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Using Augmented Reality to bridge the gaps between indoors/outdoors and centre/periphery in Cultural Heritage Communication

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The relationships between museums, artefacts and original sites are complex. How may we use mobile augmented reality (AR) to bridge the gaps between both indoors and outdoors exhibitions as well as the opposition between central collections and the more peripheral sites of the original artefacts? In this paper we present two main cases (the Viking Ship Museum in Oslo and the Calmecac Museum in Mexico City) where we have experimented with bringing a digital copy of the displaced artefact back to its original environment, as well as bringing a digital copy of the original environment into the displaced or isolated object in the museum exhibition. Further, we report on a solution to solve the problem with indoor positioning (IPS) and how it can be seamlessly combined with GPS–based outdoor positioning for smooth transitions between inside and outside. Finally, these cases were tested with three different hardware platforms - tablets, smartphones and smartglasses.

KEYWORDS

Augmented reality, situated simulations, sitsim, indoor positioning, IPS, GPS, digital cultural heritage

1. INTRODUCTION

The relationships between museums, artefacts and original sites are complex and controversial. The conflicted character and history of cultural heritage museums can be shown by a series of opposites or dichotomies, each forming crucial challenges to digital designs in cultural heritage communication. Firstly, the relationships between centre and periphery are repeatedly present. Most museums in the cultural heritage tradition have significant connections between the collected, centralized artefacts and their more peripheral places of origin. The removal of relics from their original environment, with subsequent storage and display in central institutions, has been ongoing since the beginning of private collections and has often resulted in looting and a lack of repatriation, for example the so–called "Elgin Marbles" which still reside in the British Museum. However, related processes need to take place whenever there is an archaeological excavation coupled with an active museum: artefacts need care, curation and proper conservation. Displays of cultural artefacts in situ – in their original habitat – on the other hand are rare and primarily limited to larger standing structures. From this basic situation of tension between centre and periphery a prominent paradox emerges: the museums and their exhibits have secured the original objects but are missing their initial context, while the original sites have the context but are deprived of their primary objects.

With the employment of location-based media, such as mobile augmented reality, we can, to some extent, bridge the gap between centre and periphery. Digital copies of the displaced artefact can be returned to the original site and be displayed there to the benefit of local visitors by means of smartphones,

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tablets and outdoors positioning solutions, for example: the original Viking ships on display at the central museum in Oslo, Norway, can be experienced at their original site of excavation, that is in their ceremonial grave mounds a hundred kilometres south of the permanent museum exhibition in the capital city.

This leads us to the next challenging obstacle, that between inside and outside (indoors and outdoors). If we can bring the digital copy to the original site, what about the other way around? With a simple thought process it is possible to imagine the opposite. By applying the same AR technology it is also conceivable to bring a digital reconstruction of the original environment into the museum exhibition and provide a simulation of the original context to the displaced artefact. However, this has so far been difficult. Standard global positioning systems (GPS) only work outdoors, and solutions for indoor positioning (IPS) did, for a considerable time, remain inadequate despite highly propagated implementations (Lymberopoulos and Liu, 2017). More recent solutions for positioning indoors are now rapidly changing this due to ARKit for iOS from Apple and ARCore for Android from Google (Cervenak and Masek 2019).

The centralized museum is typically located off-site as opposed to on-site museums. However, with a close combination of outdoor and indoor positioning- GPS and IPS- it should also be possible to move smoothly between the inside and the outside where it is most needed: that is in on-site museum settings where only parts of a cultural heritage site is housed indoors, while other connected quarters remain in the open. The Capitoline Museum in Rome is a typical example of such an on-site museum where the ruins of the Temple of Jupiter reside in situ inside, while the real context of the Roman Forum and the ancient city centre can be found in the immediate environment surrounding the museum building. Another instance is the Calmecac Museum in Mexico City, which houses the main entrance to the principal building for educating children of the Aztec nobility in a modern basement exhibition, while outside and nearby one may visit the excavated remains of the Templo Mayor. Both structures are part of the holy precinct of central Tenochtitlan.

The unfettered use of mobile augmented reality in a variety of museum and cultural heritage environments, whether they are centrally placed or in the periphery, on-site or off-site, indoors or outdoors, has huge potential for smooth movement and continuous use of digital simulations and reconstructions, which may extend the experience of a cultural heritage site or museum in a variety of ways and improve the learning outcome.

In the following we will present and discuss two AR applications based on the situations described

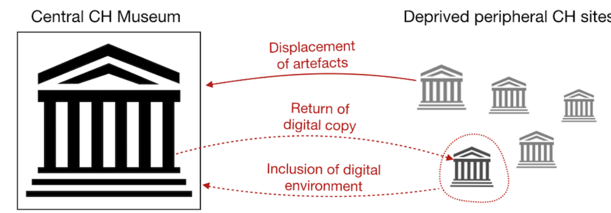

Figure 1: Typical for the dominant centre–periphery relationship in Cultural Heritage settings is the general museum placed off-site in a larger city which draws artefacts from peripheral areas, today predominantly governed by regulated public institutions, while earlier centuries saw extensive cultural looting and consequent retention on a global scale. AR reconstructions may both return artefacts in digital form to the original sites, as well as adding a digital version of the original environment to the off-site central exhibition of the authentic object

above (see figures 1 and 2). The first concerns the Viking Ship Museum in Oslo, which houses the Oseberg and Gokstad ships, both excavated and removed from their respective burial mounds in rural areas some 100–150 km south of the museum. AR simulations and reconstructions have earlier been developed for use at the original site of Oseberg (Liestøl and Rasmussen, 2010). A simulation for the Gokstad site was tested in 2013. This reconstruction was then reused for IPS-experiments in the museum exhibition in 2019. The second case concerns the Calmecac Mu-

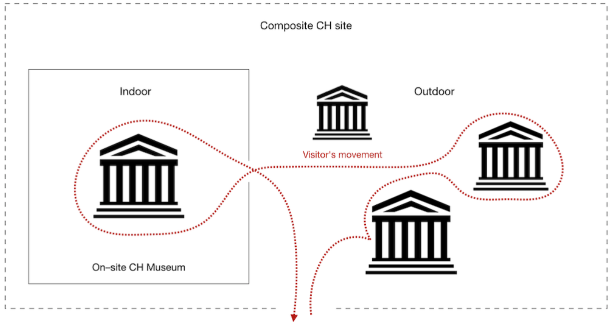

Figure 2: In an on-site museum with both indoor and outdoor exhibitions, the combined GPS and IPS solutions can create smooth and continuous AR experiences, providing rich contexts to the artefacts by means of holistic digital reconstructions and simulations as the visitors move around the site.

seum housed in the basement level of the Spanish Cultural centre in Mexico City. The Calmecac Museum displays an excavated and conserved part of the Calmecac building, a significant edifice from the inner precinct of ancient Tenochtitlan, the remains of which continue to be excavated from underneath the present day Mexico City. Less than 100 meters away from the museum, and outside, we find the excavated base of the Templo Mayor, the dominant and most important building in the inner precinct. In the spring of 2019, we developed a digital 3D reconstruction of the main buildings of the holy precinct of Tenochtitlan and deployed it in an AR application that combined IPS and GPS for positioning and continuous movement using the same simulation from inside the museum to the excavated sections outdoors. After describing the design and development as well as testing and evaluating the two AR applications, we move on to discuss the implications and potentials of the two different settings and their respective AR implementations. In the discussion we will pay particular attention to the relationship between the limited view in the walled and closed-off room in the museum exhibition, compared with the digital display of the reconstructed original environment, whether this refers to the immediate outside of the on–site museum or the distant site in the periphery.

2. FROM PERIPHERY TO CENTRE: BRINGING ORIGINAL ENVIRONMENTS TO THE CENTRAL MUSEUM

Reconstructing buildings as digital extensions to physical ruins and remains on cultural heritage sites by means of augmented reality (AR) has been experimented with for several decades. The earliest implementations were based on customized hardware and software solutions (Vlahakis et al., 2001), while over the past decade we have witnessed increased use of off-the-shelf hardware, primarily smartphones and tablets (Liestøl 2009; Madsen and Madsen 2013), but also smartglasses (Hammady et al., 2019). For the Gokstad case we used the situated simulation (Sitsim) AR platform, a type of Indirect Augmented Reality solution (Wither et al., 2011), which has been in development since 2008 (Liestøl et al., 2011). (A basic version of this Unity–designed platform – the Sitsim AR Editor – is available for free download.)

The Viking Ship Museum in Oslo houses the well preserved Gokstad Viking Ship, which was excavated in 1880 and originally built around 890 AD (see figure 3). In 2013 we created a digital reconstruction of

Figure 3: The conserved and partly reconstructed Gokstad Viking Ship on display in the Viking Ship Museum in Oslo as seen from one of the balconies in the exhibition space. The ship is more that 23 meters long, made of oak and had a crew consisting of 34 men. Visitors can walk around the ship at the ground floor level and ascend to the balconies to view the ship from above. CC: https://commons.wikimedia.org/wiki/File:Gokstad_Ship_Side_View.JPG Photo: Bjørn Christian Tørrissen

the Gokstad Ship burial scene as it may have looked just before the grave mound was erected on top of the vessel and its ceremonial belongings. This rudimentary prototype was made as part of a media design course on AR and Cultural heritage at the Department of Media & Communication at the University of Oslo. For the outdoor testing of the prototype on the grave mound the indirect augmented reality solution originally employed a full screen sensor-fusion approach to positioning and display. We knew from a series of on-site tests and evaluations with visitors that this was an implementation that worked well (Liestøl 2011). After monitoring IPS solutions for several years we decided to test Apple's ARKit. ARKit employs a technology called Visual Inertial Odometry to track the world around the device. This enables an iOS device to sense and record how it moves in a spatial environment. ARKit uses that data to create a point cloud of the room's layout, and can then position virtual environments and objects relative to the physical room in which the visitor is situated.

The low resolution 3D environment from the 2013 prototype was reimplemented in the ARKit-based version and tried out in the Gokstad section (nave) in the Viking Ship Museum. Because the testing was focused on indoors positioning accuracy, other typical features from the sitsim-platform were not included, such as spatially distributed hypertext links for access to additional information about various aspects of the reconstructed objects and environment by means of PDFs, high resolution 3D scanned artefacts, audio narration, animations, online documents, etc. The testing of the new prototype was limited to include members of the development team and went very well. Accuracy was surprisingly good compared to our experience with GPS-based positioning outdoors. 360 degrees panoramic movements to view the reconstructed original environment caused no problem for the positioning technology. Even when users ascended the steps to the balconies on each side of the entrance to the Gokstad nave, both orientation and altitude remained remarkably stable. Unfortunately, the virtual camera had remained in the regular design position of 1.7 meters altitude (average eye level) and did not compensate for the fact that the Gokstad ship in the museum exhibition is placed with its keel about 0,3 meters above ground level. This was due to the fact that for the outdoor use of the prototype the ship was partly submerged in the wet clay as in the original burial scene (see figure 4). One of our key questions, in addition to the positioning and orientation issues, was how the experience of bringing a digital copy of the original environment in contact with the real artefact inside in the museum would be perceived (Liestøl, 2015). We will return to this question in the discussion under section 4 below.

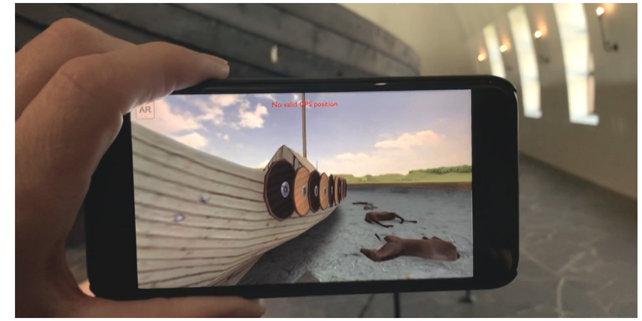

Figure 4: The 2013 prototype 3D environment repurposed for use indoors in the Viking Ship Museum in 2019 with an ARKit–based solution. The virtual camera is positioned at the usual altitude of 1.7 m. This does not match the conditions in the museum where the keel of the ship is 0.3 meters above the floor level, while in the digital reconstruction it is partly submerged in the wet clay as was the case when it was placed in the mound around 890 AD. Apart from the vertical mismatch the positioning was surprisingly accurate regarding all types of movement and orientation compared to our experiences with GPS outdoors in open landscape. © Photo: G. Liestøl.

3. FROM INDOOR TO OUTDOOR: MOVING BETWEEN INSIDE AND OUTSIDE IN ON–SITE MUSEUMS

It is well established that a digital copy of an artefact in a centralized museum can be brought back to its original physical environment and augment the cultural experience of that site. We have now shown that the same digital reconstruction can be brought into the enclosed museum and provide the displaced original object with a digital interpretation of its initial environment. Both indoor and outdoor positioning is possible. How can we exploit this in the context of cultural heritage sites where there is an indoor museum on–site as well as structures and remains outdoors? Is it then possible to use the same digital reconstruction continuously from inside the museum walls to the outside sights?

This is what we wanted to explore at the Calmecac Museum in Mexico City where the excavated fragment of a larger building, the Calmecac – originally housing the education facilities for children of the Aztec nobility – is located in a basement museum where the ruin is displayed in situ. The museum and its primary object, the steps of the main entrance to the once monumental building, makes a profound impression. As one descends the stairs to the exhibition room one also enters the level of the ancient Aztec city of Tenochtitlan, the remains of which are still preserved 2-3 meters below the street level of today's modern Mexico City. Only small parts of Tenochtitlan have been excavated, among them the Calmecac fragment and the Templo Mayor, the largest structure in the inner holy precinct of the ancient city.

In the Calmecac prototype we used the same

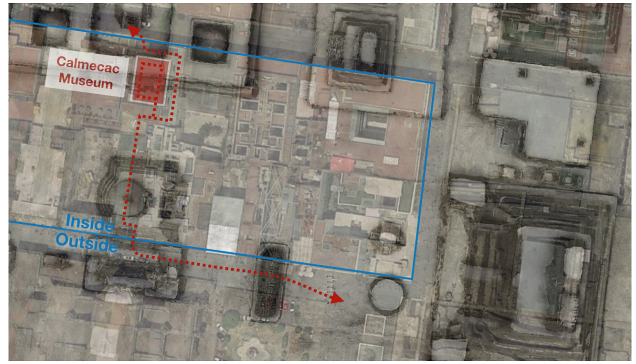

Figure 5: The users' movement in the test, from inside the Calmecac Museum in the basement, up and out through the building, and onto the street, then the movement towards the east outdoors. Google satellite photo of modern Mexico City combined with a top-down view of the inner precinct of Tenochtitlan based on the photogrammetry model. Ill. G. Liestøl.

ARKit solution for indoor positioning as in the Gokstad case described above. In addition, we wanted to create a continuous experience by using the same digital simulation first inside in the Calmecac Museum next to the excavated ruin, and then move outdoors to experience other structures both hidden inside buildings as well as displayed in the open. All the reconstructions involved were part of the holy precinct of Tenochtitlan. What today is displayed as physical fragments, distorted and detached by the modern city, could then be unified and perceived as a whole and in its hypothetically original design, the way it may have looked in the early part of the 16th century, before the city was destroyed and levelled in 1521 to serve as the foundation for the new Spanish colonial town, which later became Mexico City. Most of the main buildings in the inner precinct were modelled manually in 3D using a photogrammetry model of an authorized bronze replica as a blueprint, which is on permanent display between the Catedral Metropolitana de la Ciudad de Mexico and the excavated foundation of Tenochtitlan's Templo Mayor.

The completed prototype was tested with 14 invited individuals, mostly cultural workers, as well as people from the cultural heritage field with good knowledge about museum exhibitions in general, and the Aztec material in particular. The technical solution for using ARKit for indoor positioning with a smooth transition to applying GPS positioning outdoors worked very well. Again it became obvious how much better the precision was using ARKit compared to GPS.

After exploring the application the 14 testers answered a written questionnaire individually. The feedback was overall very positive. A couple had some technical problems due to misunderstanding the instructions. First the participants explored the annotated ruin itself with hypertext links explaining various aspects. Then they activated the total reconstruction and could observe the whole Calmecac complex as well as the surrounding buildings, including the Templo Mayor to the east. Then they left the museum space, ascended the stairs to the ground floor of the current building and walked down the passages and out onto the street. There they turned east towards the Templo Mayor some 80 meters away and about 3 meters above the street level of ancient Tenochtitlan. As they moved eastward they could observe various structures and access background information via positioned hypertext links.

The general feedback was very positive. The participants appreciated the originality of the application, the graphics of the reconstructed environment, as well as the use of sound (music and conversation among human representations)- as one stated: "The app is amazing!" On the negative side were technical issues with two testers who had not activated the full reconstruction before leaving the museum inside. This was due to misunderstandings and ambiguities in our introduction. Apart from that, most of the participants mentioned that the application could include more information and reconstruct a larger part of the ancient environment and make it richer in detail and information-comments that we of course would like to comply with.

Regarding the transition from inside to outside,

Figure 6: One participant exploring the Calmecac ruin via the screen. A 3D model of the ruin based on photogrammetry is displayed on the full screen. Hypertext links activate background information explaining various aspects of the structure: PDFs, animation, 3D-objects etc. After the Calmecac fragment had been explored one could launch the full reconstruction and start to move outdoors.

all participants, except the two with technical difficulties, experienced the transition as smooth and continuous. Here are some of the responses:

> "Yes, I felt that it was a continuous sequence."
> "Yes the experience was continuous."
> "Yes, but outside it felt a bit more real. Inside it was a museum + digital experience. Outside it felt like a digital time travel."

Figure 7: The Calmecac prototype in use outdoors facing west. On the screen we can see that the user is positioned just east of the structure known as the Tzompantli, the skull rack and two towers containing thousands of human skulls from the sacrifices conducted on the Templo Mayor. Photo Š. Ledas.

The last response is interesting since it makes an important distinction between the experience inside the museum and outside, although the full reconstruction itself did not change when moving from the one to the other (only the perspective). One explanation could be that when outside the open mode of the digital environment (horizon, sky etc.) was more compatible with the open air context the user was positioned in. Also it could be that the real sounds and sights of the physical surroundings when outside in the modern city contributed to and augmented the visual and auditive perception of the reconstructed scene.

4. STEREOSCOPIC AND 2D PERSPECTIVES: TOWARDS MUSEUMS WITHOUT WALLS

In addition to the movement from inside to outside, from IPS based on ARKit to GPS, we also wanted to know how the participants experienced the relationship between the walled-off physical museum and the reconstruction of the inner precinct as it may have looked before its destruction in 1521. Hence we included the following question:
"The Calmecac ruin is positioned in a basement with no view beyond the walls of the exhibition room. Did the simulation on the screen, with its reconstructed buildings, provide you with a feeling of the open space of ancient Tenochtitlan despite you being in a confined basement room? Please describe your experience regarding the relationship between the limited view in the exhibition room and the open view of Tenochtitlan on the screen."

All the participants gave positive responses to this question. Here are some of the answers:

> "I think this is the main attraction of the app."
> "Yes, it was quite easy to feel this."
> "Yes, it made me feel like I was outside."
> "Yes, it was quite good taking into account we were in a limited space."
> "Yes, totally. For the first time after living in this city for six years and knowing where the Templo Mayor is I really could picture how the buildings were positioned."
> "Yes, I could experience a sense of being in a wider space even when I was in the basement."


Figure 8: Left: The Calmecac prototype in use inside the museum. The device is oriented towards the west. The real Calmeca remains can be seen in the left part of the photo, behind the device. On the screen a digital copy of the real Calmecac fragment is embedded in the reconstruction of the whole structure. In the distance other buildings in the inner precinct. To what extent is the distant perspective on the screen able to override the experience of being placed in a confined vault museum? Right: The visitor has walked outside the museum to the north and can view the inner courtyard of the Calmecac 'below' the current day street level. Photo: G. Liestøl.

Throughout human history we have seen various attempts to visually overcome the confined spaces of walled rooms. In Roman wall paintings a recurring motif is the picturing of outdoor landscapes as if seen through a window or an opening in a wall, like in the preserved paintings from the Villa of P. Fannius Synistor at Boscoreale dated to 50-40 BC (Small, 2019). This "seeing through" solid surfaces exploits the 2D plane to achieve a visual extension of the 3D space. The image on the 2D surface is fixed and the illusion works best when the visitor's position when facing the image, the vantage point, is balanced by the vanishing point in the picture, particular when the linear perspective was later employed, as in Leonardo's

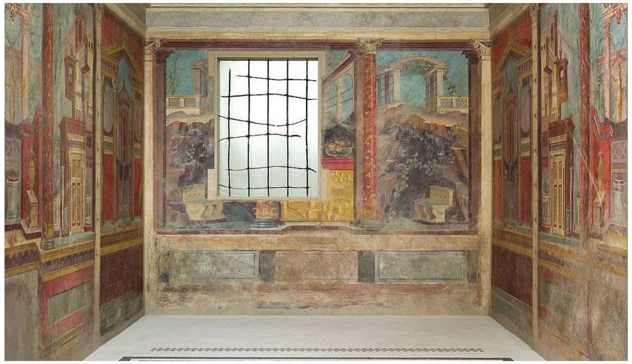

Figure 9: Ancient attempt to visualize 3D space beyond flat walls with painted and real openings. Fresco from a bedroom in the Villa of P. Fannius Synistor at Boscoreale near Pompeii, now on display in the Metropolitan Museum of Art. © in the public domain (Wikimedia Commons).

"Last Supper" from the 1490s (Schwartz, 1988). With AR the 2D plane (the screen) moves with the visitor and the perspective into the dynamic 3D graphics environment on the screen is updated accordingly in order to maintain congruity with the real physical perspective. This mobility and the dynamics of the constant updates of the perspective could to some extent account for the positive feedback.

Both the Viking Ship and the Calmecac experiments included testing with the smartglasses Magic Leap One. In these cases we used the full screens of the device for the digital representation, thus creat-

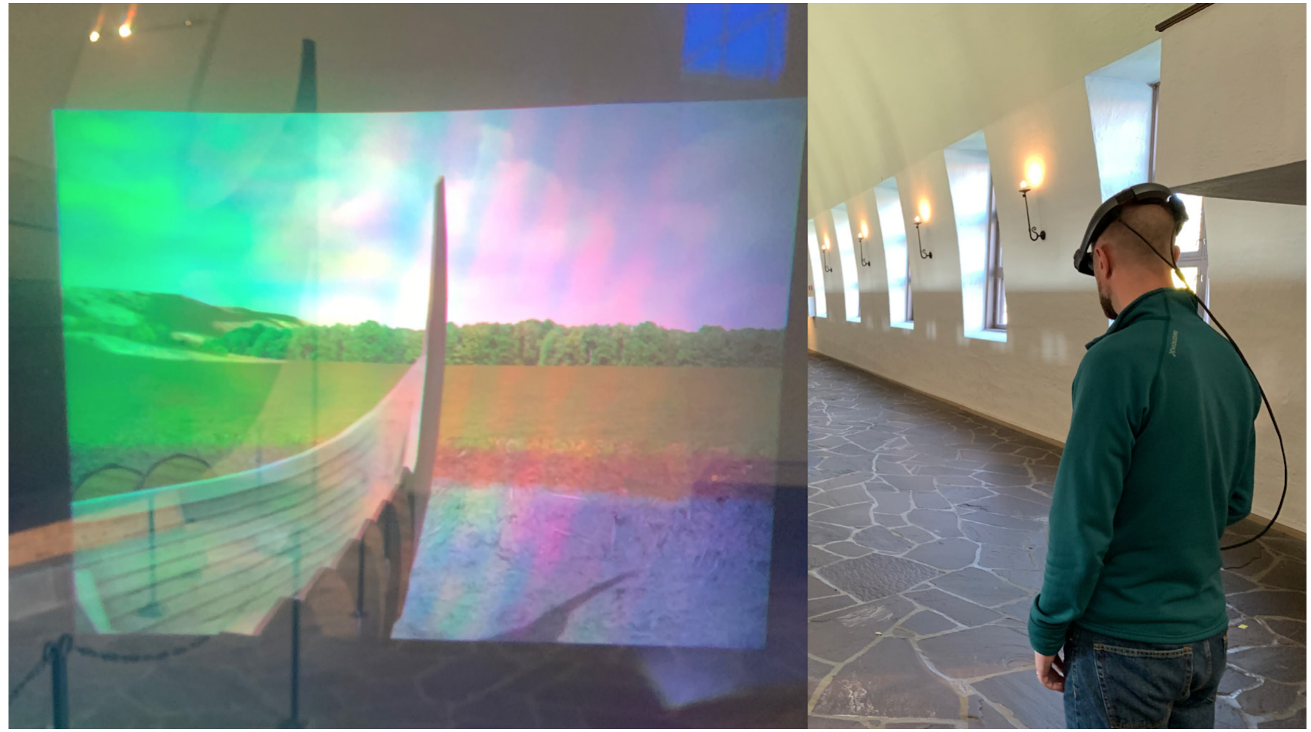

Figure 10: The Gokstad Viking Ship in its digitally reconstructed landscape viewed in the museum with Magic Leap One smartglasses. The photo to the left is captured with a camera pointed through the right eye view/screen of the goggles. The photo does not give justice to the real experience of using the device. Note that the relationship between a centrally positioned screen surrounded by direct access to the real environment is similar to the indirect augmented reality mode when using smartphone or tablet. However, in this case the aft of the real ship and its museum environment is visible through the digital reconstruction displayed on the device's screen. Ill. G. Liestøl.

ing a situation that to some extent was analog to the Indirect Augmented Reality mode when using smartphones and tablets: a rectangular central field occupied with the digital reconstruction encompassed by visual access to the immediate physical reality of the location. The smartglasses version was only tested among the participants in the development team. It is obvious that the stereoscopic effect of the two screen's double perspective, one for each eye, increased the experience of depth and distance in the digital representation, although the digital screens are not fully opaque; some parts of the real environment (the exhibition walls) are visible in the background. However, the size and weight of the device as well as its limited view does not make this platform a serious contender to smartphones and tablets, yet. This will obviously change soon as new models get lighter, smaller and better.

5. CONCLUSION AND FURTHER RESEARCH

We have seen that the use of Augmented Reality for reconstruction of past objects and environments, both for use outdoors on cultural heritage sites and inside in a museum exhibition, may have a great potential in Cultural Heritage communication. With technologies like ARKit and ARCore we have excellent solutions for indoor positioning and it is likely that this technology will be better integrated with GPS-based positioning so that increased position accuracy to a larger extent can also be achieved outdoors. We hope to continue experimentation with the cases discussed above as well as other sites and museums. It is particularly promising to experiment with applications where one can have free movement from the inside to the outside and vice versa. This will lay a new foundation for how to further explore the storytelling potential of augmented reality in Cultural Heritage settings by means of smartphones, tablets and smartglasses.

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REFERENCES

Cervenak, R. and Masek, P. (2019) "ARKit as indoor positioning system". Paper presented at the 11th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT). Available at https://ieeexplore.ieee.org/abstract/document/8970761, visited January 14 2020.

Hammady, R., Ma, M., Strathern, C. et al. (2019) "Design and development of a spatial mixed reality touring guide to the Egyptian museum". Multimedia Tools and Applications. An International Journal, pp 1-30. https://doi.org/10.1007/s11042-019-08026-w

Liestøl, G. (2009) "Augmented reality and digital genre design – situated simulations on the iPhone". Proceedings of ISMAR 2009 IEEE International Symposium on Mixed and Augmented Reality – Arts, Media and Humanities, 19–22 Oct, Washington: IEEE Computer Society, pp. 29–34.

Liestøl G. (2011) "Situated Simulations Between Virtual Reality and Mobile Augmented Reality: Designing a Narrative Space." In: Furht B. (eds) Handbook of Augmented Reality. Springer, New York, NY.

Liestøl, G. (2015) "Situated & Sensory Media between Centre & Periphery in Museum Mediation". Eds. Thwaites, H. et al. Proceedings of the 2014 International Conference on Virtual Systems and Multimedia (VSMM), 9-12 December 2014 Hong Kong. IEEE conference proceedings 2015 ISBN 9781479972272, pp. 247-250. DOI: 10.1109/VSMM.2014.7136658

Liestøl, G and Rasmussen, T. (2010) "In the Presence of the Past. A field trial evaluation of a situated simulation design reconstructing a viking burial scene" in Szücs, A. and Tait, A. W. (Eds.) Media Inspirations for Learning. Proceedings of EDEN 2010. Budapest: EDEN Secretariat, % Budapest University of Technology an Economics 2010, visited January 14 2020.

Liestøl, G., Rasmussen, T. and Stenarson, T. (2011) "Mobile Innovation: Designing & Evaluating Situated Simulations". in Digital Creativity 2011, Vol. 22, No. 3, pp. 172–184. Abingdon: Routledge, Taylor & Francis Group.

Lymberopoulos, D. and Liu, J. (2017) "The Microsoft Indoor Localization Competition: Experiences and Lessons Learned," in IEEE Signal Processing Magazine, vol. 34, no. 5, pp. 125-140, Sept. 2017. doi: 10.1109/MSP.2017.2713817 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8026207&isnumber=8026188, visited January 14 2020.

Madsen, J. B. and Madsen, C. B. (2013), "An interactive visualization of the past using a situated simulation approach". in A. C. Addison, G. Guidi, L. De Luca and S. Pescarin (eds), Proceedings of the 2013 Digital Heritage International Congress, vol. 1, Washington: IEEE Computer Society, pp. 307–14.

Schwartz, L. F. (1988) "The Staging of Leonardo's Last Supper: A Computer-Based Exploration of its Perspective" in Leonardo Vol. 21, Supplement 1988, pp. 89–96. Cambridge, MIT Press.

Small, J. P. (2019) "Circling Round Vitruvius, Linear Perspective, and the Design of Roman Wall painting", in Arts 2019, 8, 118, pp. 1-28.

Vlahakis, V., Karigiannis, J., Tsotros, M., Gounaris, M., Almeida, L., Stricker, D., Gleue, T., Christou, I., Carlucci, R. and Ioannidis, N. (2001), "ARCHEOGUIDE: First results of an augmented reality, mobile computing system in cultural heritage sites". Virtual Reality, Archaeology, and Cultural Heritage International Symposium (VAST01), Glyfada, Nr Athens, 28–30 November.

Wither, J., Tsai, Y.-T. & Azuma, R. (2011) "Indirect Augmented Reality", in Computers & Graphics 35, pp. 810–822.

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