WEB-BASED THREE-DIMENSIONAL AUGMENTED REALITY OF DIGITAL HERITAGE FOR NIGHTTIME EXPERIENCE

TOMOHIRO FUKUDA[1], SHIHO NAGAMACHI[2], HOKI NAKAMURA[3], YUJI YAMAUCHI[4], NAO ITO[5] and SHUNTA SHIMIZU[6]
[1]*Osaka University*
[2,3]*LEM Design Studio Co., Ltd.*
[4,5]*ALAKI Co., Ltd.*
[6]*FORUM8 Co., Ltd.*
[1]*fukuda.tomohiro.see.eng@osaka-u.ac.jp, 0000-0002-4271-4445*
[2,3]*{shihonagamachi|hokinakamuralem}@gmail.com*
[4,5]*{yamauchi|itoh}@alaki.jp, [4]0000-0002-8068-4611, [5]0000-0002-6258-5214*
[6]*simizu@forum8.co.jp*

Abstract. Digital heritage is a sustainable medium that allows people to understand the historical shape and context of cities and architecture, leading to visions for the future. Opportunities for the public to experience life-size representations of digital heritage in three-dimensional augmented reality (3D-AR) at outdoor sites are still limited, especially at night. Therefore, the objective of this study is to develop a web-based 3D-AR method to digitally reconstruct a heritage site. A prototype system was developed using the five-storey pagoda of Tango Kokubunji Temple, which was built around 1330 AD and later destroyed, as a digital heritage reconstruction. An interactive initial positioning method was developed to display the five-storey pagoda on real historical foundation stones by tapping a crosshair button, under the condition that the artificial lighting is insufficient at night and the distance between the viewpoint and the 3D model of the pagoda is large. Combining the lighting effects of the real and virtual worlds at night was also demonstrated. We held an event where the general public could experience 3D-AR on their own mobile devices, and conducted a usability evaluation to verify the system.

Keywords. Digital Heritage; Digital Restoration; Augmented Reality (AR); Web System; Lighting Design; Virtual and Real Worlds; SDG 4; SDG 8.

1. Introduction

Harnessing the power of heritage will accelerate the achievement of Sustainable Development Goals (SDGs) to achieve the well-being of people (SDGs 1, 2, 3, 4, 5, 6 and 11), the well-being of the planet (SDGs 6, 7, 11, 13, 14 and 15), the prosperity of communities (SDGs 5, 8, 9, 11, 12 and 14), peace within and among societies (SDGs

POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2022, Volume 1, 737-746.

10, 11 and 16), and the creation of partnerships (SDGs 11 and 17) (Labadi et al., 2021). Digital heritage is a sustainable medium that allows people to understand the shape and context of cities and architecture, leading to visions for the future (UNESCO, 2009). Historical buildings that no longer exist or are severely weathered can be restored as three-dimensional (3D) digital models and brought back to life by superimposing models onto the real world using augmented reality (AR) technology as “3D-AR” experiences (Challenor and Ma, 2019). In addition to experiencing digital heritage representations in a museum (White et al., 2007), AR allows users to better imagine buildings that existed previously at outdoor sites (Lu et al., 2010). While the use of virtual reality (VR) has been reported, which includes a complete 3D computer graphics representation of a non-existent past nightscape (Fukuda et al., 2015), an AR application that can provide an outdoor, full-scale experience of a nightscape has not yet been reported.

AR systems have long required specialised hardware and software, which prevents many individuals from using their own mobile devices to experience AR. Recently, frameworks such as ARCore and ARKit have been developed to handle AR on mobile devices. However, because of model dependency, ARCore and ARKit cannot be used on some devices and further development for both ARCore and ARKit is required, which increases costs.

Recently, these problems have been alleviated by using an AR environment that is independent of the operating system and runs in a web browser via standard scripts (hereafter, web-based AR). Although the use of web-based AR to digitally restore heritage sites has been reported (Abergel et al., 2019), we are not aware of any reports of web-based AR that can be used outdoors at night.

The objective of this study is to propose a method for experiencing digital heritage in web-based 3D-AR at night. A prototype system was developed using the five-storey pagoda of Tango Kokubunji Temple (hereafter, the five-storey pagoda), which was built around 1330 AD and later destroyed, as a digital heritage reconstruction. An interactive initial positioning method is proposed to display the five-storey pagoda on real historical foundation stones by tapping a crosshair button, under the condition that the artificial lighting is insufficient at night and the distance between the viewpoint and the 3D model of the pagoda is large. Combining the lighting effects of the real and virtual worlds at night is also demonstrated. The system was verified through an event during which the public could experience 3D-AR using their own mobile devices.

2. Project Challenges

The five-storey pagoda digital heritage reconstruction project had to overcome the following challenges:

- Users need to experience web-based 3D-AR at night. As the digital heritage site is located in a rural area with inadequate artificial lighting at night, the 3D-AR application needs to have a tracking process that keeps the 3D virtual model in the right position and orientation in the real world (live image), rather than simply displaying it. The conventional and simple method of tracking geometric markers while detecting them with a web camera is impractical owing to insufficient illumination.

- The distance from the 3D-AR viewpoint to the digital heritage display (the digitally reconstructed five-storey pagoda) is large. Mainly for safety reasons, users will experience the 3D-AR application on a raised platform about 50 m away from the pagoda site while facing the site and keeping their smartphone in front of them.
- The 3D-AR application needs to be artistic. The AR content must be attractive and interactive for the users visiting the site so they can experience what the site looked like when the five-storey pagoda was built.

Figure 1 shows a plan of the project, the viewpoint and a photograph of the foundation stones of the five-storey pagoda.

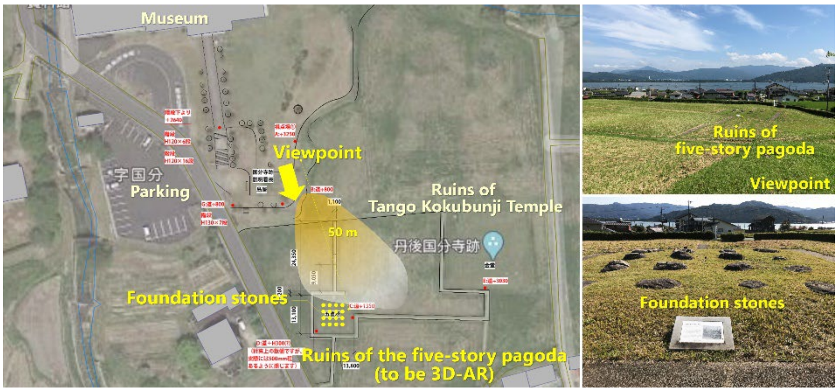

Figure 1. Tango Kokubunji five-storey pagoda AR Revival Project: (left) plan view, (top right) view of the pagoda remains from the AR viewpoint, (bottom right) closeup view of the foundation stones

3. Development of a Web-based 3D-AR Digital Heritage for Nighttime Experience

3.1. 3D MODELLING OF THE FIVE-STOREY PAGODA

There are no accurate drawings of the five-storey pagoda to be brought back to life virtually. The five-storey pagoda depicted in the ink painting "View of Ama-no-Hashidate" by Sesshu, a painter active around 1330 AD, provides helpful clues, but it contains insufficient information to create a complete 3D model.

Therefore, after discussions with the museum curator, we referred to other five-storey pagodas that were built in the same period. The design and the successive diminution with height of the five-storey pagoda differ according to the date of construction. Here, "diminution" refers to the width and eaves of a pagoda becoming smaller with each successive storey, and "successive diminution" refers to the ratio of the width of the top (fifth) storey to the first storey. The Myooin five-storey pagoda built in 1348, which was built in the same period as the Tango Kokubunji five-storey pagoda, has a successive diminution of 0.714.

Next, the distance between the two end pillars of the ground floor of the five-storey pagoda of Tango Kokubunji was 6.54 m, which is about 1.5 times longer than that of the five-storey pagoda of Myooin (4.36 m). If the successive diminution is the same as that of the Myooin five-storey pagoda (0.714), the total height of the Myooin five-storey pagoda is 29.1 m, and the total height of the Tango Kokubunji five-storey pagoda is estimated to have been 43.7 m.

This information was then used as the basis for 3D modelling. It was necessary to set the upper limit of the number of polygons and the texture image to execute real-time rendering as a web-based 3D-AR. However, when the lighting effect is rendered for the 3D model of the five-storey pagoda, the architectural components that appear on the exterior affect the expression of shading. Therefore, the architectural elements characteristic of the exterior were modelled in 3D, taking into account the upper limit of the number of polygons (Table 1 and Figure 2). The file format used was the GL Transmission Format (.gltf or .glb).

Table 1 Upper limit and used value of the number of polygons and texture

Characteristic	Upper limit	Used value
Number of polygons	100,000	99,552
Texture (pixels)	2048 × 2048	1024 × 1024

Figure 2. Created 3D model of the five-storey pagoda

3.2. DEVELOPMENT OF THE WEB-BASED 3D-AR SYSTEM

A web-based 3D-AR system was developed by adapting the A-frame framework. Figure 3 shows the directory structure of the developed web application. The main development items are described below.

- Permission to acquire mobile device information: After loading the URL to access the AR application, permission to acquire the camera image and gyro sensor/accelerometer attached to the mobile device is required.
- Initial positioning: The 3D model of the five-storey pagoda is displayed. To anchor the display to the foundation stones in the real world, first, crosshairs are displayed in the centre of the screen. The user places the crosshairs on the foundation stones and interactively taps the crosshairs to display the 3D model of the pagoda (initial positioning). After the initial positioning is complete, the 3D model is re-rendered to correctly draw it on the foundation stones when the mobile device is rotated

around the X, Y, and Z axes.

- Lighting installation in the virtual space: After the initial positioning, spotlighting effects are performed on the 3D model of the five-storey pagoda. Next, the 3D model is illuminated from the foot of the pagoda. Then, a lighting effect is supplied from the roof of the pagoda. Lighting is then supplied from the inside of the pagoda. Finally, an entertaining lighting performance is performed with the 3D model. The lighting animation lasts 3 minutes and 10 seconds (Figure 4). These lighting effects are implemented by adapting a shader program.
- Background music (BGM): After the initial positioning is complete, BGM is played.

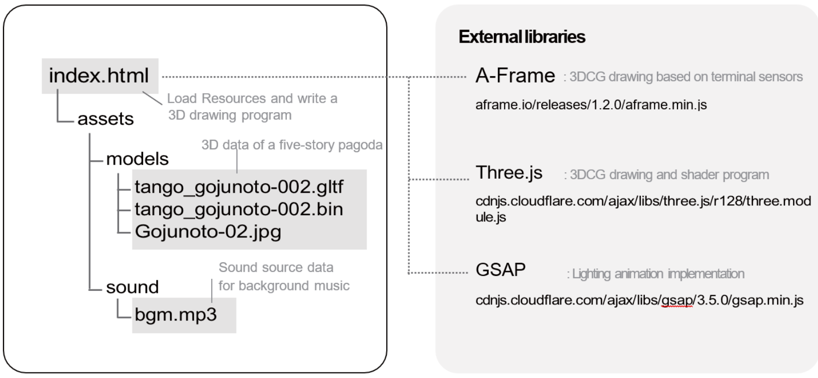

Figure 3. Directory structure of the developed web application

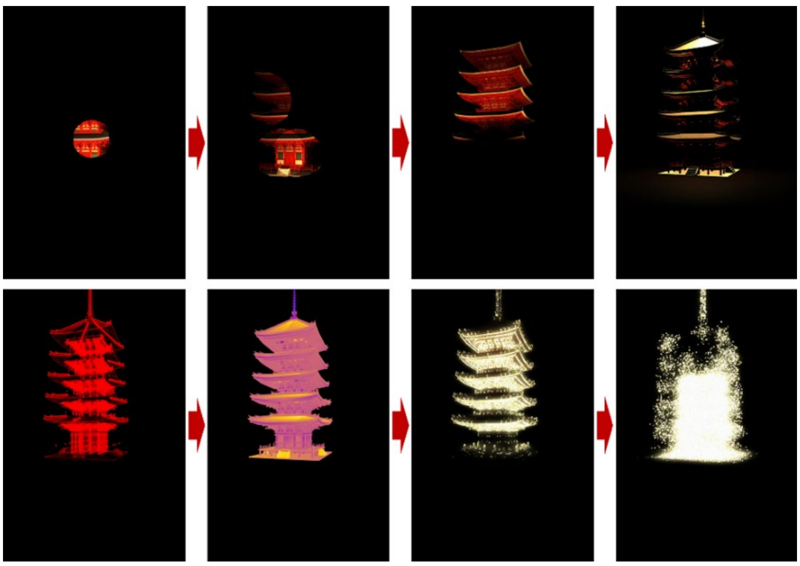

Figure 4. Screenshots of animation of lighting effects in the virtual space

3.3. LIGHTING DESIGN IN THE REAL WORLD

Because it is dark at night in the target area (almost 0 lx) and it is difficult to discern the foundation stones from the viewpoint, a narrow-angle light fixture was set up in the middle of the foundation stones. In the initial positioning described in section 3.2, this light is used as a target and users overlay the crosshairs displayed on the screen on this target to display the 3D model of the five-storey pagoda.

To create the illusion that the lighting environment of the real world and the virtual world are merged on the AR screen, the grassland and the foundation stones of the five-storey pagoda were illuminated from near the viewpoint (Figure 5). Lighting was also provided for users to approach the viewpoint.

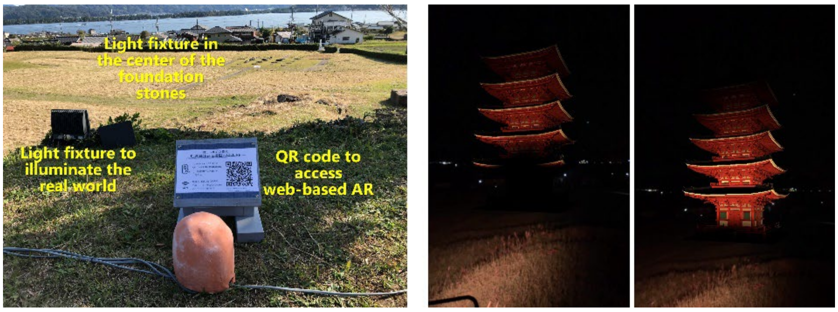

Figure 5. (left) QR code to access AR application and light fixtures, (right) AR screenshots showing the fusion of real-world and virtual world lighting

4. Verification Experiment and Results

4.1. OVERVIEW OF THE EXPERIMENT

The verification experiment took place for 29 days, from 31 October to 28 November 2020 (Figure 6). During this period, QR codes placed at the site contained the URL to access the web-based AR application described in section 3. Users visited the Tango Kokubunji five-storey pagoda site and scanned the QR code with the camera of their mobile device (smartphone or tablet) to access the AR application. The user then experienced an AR presentation lasting 3 minutes and 10 seconds by interactively tapping the crosshair button displayed in the middle of the screen, after overlaying the

Figure 6. Photos of the experiment

crosshairs on the light placed in the middle of the foundation stones. During the AR application experience, users were able to move and rotate their mobile devices freely.

At the end of the AR application, a URL was displayed, which directed users to a survey form that users could voluntarily access and complete usability evaluation.

4.2. RESULTS

The attributes of the 73 participants who responded to the questionnaire were as follows:

- The age ranges were as follows: 1 (1.4%) younger than 20, 12 (16.4%) in their 20s, 12 (16.1%) in their 30s, 21 (28.8%) in their 40s, 23 (31.5%) in their 50s, and 4 (5.5%) in their 60s. Individuals aged in their 50s and 40s together accounted for more than 60% of the respondents, but a wide range of ages was included.
- The gender was almost equally divided: 37 (50.7%) females and 36 (49.3%) males.
- 21 (28.8%) lived in Miyazu City (where the five-storey pagoda site is located), 27 (37%) lived in Kyoto Prefecture (excluding Miyazu City), and 25 (34.2%) lived in the Kinki region (excluding Kyoto Prefecture). Thus, all Respondents were from relatively nearby areas, likely because it was difficult to travel long distances in Japan owing to the ongoing pandemic at the time of the experiment.
- Only smartphone mobile devices were used, including 63 (86.3%) iPhones and 10 (13.7%) Android phones. No tablet devices were used by any of the respondents.

Figure 7 shows the results of the questionnaire. No significant differences were observed between days.

- In terms of the overall evaluation of the AR application, 68.5% rated it as very excellent and 86.3% rated it highly (Figure 7 (a)).
- As for the length of the AR application, 76.7% answered that it was just right. However, 12.3% rated it as very long (Figure 7 (b)).
- Regarding whether the five-storey pagoda model could be displayed on the foundation stones in the real world (indicated by a light in the centre), 60.6% answered that it could be displayed. On the other hand, 21.1% answered that they could not display it well (Figure 7 (c)).
- 60.9% stated that the lighting in the real world "blended in" with the lighting in the virtual world. In contrast, a small number of respondents answered that the displays were not integrated (Figure 7 (d)).

5. Discussion

We developed a 3D-AR method to display a digital heritage reconstruction of the five-storey pagoda on its foundation stones at night, when artificial lighting was not sufficient, and under outdoor conditions, when the distance between the viewpoint and the 3D model of the five-storey pagoda in Tango Kokubunji Temple was 50 m. To achieve this challenge, we set up a narrow-angle light fixture at the centre of the actual foundation stones and added a crosshair button on the screen of the mobile device,

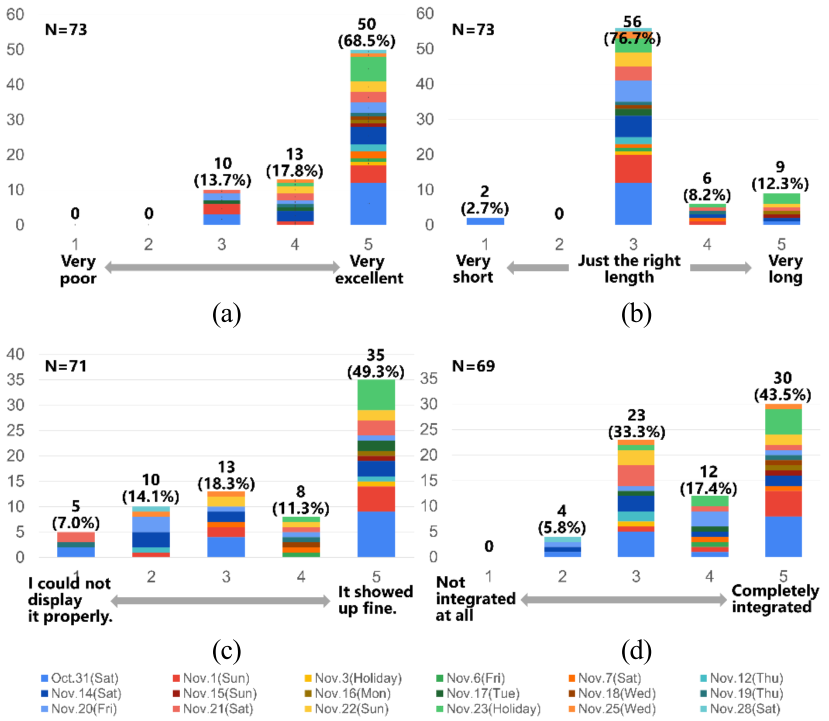

Figure 7. Questionnaire daily results: (a) Overall rating, (b) Length of the AR presentation, (c) Alignment of the five-storey pagoda model display with respect to the foundation stones and (d) Integration of the lighting in the real and virtual worlds

which the user taps after superimposing the crosshairs on the light source to display the five-storey pagoda 3D model interactively. After the initial positioning, the 3D model was re-rendered in real time by using the smartphone's gyro sensor/accelerometer to obtain the position information.

From the results of the usability evaluation (Figure 7 (c)), more than 60% of the respondents were able to display the five-storey pagoda model on the foundation stones in the real world. A possible reason why relatively many respondents reported that they could not display the five-storey pagoda model well on the foundation stones was that other activities were also occurring during the experiment period, and there were more lights in the surrounding environment and from night cruises. This may have made the target light in the centre of the foundation stone relatively less clear.

While users visiting the site virtually experienced the scene at the time when the five-storey pagoda was built, we tried to make users feel the attraction of the 3D digital heritage reconstruction of the pagoda. To achieve this, we created a 3D-AR real-time animation 3 minutes and 10-second long, during which the lighting effects changed successively based on various illumination scenarios, which included not only realistic lighting but also artistic expressions. To create the illusion that the lighting environment of the real world and the virtual world are fused, we illuminated the grassland and the foundation stone of the five-storey pagoda from the viewpoint.

In the results of the usability evaluation (Figure 7 (b)), 76.7% of the respondents answered that the length of the AR animation was just right, which suggests that the application performed well. In addition, as shown in Figure 7 (d), 60.9% of the respondents answered that the lighting of the real world and the virtual world were "integrated", which also suggests satisfactory performance.

Descriptions of the issues we found are as follows:

- There are limits to the number of polygons and texture sizes of 3D models that can be handled by current web-based 3D-AR applications. These limits are below the data-handling capabilities of most commercial architectural and urban design programs. Approaches to solving this problem include reducing the number of polygons while maintaining a realistic representation of the model, relying on the continued improvement of mobile device performance, or rethinking the role of the server and the mobile device (client). One technique for the third approach is to render a large number of 3D models at high speed on the server side and send the result of the rendering to the mobile device as a video.
- In the real world, lighting effects are caused by shading due to the position of light fixtures and the eaves of buildings. Lighting designers and computer graphics creators have had many discussions on how to express the same lighting effects in the virtual world to match those in the real world, but the construction of a shader lighting program is very challenging. The differences between virtual shader lighting effects and real-world lighting effects are still significant, and it is still difficult to express the same architectural lighting effects in the virtual world as in the real world. This is an issue that we discovered once again by merging the lighting effects from the virtual and real worlds.
- Initially, we had planned to load the content of the virtual world's lighting effects into the real world's lighting equipment in real-time, so that the light emitted from the lighting equipment would be completely synchronised with the virtual world's lighting effects, but this was not possible. Therefore, in this experiment, we prepared the content of the real-world light fixtures and the virtual-world lighting effects in advance and represented them on a device screen as if they were synchronised. It is necessary to develop a method for synchronising the lighting environment of the real world and the virtual world in real time.

6. Conclusion

Opportunities for the public to experience life-size representations of digital heritage in 3D-AR at outdoor sites are still limited, especially at night. Therefore, the objective of this study was to develop a web-based 3D-AR method to construct a digital heritage for nighttime experience. A prototype system was implemented using the five-storey pagoda of Tango Kokubunji Temple, which was built around 1330 AD and later destroyed, as a digital heritage reconstruction. The system was verified through an event during which the public could experience 3D-AR on a web browser using their own mobile devices.

The contributions of this research are as follows:

- A method was developed to combine 3D-AR and a night-time viewing environment with inadequate artificial lighting and a distance of 50 m between the AR viewpoint and the imaged object, namely, the five-storey pagoda of the Tango Kokubunji Temple. The method displayed the digital heritage reconstruction of the pagoda interactively on its actual foundation stones in the real world by allowing the user to align the virtual and real scenes by tapping on a crosshair button on the screen.

- The 3D-AR real-time presentation, which was 3 minutes and 10 seconds long, displayed a 3D model of the five-storey pagoda and included artistic lighting effects. A user survey confirmed that the lighting effects in the virtual world and the lights from the light fixtures placed in the real world were combined on the 3D-AR screen.

Future challenges include the exclusion of restrictions on the number of polygons and texture size of 3D models in the web-based 3D-AR application and the synchronisation of lighting effects in the real and virtual worlds.

Acknowledgements

We would like to thank all the participants for their support in the project, especially the Kyoto by the Sea Destination Management/Marketing Organization and the Kyoto Prefectural Tango Reginal Museum.

References

Abergel, V., Jacquot, K., De Luca, L., & Veron, P. (2019). Towards a SLAM-based augmented reality application for the 3D annotation of rock art. *International Journal of Virtual Reality,* 19(2), 17–26. https://doi.org/10.20870/IJVR.2019.19.2.2910.

Challenor, J., & Ma, M. (2019). A review of augmented reality applications for history education and heritage visualisation. *Multimodal Technologies and Interaction,* 3(2). https://doi.org/10.3390/mti3020039.

Fukuda, T., Ban, H., Yagi, K., & Nishiie, J. (2015). Development of high-definition virtual reality for historical architectural and urban digital reconstruction: A case study of Azuchi castle and old castle town in 1581, *Communications in Computer and Information Science*, 527. Springer. https://doi.org/10.1007/978-3-662-47386-3_5

Labadi, S., Giliberto, F., Rosetti, I., Shetabi, L., Tildirim, E. (2021). *Heritage and the sustainable development goals: Policy guidance for heritage and development actors.* ICOMOS. Retrieved November 25, 2021, from https://www.icomos.org/images/DOCUMENTS/Secretariat/2021/SDG/ICOMOS_SDGs_Policy_Guidance_2021.pdf.

Lu, B. V., Kakuta, T., Kawakami, R., Oishi, T., & Ikeuchi, K. (2010). Foreground and shadow occlusion handling for outdoor augmented reality. In *9th IEEE International Symposium on Mixed and Augmented Reality 2010: Science and Technology, ISMAR 2010* (pp. 109-118). https://doi.org/10.1109/ISMAR.2010.5643558.

UNESCO. (2009). *Charter on the Preservation of the Digital Heritage.* CL/3865. Retrieved November 25, 2021, from https://unesdoc.unesco.org/ark:/48223/pf0000179529.page=2.

White, M., Petridis, P., Liarokapis, F., & Plecinckx, D. (2007). Multimodal Mixed Reality Interfaces for Visualizing Digital Heritage. *International Journal of Architectural Computing,* 5(2), 321–337. https://doi.org/10.1260/1478-0771.5.2.322.