound is recorded by shotgun microphone, on boom pole next to the actor. The microphone and other pieces of equipment that might be visible in the shot are cut out in Adobe After Effect or Premiere using masks. The only important issue is that the actor does not make any movement over those elements, as it is difficult to mask them in that case, without cutting out parts of the actor.

1.8. 3D modeling virtual reconstructions

3D reconstructions of cultural monuments are created in collaboration with archaeologists/historians. They provide the basic information on the assumed original appearance of the object, either through historic photographs, sketches or typical objects from that period. During the modelling process, they are checking the object creation and giving suggestions on possible adjustments.

Modelling process consists of creating basic geometry through classical 3D modelling techniques, texturing, illumination and rendering. It is usually done in 3ds max or Cinema 4D in our production. Finalized 3D models are either rendered into images for compositing or exported as polygonal geometry to be added as an asset in the game engine where the application is programmed.

1.9. Compositing

If the application contains separate scenes or digital stories, the final post production of video and sound is done in compositing. For this we usually work in Adobe After Effects, combining recorded 360 videos, rendered 3D models and actors' footage in a single computer animation. We add to the sound mix in ambisonics audio and create VR video files that will be added to the application. These digital stories can be watched also on YouTube, but then they are not interactive.

1.10. Programming the application

The main difference between VR video and VR application is that the application supports user interaction, while the video can be watched only as a sequence without user intervention. VR applications are created for VR headsets or desktop/mobile platforms. We program them using Unity 3D game engine. All created elements are added as assets in a Unity project and combined to enable user interaction according to the application design. We implement movement in virtual environments, activating selected stories, interacting with 3D exhibits and the gameplays.

[6] Musanović et.al. 2021.

1.11. Landing page design and implementation

In order to fully facilitate and advertise a digital heritage project, we always create an adjoined landing web page. It contains the basic information on the project and production team, project trailer, as well as download links if the application is free. For museum applications we usually create teaser versions, with reduced functionalities, to attract the visitors to the museum.

2. Case studies

The results of the production process described in the previous Section will be demonstrated thorough five case studies. They date from 2015 till 2021 and the progress in technology and methodology can be noticed. Some of them are available online, while some are installed in museums as extensions of physical exhibitions.

2.1. Tašlihan

Tašlihan was the biggest hotel in the Bosnian province during the Ottoman period. It was built in 1540 and today only one wall has been preserved. In collaboration with archaeologists from the Museum of Sarajevo, who worked on the excavation of this object, we created an interactive 3D model and digital storytelling application.[7] The main storyteller is Murad bey Tardic, historical character (**Fig. 7b**), best friend of Gazi Husref Bey, who was the governor of Bosnian province and who built Taslihan and many other objects of public importance in Sarajevo.

Fig. 6. Set in the Battle of Neretva VR

Fig.7. 3D reconstruction of Tašlihan and drawing of Murad bey Tardić, the narrator character

The application is implemented as documentary movie,[8] interactive digital story[9] and serious game.[10] The interactive digital story consists of videos with interactive key words, which open new videos on user click. Serious game offers the user to enter in the Tašlihan model (**Fig. 7a and c**) after watching all stories and passing the quiz.

[7] Rizvić, Prazina 2015, 1-2.

[8] Tašlihan movie 2015.

[9] Tašlihan digital story 2015.

[10] Tašlihan game.

2.2. Bijela Tabija

The idea for the Bijela Tabija (White Bastion) project came from the archaeologist who was leading excavations on this archaeological site on behalf of Museum of Sarajevo. He approached us asking if we could visualize his assumptions on different appearances of this object in three historical periods.

White Bastion is one of the fortresses within the Sarajevo city walls. It is positioned above the city and has remains from medieval, Ottoman and Austrian-Hungarian period (**Fig. 8**). We created a desktop Virtual Reality application containing stories about the object and its history, 3D models of the object from different historical periods and 3D reconstructions of digitized archaeological findings from the site.[11] The narrator is an "eternal soldier of Sarajevo", who is changing his costume/uniform through the stories.

Fig. 8. Left - White Bastion fortress now, Right: Virtual Reconstruction with the actor, Bottom: 6 interactive models of the fortress changes through history

The project was implemented as a coproduction with Radio television of Bosnia and Herzegovina, so the stories are also broadcasted as a documentary. This is the first of our projects where we used the real actor for storytelling. The user satisfaction was so great that we continued with that practice in future projects.

2.3. Kyrenia

H2020 iMARECULTURE project had a goal to present underwater cultural heritage to museum visitors and Internet users through educational games, Virtual and Augmented Reality. We were in this consortium a partner in charge of digital storytelling. At the beginning of the project we tried to explain to the partners what is interactive digital storytelling and how we plan to conduct our research, but archaeologists were not able to imagine what exactly we will do. Therefore, we created a pilot application called Kyrenia.[12]

The topic of our application was the ship that sank around 288 B.C. near Kyrenia, Cyprus. Its remains were found in 1967. They were conserved using special chemical pro-

[11] Rizvić et al. 2016.

[12] Rizvić et. al. 2017b.

cedures. Studying them, the archaeologists discovered details from the ship's past, life on board and other interesting elements of seafaring in Mediterranean during that historic period.[13] Several replicas of the ship were created, one of them exhibited in the Thalassa Museum at Cyprus, a partner in the project.

The archaeologists were reluctant to publish any assumptions about the life on board, the crew and the captain, claiming that they are not sure about that information. We explained to them that what we publish always has some of historical uncertainty, which is clearly communicated to the viewers. Finally, we created 6 stories, about the technical characteristics of the ship, its route and cargo, and about the life on board, beliefs of crew members and sinking. The users who watch all 6 stories can embark the ship model and sail across the sea. Figure 9 presents screenshots from the application.

Fig. 9. Top: screenshots from digital stories, Bottom: landing page and virtual model of the ship

2.3. Baiae

After introducing hyper-storytelling, a new methodology for interactive digital storytelling, we created digital stories for iMARECULTURE VR application Dry visits. The application is taking the users for virtual dives to three selected underwater locations: Baiae in Italy, Mazotos in Cyprus and Xlendi in Malta.[14]

Baiae dry visit is recreating the ancient city of Baiae, located close to Naples, Italy. This city was a vacation spot for Roman aristocracy and was full of luxurious villas and artworks. Due to tectonic movements, half of the city is now under the sea and the rest is turned into the archaeological park. Visitors who have diving certificates can visit also the underwater area. In our application, the user first makes a virtual dive and explores the area and then the water disappears and virtual reconstruction opens for exploration.

Italian archaeologists prepared scenarios for digital stories placed in a virtual reconstruction of the city, with the goal to introduce the users to life there during the Roman period. Based on that scenario we created digital stories about the Roman aristocrat

[13] Katzev 2005, 72-81; Demesticha 2012.

[14] Rizvić et.al. 2019.

who is buying a statue from a sculptor to decorate the garden in his villa. The stories are activated from the underwater virtual environment in places where they supposedly happened. Watching them on VR headsets, the users can look around and feel immersion in the past (**Fig. 10**).

Fig. 10. Screenshots from Baiae Dry Visit digital storytelling

2.4. Roman heritage in the Balkans

Roman heritage in the Balkans was a collaboration between Bosnia and Herzegovina, Serbia, Montenegro and Albania in the digital presentation of cultural heritage from the Roman period. Archaeologists from all 4 countries selected 8 Roman heritage sites (2 per country) that are most significant and suitable for virtual presentation. They also provided the inputs for scenarios of digital stories.

VR application is designed as a set of 8 digital stories, where the actress plays different roles related to historical characters from the Roman period (**Fig. 11**). Every story starts with her as goddess Minerva, introducing the selected location. Stories are computer animations of 360 videos from real locations and 3D reconstructions of cultural monuments created in collaboration with archaeologists. After watching all stories, the users are presented with a quiz consisting of questions from the stories. If they pass the quiz, they can explore the selected museum exhibits from all locations digitalized by photogrammetry and interact with them.

Fig.11. Screenshots from Roman Heritage in the Balkans stories

The content created for this project related to the area of Sarajevo was reused in the Augmented Reality application Roman Heritage of Sarajevo. After downloading the mobile application and printing the map available on the landing page, the user can activate computer-generated content by scanning the tracker images from the map. There he/she can see the actress telling stories about a villa and terme found in Ilidža near Sarajevo and see 3D reconstruc-

Fig. 12. Augmented Reality application Roman Heritage of Sarajevo

tions of those objects, as well as museum artifacts found on the site (**Fig. 12**). The application can be activated from the very location of the Roman remains and then it offers additional contents.

3. **User experience evaluation**

For all mentioned projects we conducted user experience evaluation studies, so we can determine the usability, user immersion and satisfaction. The applications were evaluated as very successful. Users expressed a high level of immersion and entertainment, as well as the educational dimension of the digital content. They particularly appreciated the use of actors as storytellers, emphasizing the empathy they felt through the stories. Some users stated that through our applications their dream of time travel came true. Most of the users appreciated the realism of Virtual Reality, although a smaller number were having some problems with interaction and motion sickness. Augmented Reality was appreciated as the technology available for everyone, as everyone has a mobile device, while not many people possess VR headsets.

Our collaborators archaeologists and historians are very satisfied with the results of our joint work and they have many new ideas for future applications. They understand the potential of digital technologies for the visualization of their assumptions and research.

CONCLUSIONS

We presented the methodology and case studies based on visualizations of archaeological interpretations through digital cultural heritage. Through our collaboration with archaeologists and historians, we learned to communicate using a common language, without the burden of technical terms and imposing technical solutions. Every interdisciplinary collaboration has to be founded on mutual respect of different professionals and investing everyone's knowledge in the common output. The crucial moment of communication with archaeologists and historians was the demo of existing applications using Virtual Reality equipment. From their own user experience, they would devise ideas for the common project and enter the production process.

Museum curators also benefited from these projects, understanding how to extend museum exhibitions with digital content and provide visitors with experiencing cultural heritage. Through Virtual and Augmented Reality, they offered the visitors interaction otherwise impossible in the museum and introduced them to with aspects of the exhibition that cannot be visible in reality. We believe that every museum should have a VR showroom with applications that will fill the gaps in presenting the topics of the exhibition and attract visitors to the museum.

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Rezime:

VIZUELNA INTERPRETACIJA ARHEOLOŠKOG NASLEĐA U VIRTUELNOJ I PROŠIRENOJ REALNOSTI

Ključne reči: arheološko nasleđe, virtuelna (proširena) realnost, imerzivne tehnologije, virtuelna arheologija, interaktivni digitalni storiteling

Digitalizacija nasleđa je u poslednje vreme obezbedila odgovarajuću metodologiju i tehnologiju, pruživši arheolozima mogućnost da vizuelizuju svoje interpretacije objekata ili lokaliteta kulturnog nasleđa. Tako su 3D rekonstrukcije u visokoj rezoluciji, zatim aplikacije koje podržavaju virtuelnu odnosno proširenu realnost, uz druge alate digitalnog nasleđa, otvorile još više svet arheologije ka širokoj publici putem takvih sadržaja u muzejskim postavkama ili *online* zbirkama. Iz tog razloga, ovom prilikom smo predstavili rad Sarajevo Graphics Group Laboratory sa Univerziteta u Sarajevu, koji se odnosi na digitalnu prezentaciju kulturnog nasleđa iz Bosne i Hercegovine, Srbije, Crne Gore, Albanije, Grčke, Kipra i Italije. Prikazani projekti ilustruju primere uspešne interdisciplinarne saradnje, elaborirajući izazove sa kojima su bili suočeni, kao i stečena saznanja. Rezultati studije o iskustvima korisnika pomenutih sadržaja pokazali su u kojoj meri su i zaista postignuta njihova imerzivna iskustva kroz korišćenje razvijenih aplikacija.