VR CULTURAL HERITAGE SITES:
A CASE STUDY ON CREATING IMMERSIVE VISUAL & AUDITORY EXPERIENCE

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ABSTRACT

Cultural heritage sites are places of special significance to the common heritage of humanity. They are invaluable monumental architecture, but many of them are at risk of being lost due to either natural deteriorations or man-caused damages. This research studies how Virtual Reality technology can help promote preservation for these cultural heritage sites. Using 3D model, panoramic photography, sound simulation and sound recording, we created three immersive VR cultural heritage sites experience with visual and audio components. We also conducted a user study with 30 total responses. Overall user responded very positively with enjoyment. It was also found users exhibit an increased level of interest and awareness for cultural heritage site and its preservation after viewing our VR Cultural Heritage Sites demos.

Keywords— Virtual Reality (VR), Cultural Heritage Preservation, Digital Heritage, Immersive Experience

1. INTRODUCTION

Cultural heritage sites are masterpieces of human creative genius with outstanding values. According to the World Heritage List selection criteria from United Nation Educational, Scientific and Cultural Organization (UNESCO), cultural heritage sites are exceptional architectures that exemplify human civilization's advancement. They are unique testimony to the cultural traditions, ideas, or arts of human civilization, and are invaluable legacies from the common heritage of humanity. [1].

It is one of the global mission of United Nation that we shall put in effort for cultural heritage site preservation, because many of these invaluable sites are at risk of being lost, due to either natural disaster, man-caused damages or deteriorations over time. Research efforts aiming to help preserve cultural heritage sites align with this mission, and are very supported by the global community.

The application of Virtual reality (VR) on cultural heritage site has been a research of interest to a number of previous researchers. In the article "Experiential archaeology: is virtual time travel possible?" published on The Journal of Cultural Heritage, E. Ch'ng reviewed a number of research projects on virtualisation of cultural heritage sites and the technologies involved. [2] The article concluded with the vision that via the advancement of technology, virtual time travel and experiential archaeology will be made possible with full immersion, simultaneous engagement of the five senses, and a virtual world that looks real, sounds real and feels real.

While the engagement of the all five senses is not available in current technology yet, we are seeing rapid development in VR in recent years. High realism in visual and auditory component in VR experience is becoming more attainable. This research aims to study how far we have progress in terms of recreating cultural heritage sites in the virtual world that looks real and sounds real.
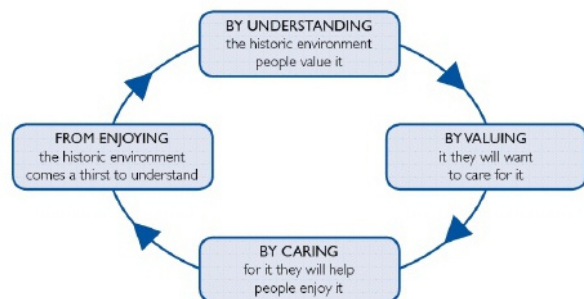

Fig 1. The heritage cycle describing how we can make cultural heritage preservation apart of our future. [3]

Another interest of this research is to understand how VR cultural heritage site does in promoting cultural heritage preservation. Our hypothesis is that, similar to a visit to the physical cultural heritage site, VR cultural heritage site experience will be a key to promoting cultural heritage preservation as illustrated by the heritage cycle diagram in Figure 1. Through the VR experience, user will be able to enjoy the sights and sounds of the cultural heritage site,

which will trigger their desire to understand the historic environment. From there they will see greater value in the cultural heritage site, and care more about cultural heritage preservation.

The research questions we hope to answer by this case study are the following:

- Can we effectively convey the cultural significance of a heritage site through a VR experience?
- Can a multi-sensory VR tour feel as realistic and inspiring as physically visiting heritage sites?
- How does a VR experience stand in comparison to other media?
- How effective are the different methods for creating visual and audio components for a VR cultural heritage site?

2. METHOD

We now present the methods we used to create the visual and the audio components of the immersive VR experience in our case study. For the visual component, we applied two methods, (1) use of 3d model, and (2) panoramic photography. For the audio component, we also applied two methods, (1) sound simulation, and (2) use of sound recording.

2.1. Use of 3D Model

3D models are digital representations of physical object using a collection of points in 3D space, connected by various mathematical constraints such as geometric shapes, plane intersection, curved surface etc. In video games, 3D models are used as assets to render characters, objects, and environment in the game world. The same workflow can be utilized in creating VR experience. In the G. Papagiannakis et al's virtualization work of Hagia Sophia [3], 3D modelling was used with textures to represent the cultural heritage site, the ancient edifice, and historical characters, rendering a 3D simulation of a cultural heritage site.

If a cultural heritage site has been 3D modelled and textured, the site can be rendered in Virtual Reality using a 3D engine. In this case study, we choose to use the 3D game engine Unity3D because its support for easy export to latest VR devices. As for the 3D model, we selected the Šibenik Cathedral model, which was made available to the computer graphics community by Marko Dabrovic for research purpose. We are using a version of the Šibenik Cathedral model with high resolution textures and bump maps painted by Morgan McGuire [4].
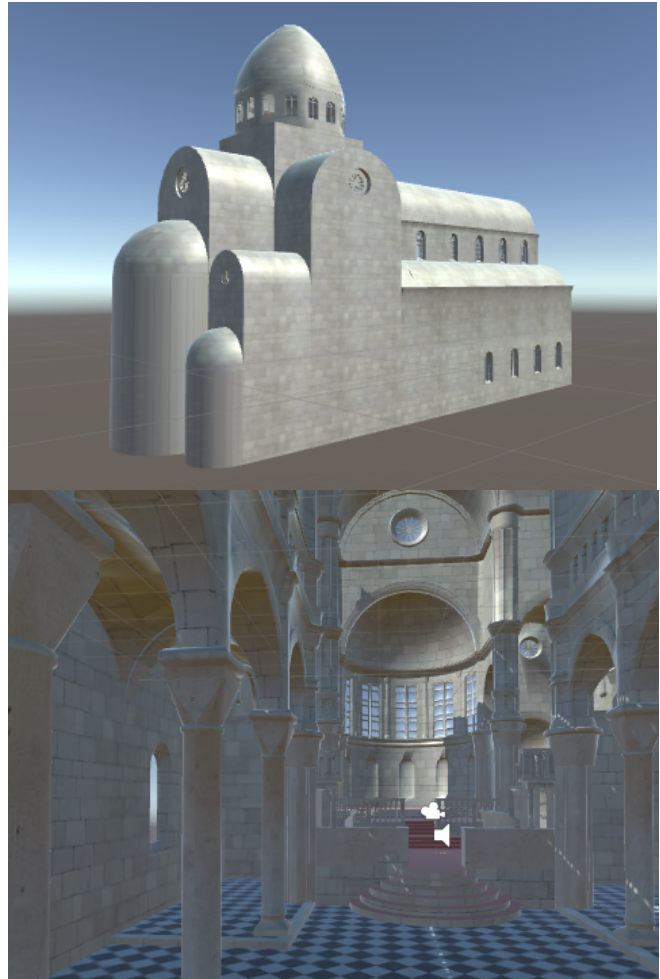

Fig 2. Screenshots of the rendered 3D model of the exterior (top) and interior (bottom) of Sibenik Cathedral model.

2.2. Panoramic Photography

Panoramic photography is the class of photograph which captures the physical world with large field of view. It is one of the techniques currently used by researchers in Art History and Archaeology to document cultural heritage sites. The photographs are taken by special panorama camera, which takes images of the site in all directions. The images taken are then digitally stitched together, creating a continuous, seamless panoramic view of the 360 degrees surrounding.

In this case study, we obtained panoramic photography from the Media Center Image Database (MCID), hosted by the Department of Art History and Archaeology. Under the permission of the Media Center, we rendered the original panorama fieldwork as a 6-sided cube map, and applied it as the skybox for our VR scene in Unity3D. There are two cultural heritage sites for which we applied this method – Hagia Sophia, and Pammakaristos, both in Istanbul, Turkey.

Fig 3. Screenshots of the rendered panoramic photography of the Pammakaristos (top) and Hagia Sophia (bottom).

2.3. Sound Simulation

Sound simulation is the technique of estimating and rendering sound propagation in virtual environments. With the RESound system which computes ray-based sound paths, M. Taylor et al presented how sound and reverberation can be simulated in a 3D scene [5]. Since many cultural heritage sites were built with special acoustic properties allowing high level of reverberation, sound simulation can be applied to the audio component of a VR cultural heritage experience.

In this case study, we used Phonon Reverb, a sound simulation tool to simulate the reverb in a cultural heritage site. First, we simplified the original Šibenik Cathedral model to reduce the number of vertex count, and labeled it as the sound simulation model. The sound model was placed in the scene at the exact same location as the visual 3D model. Then with the Phonon Reverb tool, we created an

acoustic grid scene with spacing set to 5. It generated a total of 61 grid points used to calculate reverb. Finally, we supplied anechoic recordings of symphony music, which was convoluted with the result baked reverb, creating the simulated sound for our VR cultural heritage site experience.

2.4. Use of Sound Recording

Another approach for the audio we used was sound recording taken in the actual cultural heritage site. We found recording of performance of Byzantine chanting taken place in Hagia Sophia, distributed on the internet for promoting the study of Byzantine music and history. Since the recording already includes the echoes created by the architecture of Hagia Sophia, we were able to directly play the sound recording in the VR cultural heritage site experience without extra processing.

3. USER STUDY SETUP AND DESIGN

3.1. The Three VR Cultural Heritage Site Demos

Using the methods described in the previous paragraphs, we successfully created three VR Cultrual Heritage Site demos. Our user study is designed based on these three demos. Further details about the three demos are shown in Table 1.

Table 1. Details of the three VR demos.

Cultural Heritage Site	Visual Component	Audio Component
Pammakaristos, Istanbul, Turkey	Panoramic Photography	None
Hagia Sophia, Istanbul, Turkey	Panoramic Photography	Sound Recording
Cathedral of St. James, Šibenik, Croatia	3D Model	Sound Simulation

3.2. User Study Procedure

For the user study, we designed a set of questions that probes into user's cultural heritage awareness level, interest level to the site, and experience with the VR demos. We asked both quantitative and qualitative questions, along with free response question allowing user share any comments they have about their experience. There are three sets of user studies, Set A for Pammakaristos, Set B for Hagia Sophia, and Set C for Šibenik Catherdral. See Appendix A for a sample of the user study questions.

Every time we carry out the user study, we follow the same procedure as described below:

1. 1. User is first presented with images and/or video, along with an oral presentation of the cultural heritage site.

2. User then answer a set of questions regarding their cultural heritage awareness level and their thought on the site.

   e.g. Rate your level of agreement to the following statements from Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree.
   "*I think cultural heritage preservation is just as important as other world issues (such as gender equality, preservation of endangered species etc.)*,"

   "*I want our future generations to see Pammakaristos at the same state it is today*," etc.

   e.g. How likely are you to tell a friend about Pammakaristos?

   e.g. Describe what you think of Hagia Sophia in a few words.

3. User is given the VR demo for viewing for as much time as they desire.

4. User then answer the same set of questions as before the VR demo, as well as a set of questions about their experience with the VR demo.

   e.g. Rate the realism of your experience from 1 to 10.

   e.g. How did the experience affect your opinion of the site? (1 for most negatively, and 5 for most positively)

4. RESULTS AND DISCUSSION

We recorded a total of 30 user study responses, consisting of 11 responses for Set A (Pammakaristos)**,** 10 responses for Set B (Hagia Sophia), and 9 responses for Set C (Šibenik Cathedral).

4.1. Increased Level of Interest and Cultural Heritage Awareness

Comparing the user response before and after the VR demo, there is a clear sign of increased level of interest and cultural heritage awareness. For all three sets of the user study, we noticed an increase in likelihood that the user would tell a friend about the site after viewing the VR demo. As shown in the results for Set B Hagia Sophia in Figure 4, before the VR demo 30% of the users responded with "Maybe, more unlikely than likely" (indicated in yellow in the pie chart).

60% of the users responded with "Maybe, more likely than unlikely" (indicated in red), and only 10% of the users responded with "Definitely" (indicated in blue). However, after viewing the VR demo, many changed their mind. User who responded "Definitely" increased to 50%, while user responding in "Maybe, more likely than unlikey" became 40%, and only 10% of user responded in "Maybe, more unlikely than likely". Similar results were seen in the other two sets as well. For Set C Šibenik Cathedral, as shown in Figure 5, while the number of user responding "Never" (indicated in green) or "Definitely" did not change after the VR demo, user who responded "Maybe, more likely than unlikely" increased from 22.2% to 55.6%, and user who responded "Maybe, more unlikely than likely" decreased from 55.6% to 22.2%.
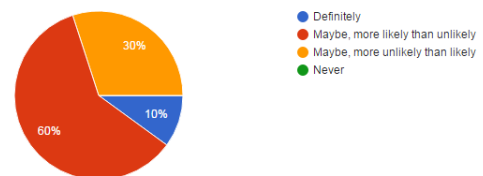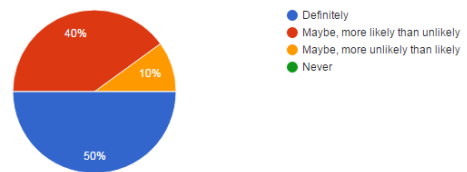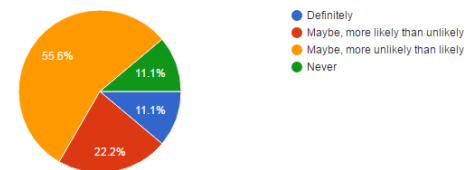

Fig 4. Results of before (top) and after (bottom) user viewing the Hagia Sophia VR demo

How likely are you to tell a friend about Šibenik Cathedral? (9 responses)

- Definitely
- Maybe, more likely than unlikely
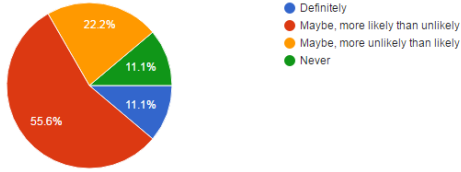- Maybe, more unlikely than likely
- Never

22.2%
11.1%
11.1%
55.6%

Fig 5. Results of before (top) and after (bottom) user viewing the Šibenik Cathedral VR demo

As the saying goes 'sharing is caring', the fact that user are more likely to share about the cultural heritage site suggests that they became more interested, and more engaged because of the VR cultural heritage experience.

As for the questions regarding user's awareness for cultural heritage preservation, we see a trend that users show more agreement to the statements after viewing the VR demos. For example, on the statement "*I think cultural heritage preservation is just as important as other world issues (such as gender equality, preservation of endangered species etc.)*", before the VR demo, out of 30 responses, 3 were "Disagree", 4 were "Neutral", while 17 were "Agree", and 6 were "Strongly Agree". After the VR demo, we notice that some users who originally disagree or has neutral opinion now voted on "Agree", increasing the number of users who responded "Agree" or "Strongly Agree" to 26 out of 30. This shows an increased in priority for cultural heritage preservation within the users after viewing the VR demos.

I think cultural heritage preservation is just as important as other world issues
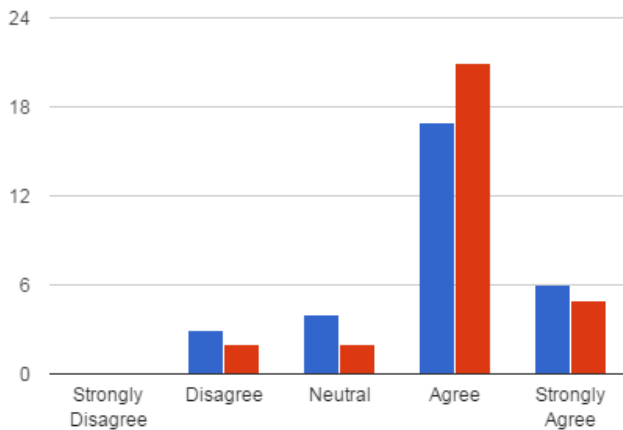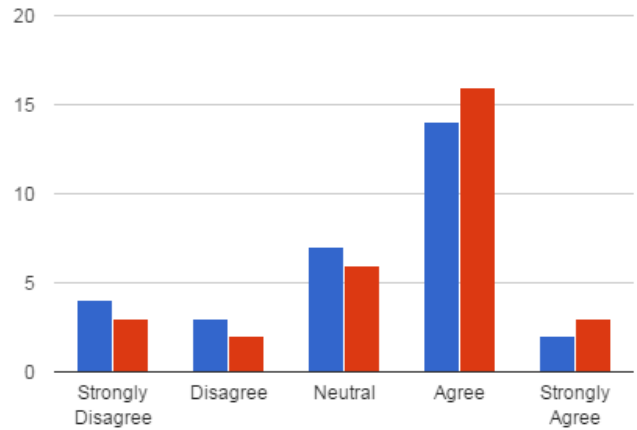
Fig 6. Results of statement agreement questions. Responses before VR demo indicated by the blue bar, and after VR demo indicated by the red bar.

We saw similar results in other statements as well. For the statement "*I would donate to the preservation of cultural heritage site*", before the VR demo, 4 users voted on "Strongly Disagree", 3 voted on "Disagree", 7 on "Neutral", 14 on "Agree", and 2 on "Strongly Agree". After viewing the demo, the number of user voting "Strongly Disagree", "Disagree", or "Neutral" all decreases, while the number of user voting "Agree" or "Strongly Agree" increases to 16 and 3 respectively. This increase in likelihood in donation for cultural heritage site preservation is a very good indicator that the VR demos indeed help raise the level of awareness of cultural heritage site preservation within our users.

4.2. Realism Ratings Results

Immediately after the user finished viewing the VR demos, we asked them to rate the realism of the VR Cultural Heritage Site experience in the scale of 1 to 10, where 10 is the highest level of realism, and 1 is the lowest. We took the average of these ratings and it is found that the VR demos were rated rather high on the scale, as shown in table 2.

Table 2. Realism ratings result of the three VR demos.

VR Cultural Heritage Site	Average Rating
Pammakaristos	8.36
Hagia Sophia	8.60
Šibenik Cathedral	7.00

4.3. User Feedbacks on the VR Experience

- For the VR experience with audio component from sound recording, the majority of the user (9 out of 10) agree that the audio helped with immersion.

While for the VR experience with audio component from simulation, slightly more than half of the user (5 out of 9) thinks that the audio helped with immersion.

- For the VR experience created with panoramic photography, most user (17 out of 21) agree that the demo effectively help them understand the significance of the site, whereas for the VR experience created with 3D model, slightly more than half of the user (5 out of 9) thinks that the VR demo effectively help them understand the significance of the site.

- For the VR experience created with panoramic photography, a major part of the user (16 out of 21) felt like they were 'physically' there while viewing the VR demo than not, whereas for the VR experience created with 3D model, slightly less than half of the user (4 out of 9) felt like they were 'physically' there.

- Mixed feedback about whether a VR experience can 'replace' physically visiting the site. There were user who strongly disagree, user who agree, and also many who voted neutral.

5. DISCUSSION, LIMITATIONS AND FUTURE WORK

5.1. Notes on Panoramic Photography

In this case study, panoramic photography only became a viable option because the cultural heritage site was recorded in panorama by the MCID researchers. It should be noted that this is not the case for any other cultural heritage sites. If we were to create a VR cultural heritage site experience completely from scratch by this method, we would have to, first of all, travel to the site physically, and have special panorama camera in hand for taking panoramic photography.

There are also a few other limitations regarding the panoramic photography method, listed below in no particular order:

- *Lack of depth*.
  Due to the fact that panoramic photography is essentially 2D images stitched together, it does not contain depth information of the scene. User commented that viewing the panoramic photography feels like looking into a giant flat picture that occupies the whole surrounding. Lack of depth is an unavoidable issue stemmed from the nature of the class of panoramic photography we

used. However, we are informed that there is a new class of panoramic photography with depth enabled that might be great for future work of VR cultural heritage site.

- *Resolution*.
  During the user study, more than one user inquired about whether there is zooming in support in the VR experience because they would like to see the details in the panoramic photography more clearly. Unfortunately, the resolution of the panoramic photography was not very high and cannot fulfil the curiously of the users. In future work, we recommend using panoramic photography of higher resolution if possible.

- *Feeling of floating in the air*.
  Another comment many user reported was that there is a feeling of floating in the air with the VR demo. We believe this issues is due to lack of lower body of the user and the lack of depth in the panoramic photography.

- *Inaccuracy in scale and size*.
  Some user who have been to the actual cultural heritage site reported that they found the VR cultural heritage site to be slightly off in scale and size. While part of this issue is thought to be again, due to the lack of depth, it is also possible that there are other inaccuracies in scale and size introduced by panoramic photography.

5.2. Notes on 3D Modelling and Sound Simulation

Out of the three VR cultural heritage site experiences we created, the Šibenik Cathedral experience received the lowest realism rating at 7.00 in comparison to the rating of 8.36 and 8.60 of the other two VR experiences. It is believed that the realism difference is due to different method applied to create the visual and auditory component. The Šibenik Cathedral VR experience the only VR demo out of the three that was made with 3D model and sound simulation. While this is certainly not enough information to conclude whether 3D modelling and sound simulation are less effective methods for creating immersive VR cultural heritage site experience than the others, we'd like to analyze the various shortcomings of our demo below:

- *Flickering lights*.
  Our VR demo has a known issue of flickering lights. When user switch from one viewing angle to another, it occasionally trigger flickering in the lights. This is believed to be due to the mobile devise memory conservation strategies the game engine Unity3D was applying in the back. Some lights in the scene might have been turned off when

the user isn't looking in the direction, causing the flickering issues. For future work on creating VR cultural heritage site from 3D model, we recommend implementing better lighting system.

- *Lack of realistic details.*
In the 3D model we used, many details from the physical site were lost. They are either not modeled, (e.g. the sculpture details on the exterior wall, which are of very high significance to the Šibenik Cathedral), not included in the textures (e.g. the stain and dustiness of the cathedral), or not properly lit (e.g. the stained glass). We received many comments about the lack of realistic details and we believe this is one of the major cause of the lower realism rating of the VR cultural heritage site.

- *Sound simulation.*
Our user study revealed that some users find the reverberation effect in the VR demo not very noticeable. We hypothesis that this can be due to a number of reasons such as bad headphones, user error, inaccurate scale of the 3D model, wrong setups with the Phonon Reverb tool, or unknown bugs with the technology stack we build on. During the development of the demo, we had many trouble with getting the reverbs to bake correctly. Part of it was due to the fact that our 3D model's geometry has too many vertices for our technology stack to handle. The issue improved after we simplified the model, however, it is possible that our sound simulation still does not work completely. Sound simulation is used in many professional video game development. It is proven that it is a method that works very well in creating realistic reverberation simulation based on the environment model. For any future development of VR cultural heritage site experience, it will be a good idea to create better sound simulation.

With that said, we still believe that 3D modelling and sound simulation are good methods for creating VR cultural heritage sites. Our research work is limited by the model we can obtained, tool-specific skills and time, and as the result that our VR demo is not of the highest quality that can be achieved with latest technology. We hypothesis that with better execution, perhaps involving other methods such as 3D laser scanning, HDR photorealistic texturing, photogrammetry, we can create more realistic VR cultural heritage sites.

5.3. VR Discomfort

VR discomfort is a known issue with current virtual reality technology. During the development and user study, we have observed the fair share of what VR discomfort could do. Since virtual reality involves tricking our vision perception, it is quite draining to our sight and brain. Many users reported tired eyes, slight dizziness, and in some case headaches. These symptoms of VR discomfort are particularly common with longer viewing sessions. Another kind of VR discomfort we noticed was with transitioning from the viewing the VR experience back to reality. Many users were slightly shocked by the sudden change of what they see.

Reducing VR discomfort is undoubtedly one area worth investigating in future work. One can imagined that with lesser VR discomfort, user would be able to enjoy VR experiences more and for longer time without irritation.

6. CONCLUSION

In this case study research, we have explored the method of panoramic photography and 3D modelling for creating visual component for a VR cultural heritage site experience. We have also explore the method of sound simulation and sound recording for the auditory component. We were successful in creating multiple VR cultural heritage site experiences that involve both visual and auditory stimulations. Based on the result of our user study, it is clear that enabling multiple senses in VR definitely help with immersion, and thus realism of the VR experience. We have shown that the cultural significance of a cultural heritage site can be effectively convey to the viewer through virtual reality technology. Many of the user in our study have never heard of three cultural heritage sites of this study. While they certainly became more familiar with the idea of cultural heritage preservation through the non-VR portion of the study, our study indicates that accompanying this kind of learning with VR experiences definitely helps our user relate better with the cultural heritage sites. With VR technology, they were able to see the space and feel the atmosphere. Acting as an empathy machine, the VR cultural heritage site experience were very effective in educating our user about the importance of cultural heritage preservation.

One of the most encouraging user feedback we receive was that they would love to see more cultural heritage site visualized in the same way we have created our VR demos. Although with our current state of VR technology, we are not able to completely convince user of being presence in the actual cultural heritage site yet, we are keeping an open-mind that one day, with the advancing technology that might enable the other of the 5 senses, a multi-sensory VR experience might feel completely realistic or even indistinguishable from visiting a cultural heritage site physically.

For the mean time, however, we hope that our research work is inspiring in terms of VR technology application. We have

shown that VR technology have great effects in promoting cultural heritage site preservation, and we hope to see more similar uses of immersive VR in the future.

7. ACKNOWLEDGEMENTS

8. REFERENCES

[1] United Nation Educational, Scientific and Cultural Organisation, "Criteria for the assessment of Outstanding Universal Value," p. 20 – 24, Operational Guidelines for the Implementation of the World Heritage Convention, July 2013.

[2] E. Ch'ng, "Experiential archaeology: is virtual time travel possible?", Journal of Cultural Heritage, Vol. 10, No. 4, pp.458– 470, 2009.

[3] S. Thurley, "Into the future. Our strategy for 2005-2010," English Heritage Conservation Bulletin, 2005.
[4] G. Papagiannakis, A. Foni, N. Magnenat-Thalmann. "Virtual Hagia Sophia: Restitution, visualization and virtual life simulation," UNESCO World Heritage Congress, October 2002.

[5] M. McGuire, Computer Graphics Archive, accessed Sep 25, 2015. http://graphics.cs.williams.edu/data

[6] M. Taylor, A. Chandak, L. Antani, and D. Manocha, "RESound: Interactive sound rendering for dynamic virtual environments," in In Proc. 17th International ACM Conference on Multimedia. Beijing, China, Oct. 2009.

8. APPENDIX A – SAMPLE USER STUDY

VR Cultural Heritage Site User Study - Set B

* Required

Hagia Sophia, Istanbul, Turkey

How familiar are you with Hagia Sophia prior to this study? *

○ I have visited Hagia Sophia.

○ I have some knowledge of it (i.e. heard of the name, seen pictures etc.)

○ Never heard of it.

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Now, the researcher will give a brief presentation about the history, art and architecture of Hagia Sophia, and you will also watch a video taken at the site. Feel free to ask any questions that you might have.

Describe what you think of Hagia Sophia in a few words. *

Your answer

How likely are you to tell a friend about Hagia Sophia? *

Choose ▼

Please rate your level of agreement with the following statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think that Hagia Sophia is a site of high cultural heritage significance.	○	○	○	○	○
I want our future generations to see Hagia Sophia at the same state it is today.	○	○	○	○	○
I would donate to the preservation of cultural heritage sites such as Hagia Sophia.	○	○	○	○	○
I think cultural heritage preservation is just as important as other world issues (e.g. preservation of endangered species, gender equality, etc.)	○	○	○	○	○

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Next, you will be viewing the interior of Hagia Sophia through the VR headset. You may look around for as long as you wish. When you are ready, please take the headset off and answer the following questions.

There is an audio component to this, so make sure you wear the headphones.

Rate the realism of your experience. *

	1	2	3	4	5	6	7	8	9	10	
Lowest	○	○	○	○	○	○	○	○	○	○	Highest

How did the experience affect your opinion of Hagia Sophia? *

	1	2	3	4	5	
Negatively	○	○	○	○	○	Positively

Describe in a few words what you think of Hagia Sophia based on what you just experienced. *

Your answer

How likely are you to tell a friend about Hagia Sophia? *

Choose ▾

Please rate your level of agreement with the following statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think that Hagia Sophia is a site of high cultural heritage significance.	○	○	○	○	○
I want our future generations to see Hagia Sophia at the same state it is today.	○	○	○	○	○
I would donate to the preservation of cultural heritage sites such as Hagia Sophia.	○	○	○	○	○
I think cultural heritage preservation is just as important as other world issues (e.g. preservation of endangered species, gender equality, etc.)	○	○	○	○	○
I feel like as if I was 'physically there' while viewing the VR panorama of Hagia Sophia.	○	○	○	○	○
The VR experience was effective in helping me understand the significance of Hagia Sophia.	○	○	○	○	○
The VR experience can 'replace' the experience of physically visiting Hagia Sophia.	○	○	○	○	○
I think the audio helps with the immersion of the VR experience	○	○	○	○	○

Do you have any other comments about your experience? Please share with us below.

Your answer