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Use of Augmented Reality in the Preservation of Architectural Heritage: Case of the Aqueduct Kuru Kopru (Kayseri, Turkey)

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Abstract

Purpose

The architectural preservation embeds all the activities dealing with the sustainability of the built heritage. The representation and diffusion of heritage take a core place in that process. This study aims at the diffusion of the Aqueduct Kuru Kopru towards a broad public audience, establishment of the awareness that Augmented Reality (AR) methods can be used for the evaluation and presentation of the semi-collapsed structures and serving as a model for the representation and diffusion of virtual reconstructions of Architectural Heritage (AH).

Design/Methodology/Approach

This work refers to restoration and heritage visualization charters, combines Computer-Aided Design (CAD), photogrammetry survey method, and advanced texturing techniques to acquire and model virtual reconstructions of the Aqueduct Kuru Kopru from the Roman-Byzantine period to the year 2017. The paper also describes the frameworks for the implementation of a non-immersive and an immersive AR application to visualize modelled reconstructions. The method used consists of three main stages: modelling of the virtual reconstructions, texturing of models, and development of AR applications.

Findings

This study establishes AR and cultural heritage digitization techniques as efficient tools to represent and diffuse the Aqueduct Kuru Kopru. It engages a broad public audience in better comprehension and assessment of the aqueduct.

Research Limitations/Implications

The fact that the research is based on a single case study is a limitation for its generalisation. However, the case examined provides a basis for future work that may validate its findings in different contexts.

Originality/Value

The paper proposes the rediscovering of long-abandoned aqueduct Kuru Kopru by learning its spatio-temporal evolution through AR. The developed methodology can be easily implemented and puts forward the use of low-cost materials.

Keywords: *Architectural preservation, augmented reality, Kayseri Kuru Kopru, aqueducts*

INTRODUCTION

The principles laid down in the foundations of modern architectural restoration stipulate, "the cultural heritages constitute pieces of evidence of the history of humanity." In this sense, all necessary measures must be taken to ensure their sustainability (Ahunbay, 2014). Various charters and conventions defined internationally by organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Council on Monuments and Sites (ICOMOS), or locally by states define heritage classifications, selection criteria, and restoration principles. The UNESCO classifies Cultural Heritage (CH) according to tangible and intangible values (UNESCO, 2018). The tangible heritage includes movable heritage (paintings, sculptures, wall drawings, etc.) and real estate heritage (historical buildings, archaeological sites, monuments), which is the main object of architectural restoration. The restoration of AH is a multidisciplinary work resulting from a process of documentation, research, analysis of degradations, the definition of a conservation approach, determination of the nature of the interventions, and a monitoring process (ICOMOS, 2013). Beyond this process aiming at the physical preservation of the Cultural Heritage (CH), the ICOMOS Charter for the Interpretation and Presentation of Cultural Heritages Sites states the diffusion of CH towards a broad public as an essential component of the preservation process. The charter stresses that any interpretation and preservation of CH must be based on the scientific research methods, has to provide a global and contextual comprehension and physical and intellectual access to the CH site (ICOMOS, 2008). To this charter, Töre identifies The London Charter for the Computer-Based Visualization of Cultural Heritage and the Seville Charter as the main charters for the dissemination of CH (Töre, 2017). The London Charter for the Computer-Based Visualization of Cultural Heritage presents the intellectual and technical principles for the visualization of CH through implementation, aims and methods, research sources, documentation, sustainability, and access principles (Denard, 2009). To increase the applicability of the London Charter, Seville Charter puts forward eight principles, namely interdisciplinary, purpose, complementarity, authenticity, historical rigour, efficiency, scientific transparency, and training and evaluation. These principles posit that computer-based visualization of CH must be done by an interdisciplinary expert group as a complementary effective management tool**.** It must be based on historical, archaeological and architectural evidence; must also preserve the authenticity of the heritage and be developed efficiently. The Cultural Heritage is visualized as virtual restoration, virtual anastylosis, virtual reconstruction, or virtual recreation. Virtual restoration refers to the process of creating and using a virtual model to reorder available material remains in order to recreate visually something that existed in the past. In virtual reconstruction, a virtual model helps to recover

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visually a building or object made by humans at a given moment in the past. As far as virtual recreation is concerned, a virtual model is used to recover or to recreate an archaeological site visually at a given moment in the past. (Virtual Archaeology International Network, 2016).

The digitization of CH stands as the core part of the virtual digital heritage. This digital approach is sometimes called informational preservation, referring to its capacity to save without damages, several features of the artefact for possibly further reconstruction (Töre, 2017). Several methods and techniques have been used to acquire, register, integrate, and texture data. (Zhao, 2009) describing the modelling of virtual environment distinguishes model data types and modelling methods. While model data types bear methods for the acquisition of data and the link they have with some aspects of real-world objects, modelling methods emphasize the perception modalities of the final user and the features of the simulated object in the virtual environment. In this approach, the data acquisition sub-category gathers primary techniques to digitize the CH. They are actual measurement, mathematical measurement, and artificial construction. Actual measurement involves using data acquisition equipment such as 2D and 3D scanning techniques (Zhao, 2009). Classified onto Image-based modelling, Range-based modelling, Image-based rendering, photogrammetric, and the combination of image-and range-based modelling, these techniques for 3D reconstruction are well described in (Noh et al., 2009) and (Voinea et al., 2018).

Regarding mathematical measurement, a model of the real environment is generated by mathematical models and experimental analysis(Bekele et al., 2018). For instance, (Berk, 2018) proposed a semi-automated generative computer-aided form-finding system to deduce the authentic morphology of traditional Siirt Cas Houses in Turkey. The proposed system extrapolates authentic morphology from existing Siirt Cas Houses analyzing their features and comparing them to original Siirt Cas Houses construction techniques, urban expansion patterns, shapes, and the rhythmic layout of façade elements. Lastly, artificial construction techniques spawn an environment created by the human imagination (Bekele et al., 2018). This latter approach seems unsuitable regarding the scientific foundation that the preservation of CH required. Once the CH is digitized, its features are diffused and communicate thanks to several options like Augmented Reality.

Azuma defines the Augmented Reality (AR) as a variation of Virtual Reality (VR) that is characterized by the combination of Reality and Virtuality, a three-dimensional alignment of those realities and simultaneous interactivity. While VR is an interactive, immersive, and virtual environment entirely produced by computers, the AR allows the user to see his real environment augmented by a virtual layer like virtual 3D models (Azuma, 1997). The full understanding of the relation between AR and VR is provided by the path, namely the virtuality continuum. At the ends of the path, there is Reality and Virtuality

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respectively, and between them AR and VR. AR is close to Reality, while VR is close to Virtuality, and the mix between the AR and VR is called Mixed Reality (MR) (Milgram & Kishino, 1994). Pragmatically, AR is considered as a partial or total immersive real-time interactive communication tool that increases the different senses of the user by adding virtual contents to Reality. An augmented reality system incorporates hardware and software architecture. The hardware architecture comprises output interfaces (VR/AR helmets, mobile screens, among others), input interfaces (mouse, touch controllers, remotes, etc.), tracking systems (optical sensors, GPS, accelerometers, gyroscopes, among others) and processors (tablet, workstation, etc.)(Carmigniani & Furht, 2011). The Augmented Reality's software architecture principally includes tools for 3D modelling (Blender, Unity 3D, 3DS Max, Google Sketchup, etc.), a database for markers, a 3D engine (Unity3D, Papervision3D, Away3D, Sandy3D among others), the mobile applications and the software development kits (Augment, Vuforia, etc.). There are several classifications of AR systems basing on the type of hardware architecture, recognition methods, and the environment (outdoor, indoor, etc.). Nonetheless, AR systems can be grouped into image recognition based systems and imageless recognition based systems. Image recognition based systems utilize a printed image or recognize a real object as a trigger (marker) and align with them a pre-recorded virtual data. The second group is a conglomerate of all other types of systems (applications based on projection, on different recognition systems, on location, among others) (Içten & Bal, 2017).

The combination of digitization techniques of CH and virtual technologies like AR rises what is indiscriminately called a technological approach of CH or a Virtual Heritage System. This system helps to document the built heritage for further reconstructions in case of phenomena like hurricanes, tsunami, and wars that can severely damage the structure. It is also the support for the diffusion and the visualization of no longer existing historic buildings parts. Moreover, this system intervenes in the implementation of virtual tour and museums, of educational content and the enhancing accessibility to historic sites by providing points of views that could be hard to observe in the real world because of the size of the building or issues about its physical accessibility(El-Hakim et al., 2004). Specifically, (Bekele et al., 2018) state that the three main application fields of AR in CH are enhancing visitor's experience, heritage reconstruction, and heritage management and exploration. Accordingly, they mainly distinguish applications dedicated to exhibition improvement, exploration, and reconstruction. Exhibition oriented applications enhance the user experience during heritage tours. Regarding exploration applications, the user visualizes and explores the past and present view of the built heritage for interpretation, discovery, and gaining new insight and knowledge (Bekele et al., 2018). In this category, we could notice the possibility of making tests on new restoration techniques from synthetic

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models and formulating hypothesis analysis (de la Fuente Prieto et al., 2017). Whereas explorations applications are more professionally oriented, reconstruction AR applications by enabling interactions with reconstructed heritage views, target a broad public audience without necessarily the requirement of discovering new insights (Bekele et al., 2018). Concisely, AR in the preservation of the AH field is visualization support of virtual restoration, virtual anastylosis, virtual reconstruction, or virtual recreation, and aiming at the improvement of site tours, the exploration of heritage "unseen" features, and the interactions with heritage reconstructed view by a broad audience. Even though several experiences have been developed for the digital preservation of CH, it appears that there is not a unified framework followed by different study cases. Although (Di Mascio et al., 2016) and (Özer et al., 2016) attempted to sum up the process in three main stages: data collecting, data processing, and presentation. The data collection gathers the process of collecting all items needed for digital preservation. They can be sketches, old photographs, videos, laser surveys, models, and a photogrammetric survey, among others. The second phase, namely data processing, has two sub-categories. The first one deals with the generation of the 3D replica (as-built 3D reconstruction) from surveys. The second one is the processing of collected items to generate analytic drawings, realistic renderings, structuration of information management system, and to prepare AR, VR, or MR applications. In the last step, processed items are presented in the form of AR, VR, or MR applications or even in 3D printed model.

The project ARCHEOGUIDE is one of the first attempts to integrate AR to AH. It is an exhibition oriented mobile AR application for archaeological site embedding virtual reconstruction of ruined monuments and virtual recreation of antique sport. A custom tour path is generated according to the user profile. Along the tour, a "cumbersome" unit carried by the user tracks the position and communicates with a central repository to add aligned virtual content to the user view (Vlahakis et al., 2001). The Augmented Reality In Cultural Heritage (ARICH) is another one of the early studies in this field. It proposes an indoor AR application where modelled 3D reconstructions by means of multiple techniques and referring to architectural plans are presented. This project is reconstruction oriented with a real emphasis on learning (Mourkoussis et al., 2002). Up to now, several AR applications have been developed. They provide new technological approaches and techniques, and their whole range can not be covered within this study. A holistic approach of the AR in CH and AH accordingly is discussed in (Bekele et al., 2018). Nevertheless, applications like Nanchang and Guangji temples AR, @rkademi, Aurelian wall AR project, and Parion Theatre AR project should be mentioned because they have somehow close ties to the applications developed in the current study. Nanchang and Gangnji temples are Chinese iconic and historical buildings used as a case study for the development of reconstruction oriented immersive MR application. This application aims at the digital preservation of these artefacts and the spreading of their features. Unmanned Aerial Vehicle Photogrammetric survey and panoramic photograph shooting are done to obtain 3D replica and panoramic database, respectively. The user can choose either AR or VR scenes through a mobile device interface. The AR scene is based on an image-based indoor architecture system meaning that the user triggers the 3D reconstruction model by scanning a printed 2D marker (Zhang, 2016). As far as the Rome Aurelian wall AR project is concerned, it integrates exhibition and reconstruction oriented AR applications. An integrated survey method combining topographic and photogrammetric surveys is used to replicate the wall digitally. Thereafter, basing on virtual reconstruction hypothesizes and using textures retrieved from the photogrammetric survey, the reconstruction of no-longer-existing Northern door is modelled. The model is uploaded into a commercial AR platform and view in both outdoor and indoor conditions. In outdoor, different points of view of the Northern door are provided in-situ through a mobile device and according to pre-defined hotspots where the user has to stand by. The indoor application aligns the 3D model to a 2D marker(Canciani et al., 2016). @rkademi is an AR experience developed for the twin palaces located at the Fındıklı campus of Istanbul Mimar Sinan Fine Arts University in Turkey. This exhibition-oriented experience integrates into a mobile AR platform 25 scenarios (old photographs, sketches, audios…) and relates, along a QR codes path tour, previous states, and evolution of palaces. Thus, the scanning of each QR code triggers the playing of specific audio and display of a picture aligned with the current Reality (Binan et al., 2013). Similarly, the Parion Theatre AR project takes place in Turkey at the old city of Parion and aims at the digital preservation of the theatre and the diffusion of its features to archaeologists, architects, and tourists. After the theatre and its surroundings were surveyed by the photogrammetric surveying technique, part of the obtained 3D replica is 3D-printed in a white texture. The 3D printed area is laid on a printed site plan, and thanks to markers, the textured site 3D replica, structure elements in fillet mode, and sections are shown through dedicated mobile AR application (Özer et al., 2016).

In this study, two reconstruction-oriented AR applications are developed to present and diffuse towards the professional and non-professional audience the features of the Aqueduct Kuru Kopru by modelling the existing state (virtual 3D replica) and previous states reconstructions. The Kuru Kopru aqueduct is erected in the Kuru Kopru neighbourhood, K35-d-09 block, plots 1073-1074 in Talas district, Kayseri town in Anatolian region of Turkey. Kayseri is one of the oldest cities in Turkey, with a history dating back to 3000 BC. The city has been controlled by several civilizations, especially Hittite, Roman, and Byzantine. Built during the Roman-Byzantine period around the 8th century to meet the water needs of the city, the Aqueduct Kuru Kopru was part of the water supply system where water was taken from the

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village of Gurpinar and was made flow through channels dug into rocks (Sezer, 2012). Built at the bottom of the Gomurderesi valley, the aqueduct is 172m long, with an average height of 16m, 12 round arches, and a three-pointed arch (**Figure 1**). With a thickness of about 150 cm, its walls are built with the caisson wall technique and are characterized by the use of ashlar and partly pitch-faced stones as outer leaves. The space between the leaves is filled with quarry stone and pozzolanic lime mortar. While the ashlar is mainly pink and grey andesite tuffs, pitch-faced and quarry stones are pink-grey andesites and basalt tuffs. The buttresses at the north elevation are built with the same techniques and stones (Kozlu, 2010). There are ten buttresses in the north elevation, of which nine were built in the Roman-Byzantine period, and the tenth was added in the Seljuk-Ottoman period. The water channel has a width ranging between 70-80cm, and its form is shaped by two lateral walls of a height of about 50 cm (GEEAYK, 1988).

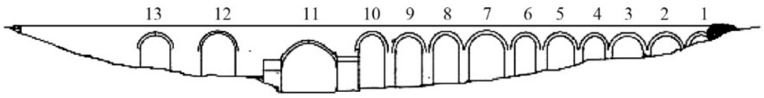

Figure 1. South elevation of the Kuru Kopru Aqueduct during the Roman-Byzantine period (Sezer, 2012).

From the Roman-Byzantine period until the year 2017, the aqueduct experienced four main changes:

1. Seljuk-Ottoman Period: Three arches (numbered 10, 9, and 8) located to the east of the valley bottom were closed with filling walls in order to transform the aqueduct into a water dam whereas arches 1 to 7 were closed by ashlars as a preventive measure to beat their collapse. A buttress was added at the north elevation nearly in the middle of arch 7 to support the filling wall (Sezer, 2012) ;
2. Recent period: In an unspecified date of the recent period, an inappropriate stone and briquette construction was added at the north elevation of the bridge between arches 5 and 6 ; (Sezer, 2012);
3. In 2016: A large part of the aqueduct was in advanced degradation. Arches 12 and 13 were utterly collapsed, and arches 3 and 4 were largely destroyed. On the various spots of the structure, the stones fell, the water canal and its walls collapsed, vegetation and moss grew on the buttresses, among others.
4. In 2017: While the previous deteriorations were worsening, the part of the water channel, supported by arches 3 and 4, was destroyed.

Referring to the history above of the aqueduct and an approach based on three stages: modelling of virtual reconstructions, texturing of models and development of AR applications, the following virtual 3D reconstructions were modelled and presented in AR:

- Kuru Kopru during the Roman-Byzantine period;
- Kuru Kopru during the Seljuk-Ottoman period;
- Kuru Kopru during the so-called recent period
- Kuru Kopru in the year 2016

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- Kuru Kopru in the year 2017.

All of these models are presented in two AR applications. The first one; KurukopruAR; is an immersive AR application requiring a printed marker, an AR helmet (Google cardboard), a smartphone, and a Bluetooth Remote Control. By scanning the printed marker and using the remote control, the user can chronologically display each model and the related data in either English or Turkish languages. The second one, KurukopruB, links the reconstruction models to the Aqueduct Kuru Kopru presentation booklet. In this brochure, a marker was inserted for each period of the aqueduct. The user displays the appropriate model by scanning each marker.

This work seeks to reach the following specific objectives:

- Contribute to the diffusion of the Aqueduct Kuru Kopru;
- Establish awareness that semi-collapsed structure could be evaluated and presented thanks to AR methods;
- Serve as a model for the representation and diffusion of virtual reconstructions of the built heritage.

METHODOLOGY

The developed method follows three steps as described by the framework below (**Figure 2**):

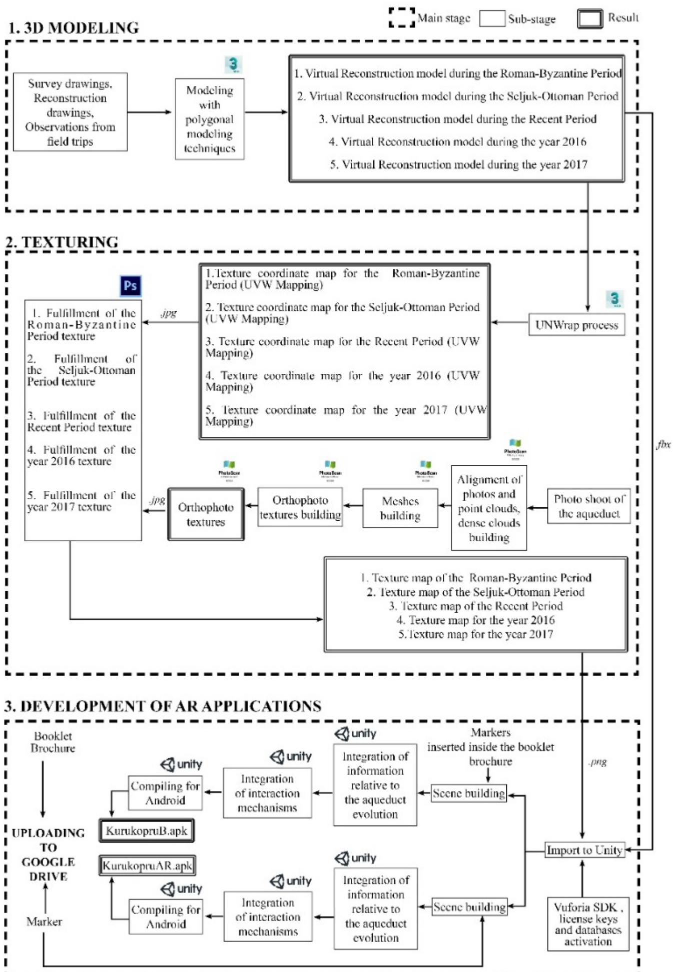

Figure 2. The framework developed for Kuru Kopru Aqueduct Augmented Reality applications

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Modelling of the Virtual Reconstructions

At this stage, evolution through the time of the aqueduct was modelled. Modelling was made based on field trips conducted during the years 2016 and 2017, surveying and reconstruction drawings made by the architect Mustafa Sezer as part of the restoration project of the aqueduct. This restoration project has been validated by the Directorate in charge of the preservation of CH in Kayseri but has not yet been implemented. The graphic folder of the restoration project used consists of survey drawings for the year 2011, the reconstruction drawings of the Roman-Byzantine Period, and the Seljuk-Ottoman Period. All of the Autocad drawings were imported into a single Autodesk 3DSMax file and organized in layers. For each drawing, plan, sections, and elevations were aligned (**Figure 3**). By using a polygonal modelling technique, the Roman-Byzantine virtual reconstruction was modelled bearing on the reconstruction drawing of the Roman-Byzantine period (**Figure 4**). To obtain the Seljuk-Ottoman reconstruction model, filling walls and added buttresses were modelled and integrated into a copy of the previous model. Similarly, the virtual reconstruction model of the Recent Period was made through the modelling and integration of the inappropriate stone and briquette wall construction to the copy of the Seljuk-Ottoman model. Afterwards, on the survey drawings and observations carried out on the site, the virtual model reconstruction for the year 2016 was gotten by modelling degradations on the copy of the Recent Period model. The reconstruction model of the year 2017 resulted from the removal of the water channel part supported by arches 3 and 4 from the copy of the reconstruction model of the year 2016. The real textures of the aqueduct were applied to the reconstruction models to ensure their scientific truth, to increase the perception of the reality and the user experience.

Apart from the virtual reconstruction models, two versions of landscapes were modelled based on the topographic data extracted from the drawing survey, and contour lines generated using the software Global Mapper and the aerial view of the site. The first landscape model was used as a topography for the reconstruction models from the Roman-Byzantine Period to the Recent Period while the second was used for the remaining models. While the first model is textured with uniform grass due to the lack of information relative to the landscape condition from the Roman-Byzantine to the Recent Period, the second depicts the actual state of the aqueduct surrounding. The models used in this work record 63226 polys and 64167 vertices; which are lower than the recommended maximum value of 100000 vertices (Unity, 2018); to avoid memory issues while loading models in the mobile AR applications.

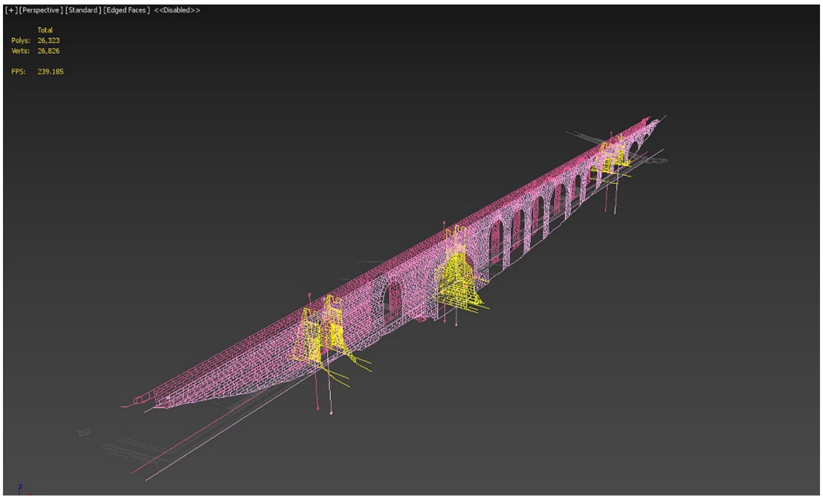

Figure 3. Alignment of plan, sections and elevations in Autodesk 3DS Max software

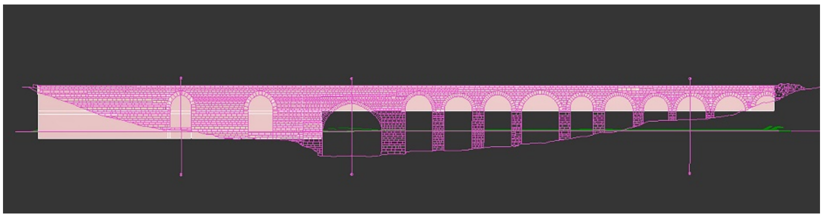

Figure 4. Modelling of the Roman-Byzantine period reconstruction model with the polygonal modelling technique

Texturing of Models

The texturing stage includes the production of a texture coordinate map for each model and the application of real textures obtained from the site to the maps mentioned above. Texture coordinate maps were produced through the application of the Unwrap UVW modifier onto each model. Unwrap UVW mapping allows the assignation of texture coordinates to objects and sub-objects. This mathematical technique uses a system called UVW coordinate system similar to the XYZ system to control the way procedural materials appear on the surface of an object (Autodesk, 2018). At the end of this process, five 10000 x 10000 pixels of square texture coordinate maps were generated (**Figure 5**).

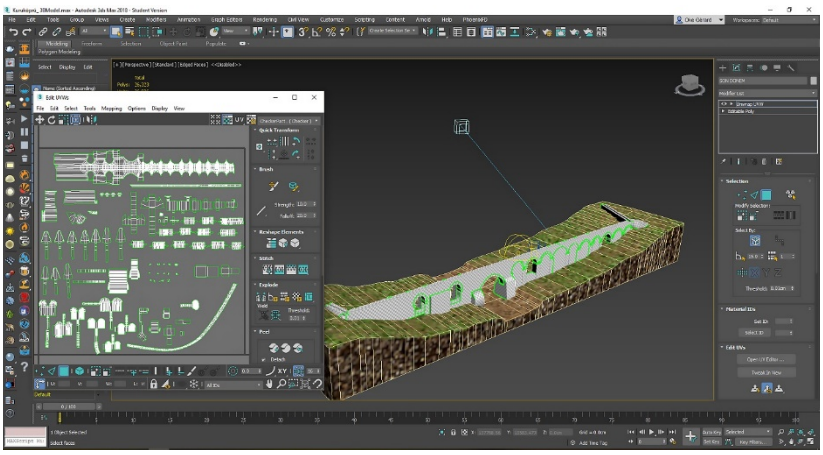

Figure 5. Texture coordinate map (front plan) and the reconstruction model to which it is linked (back plan).

In the second step of this process, the aqueduct photos from the site were taken and processed to have orthophoto textures. To reach this

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result, the photogrammetry technique, which can be defined as the science and art of determining qualitative and quantitative characteristics of objects from the images recorded on photographic emulsions, was used. While objects are identified and qualitatively described by observing photographic image characteristics such as shape, pattern, tone, and texture; their quantitative characteristics such as size, orientation, and position are determined from measured image positions in the image plane of the camera taking the photo (The University of Arizona, 1993). The photogrammetry process started with the photo shooting of the aqueduct. The aqueduct was shot using a semi-professional camera Canon 1100D with a 55 mm focal length. During the shooting process, great attention was given to the weather to avoid shading effects on photos. A total of 1500 photos grouped into four sets (north and south elevations, details, upper part) were made. Within each set, photos were overlapped to about 60% to allow the reconstitution of the texture thanks to the analysis and the interpretation of mutual pixels between photos through the photogrammetry algorithm. However, a significant area of the upper part and north elevation was not shot due to the advanced degradations of the aqueduct and the presence of large trees in the front of the north elevation. Photos were imported to the Agisoft Photoscan software, where they were aligned, and point clouds were generated. From point clouds, dense clouds, meshes, and orthophoto textures were created (**Figure 6**).

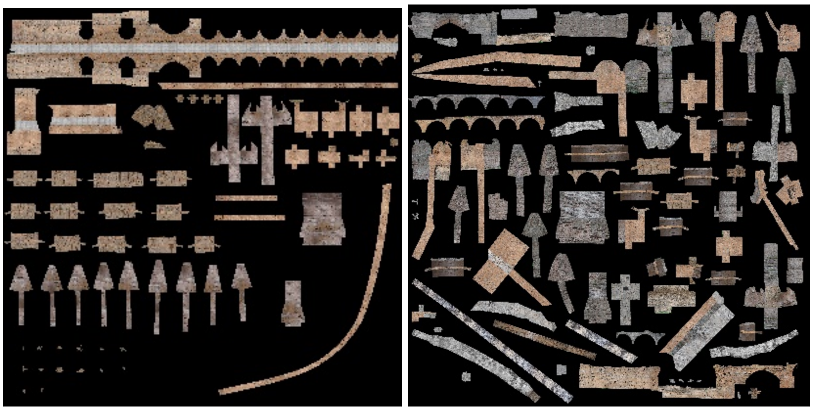
Figure 6. A part of orthophoto textures for the south elevation of the aqueduct

The created textures were exported in .jpg format as orthophoto textures and were applied onto the texture coordinate maps employing Adobe Photoshop software. The principle was to apply orthophoto textures to each texture coordinate map to replicate the textures of Kuru Kopru aqueduct precisely as they were during its evolution. Once orthophoto textures were applied to coordinate maps, it appeared that some parts of textures were missing either because they had disappeared, degraded, or could not be taken on the photos. To solve these issues:

- Orthophoto textures were used to reproduce current missing parts belonging to the Roman-Byzantine period;
- Filling walls textures of the existing closed arches were used to complete other filling walls of Seljuk-Ottoman period that are lost today;

- Existing briquette textures were used to complete parts of the briquette structure of the Recent period that are degraded today;
- Orthophoto textures served as the basis to complete parts of the aqueduct textures that could not be reached on the site. This method was used for the 2016 and 2017 texture coordinate maps.

At the end of this process, five texture maps and two landscape texture maps were brought out (**Figure 7**). Finally, virtual reconstructions of aqueduct and texture maps were imported to the 3D engine Unity software for the development of the AR applications.



(a) (b)

Figure 7. (a) Texture map for the Roman-Byzantine period; (b) Texture map for the year 2017

Development of AR Applications

Reconstruction models in Autodesk Filmbox (.Fbx) file format and texture maps in .png file format were imported to a 3D engine Unity software as a basis for the development of AR applications. The Vuforia Software Development Kit (SDK) was integrated into Unity software as the AR development platform. Two image-based AR applications were developed: KurukopruAR presenting reconstruction models and their detailed history in an immersive environment, and KurukopruB associating each model to a different marker inserted in the Kuru Kopru presentation booklet. For each application, markers database and a license key were generated from the Vuforia developer account**.** Once models and textures were imported in Unity, each texture map was applied to the appropriate model to generate the virtual textured reconstructions models of the aqueduct (**Figure 8**). Lighting, menus, targets, cameras, and texts (number of arches, names of elevations) were added to models to compose the scene. After that, the interactivity mechanisms were added to the scene, and an android compatible KurukopruAR.apk and KurukopruB.apk executable files were generated.

(a)

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(b)

(c)

(d)

(e)

Figure 8. Virtual reconstruction models (a): during the Roman-Byzantine period (south perspective); (b) during Seljuk-Ottoman period (north perspective); (c): During the Recent Period (south perspective); (d): during the year 2016 (south perspective); (e): during the year 2017 (north perspective)

KurukopruAR Application

KurukopruAR application is an immersive application requiring the use of an AR headset and a Bluetooth Remote. Its general architecture could be summarized as follows (**Figure 9**):

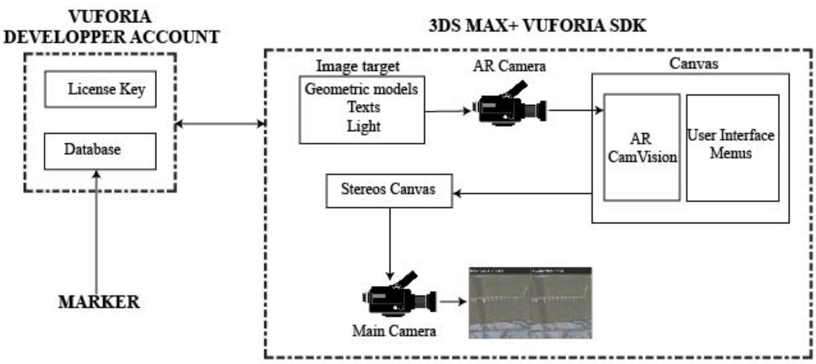

Figure 9. KurukopruAR application architecture

AR camera saves the image of models already aligned to the marker (**Figure 10**). This captured image at each frame is saved as the camera texture under the name ARCamVision in the frame called Canvas. This frame also integrates the nine menus of the user interface. The first menu explains the use of the Bluetooth remote; the second asks the user to choose between English and Turkish as the language of the application, the third menu shows a general introduction to the Kuru Kopru aqueduct while the fourth to the eighth display reconstruction models chronologically (**Figure 11**). The ninth menu concludes the application. Canvas content is sent to a frame called Stereo Canvas, where it is divided into two equal frames. The content of the stereo camera is sent to the Main Camera and displayed on the user screen. For the usability of the application, the following codes were written in C#:

- "InputManager," which manages the buttons of Bluetooth Remote;
- "Language," where the texts that will be displayed in the application are written;
- "UIController," which manages the content of the user interface. For instance, it allows the display in a precise menu of a specific text taken from the code '' Language '';
- "MainController," which coordinates the codes above: it manages; for example, the display order of models and menus.

Figure 10. Marker for the KurukopruAR application

Figure 11. Screenshot of KurukopruAR application

KurukopruB Application

KurukopruB application is based on a Turkish-English Language Kuru Kopru presentation booklet brochure (**Figure 12**). Inside this brochure, five different markers are inserted, and each marker is associated with a

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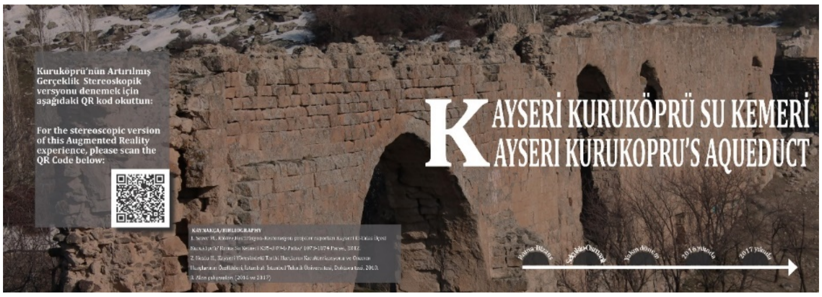
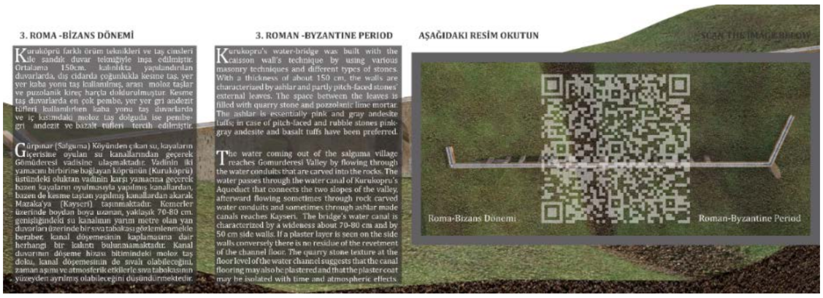
unique reconstruction model of the aqueduct. Its general architecture can be summarized as follows (**Figure 13**).



(a)



(b)

Figure 12. (a) Kuru Kopru booklet Brochure cover page; (b) Page and marker inside the booklet

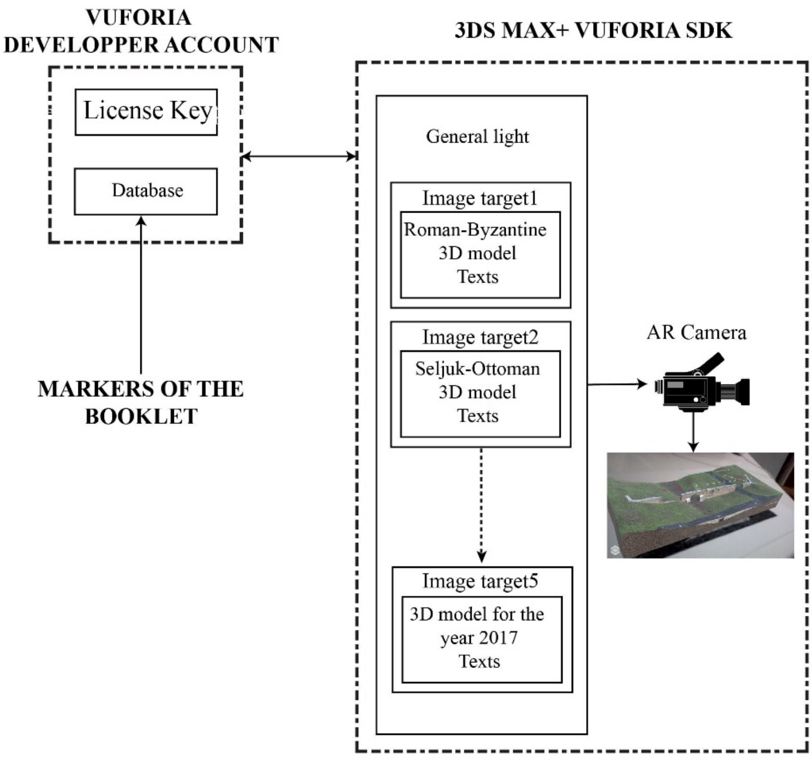


Figure 13. KurukopruB application framework

The AR camera captures and displays the reconstruction models linked to the scanned marker, and thanks to the use of the Lean Touch Plus asset, the user can zoom, shrink and rotate with fingers the reconstruction models. By scanning a marker, the associated model is displayed, as shown in **Figure 14**.

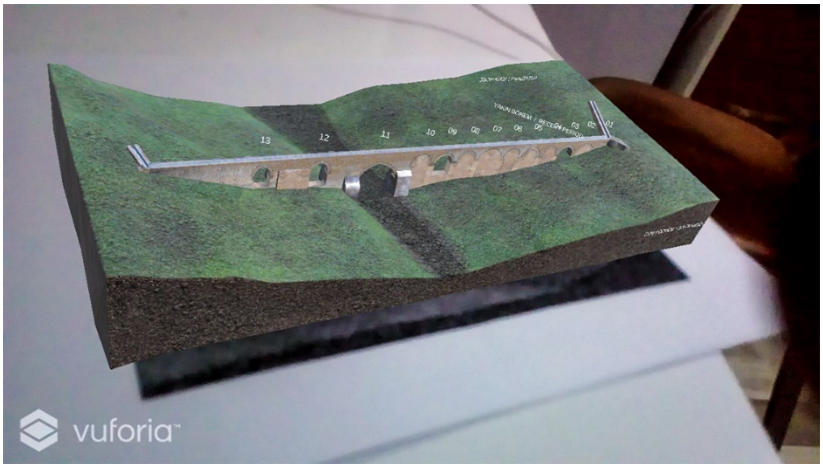


Figure 14. Screenshot of KurukopruB application

AR applications and their targets were arrayed in KurukopruAR and KurukopruB folders, which were later uploaded to Google Drive. While the download link of KurukopruAR is https://drive.google.com/drive/folders/19vqg1_8vXWnoS3-ndeJULC_Ew-_Tv3Z?usp=sharing, that of KurukopruB is https://drive.google.com/drive/folders/19vqg1_8vXWnoS3-ndeJULC_Ew-_Tv3Z?usp=sharing.

CONCLUSION

The digital technologies provide additional tools for the informational preservation of AH. Thanks to digitization and modelling techniques, it is now possible to acquire the existing as-built AH digitally and virtually rebuilt its previous states. This ability allows the visualization of the AH as virtual restoration, virtual anastylosis, virtual reconstruction, or virtual recreation. The AR as a communication tool is the support of the diffusion of the above-mentioned 3D models aiming at the enhancement of tour guidance, exploration of new insights and techniques for professional purposes, and interaction with reconstructed models for inclusive learning.

This study, through developed two AR applications, positions itself in the segment of reconstruction models for the representation, diffusion, and general learning of the Aqueduct Kuru Kopru features by a professional and non-professional audience. The specific objectives namely the contribution to the diffusion of the Aqueduct Kuru Kopru, the establishment of the awareness related to the possibility of evaluation and presentation of semi-collapsed structures thanks to AR methods and the plausibility for this study to serve as a model for the representation and diffusion of virtual reconstructions of AH are achieved as follows:

- Contribution to the diffusion of Aqueduct Kuru Kopru: the diffusion of the aqueduct refers to the ease of access to the aqueduct from any place in the world. The publishing online of the developed AR applications makes this purpose achieved by allowing professionals

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(architects, archaeologists, engineers, researchers, scholars) and non-professional (tourists, students) to reach virtually the aqueduct features and its evolution through the time. Moreover, in case of the availability of the KurukopruB application booklet in tourism promotion centres, more people could be impacted and be aware of the cultural and architectural values of the aqueduct.

- AR methods can favour the evaluation and the presentation of semi-collapsed structures: as stated, Kuru Kopru Aqueduct is currently in advanced deteriorations conditions. Hence, it is tough for visitors to figure out the previous states of the aqueduct. By providing the current aqueduct's 3D replica and old 3D reconstructions through the AR applications, it is somehow easy to compare its different states visually, understand its decay process and enhance the awareness for its preservation. From a professional perspective, developed AR applications could be helpful for the visual inspection of the rate of decay of materials and degradations and the selection of the most adapted restoration approach. Thus, the application of the developed AR approach to other semi-collapsed AH could allow their better evaluation and preservation.
- Serve as the model for the representation and diffusion of virtual reconstructions of the built heritage: it is crucial to ensure the scientific validity of the representation and the diffusion of virtual reconstructions of AH by nesting the proposed method within the framework of international charters. The elaborated AR method obeys to the preservation-related international charters and especially to Seville charters. In other words, it is founded by the principles of purpose, complementarity, authenticity, scientific transparency, and historical rigour. The purpose is the presentation of reconstructions models to achieve ubiquitous learning; the complementary principle is achieved by allowing the visual comparison and diffusion of aqueduct features. The authenticity is ensured by the use of the Aqueduct real textures; the scientific transparency and historical rigour are validated by the use of approved restoration project, scientific articles, and thesis for documenting and, lastly, the validation of efficiency principle is proved by the use of low-cost material (semi-professional digital camera) for a relatively high-quality result. Thus, the developed method could be used efficiently for the representation and visualization of other AH.

From economic and commercial perspectives, the usage of low-cost materials to capture, process, and develop AR applications for the Aqueduct Kuru Kopru demonstrates the potentialities for tourism organizations and public policy to favour the development of several applications that will efficiently engage each one in interactions with any AH. The AR applications that would be developed within this scope could be an appeal for tourists to visit the real AH sites. Thus, the increasing of the number of tourists visiting AH sites could positively impact the tourism economy. In other respects, the digitization of the

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aqueduct provides to the body of knowledge a virtual database that could be the starting point of other scientific researches related to the aqueduct Kuru Kopru. From the teaching perspective, developed AR applications could serve as a study case showing to architecture students the degradations that could occur on an abandoned and exposed to natural and human factors built heritage.
For the further developments, in situ Kuru Kopru AR could be implanted. No-longer existing parts could be added directly on the aqueduct remains to offer more contextualised content to the users.

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Resume

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