Long Paper

Possibilities and Requirements for Augmented Reality Applications in a Complex Heritage Landscape

An Analysis from a Technician's and a Curator's Perspective

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Abstract: The digital transformation changes the way the public perceives and interacts with cultural heritage in the museum and beyond. Augmented Reality can be away to address this challenge and to develop new ways to convey information raise awareness and facilitate appreciation of cultural heritage. Application Areas for Augmented Reality (AR) continue to expand and also museums and administered heritage sites are increasingly discovering the opportunities of this technology. This poses challenges for the curator or the management, as they must grasp the technical possibilities and decide with their professional expertise where and how they can arouse interest in the visitor and impart knowledge. Therefore, different factors and requirements from a technician's and a curator's perspective arise, which will be analyzed and evaluated in this paper. From the technical side, questions on the tracking method, and device policy have to be made. Especially in connection with in-situ preserved heritage outdoors, marker-based positioning is not ideal. In this case, photogrammetric and videogrammetric models of the heritage object can be used for the tracking and positioning of augmented reality-content. This contribution aims to provide assistance and impulses for AR Applications. Based on this, an AR use case for the UNESCO world heritage Orkhon Valley in Mongolia will be presented, explaining advantages, difficulties and the employed software and workflow.

Keywords: *Museum—Augmented Reality—Videogrammetry—Orkhon Valley—Mongolia—Kharakhorum*

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1. Motivation and Introduction

The Orkhon Valley in Mongolia has been a cradle of important nomad polities such as the Great Mongol Empire. Not only the Mongol Empire had its capital in the first half of the 13th century – Karakorum (Hüttel, 2016) – in this area, but also during the times of earlier steppe empires, such as the Xiongnu, Gökturk and Uyghur, the Orkhon Valley was a focal point in the itinerary of the court of the nomad rulers. The landscape of the Valley is dotted with the archaeological traces of these times. Important sites, such as deserted cities, smaller settlements, burial mounds, memorial complexes, and the like (Bemmann et al., 2011). In the tradition of the nomads of the steppe, the whole area around the Orkhon was a sacred landscape, the possession of which provided the legitimacy to rule over the steppe (Allsen 1996, pp.124–128). It is thereby well justified, that the whole landscape of the Orkhon Valley is inscribed as an important heritage of mankind in UNESCO's world heritage list[1].

The research on the sites of the Orkhon Valley began in the late 19th century and was conducted by Russian, Soviet and Mongolian researchers during the 20th century (Becker, 2007). After the fall of the iron curtain, interest in research on these sites widened and international expeditions together with Mongolian scholars contributed to the improving of knowledge about the Orkhon Valley and its archaeological and historic sites. The Mongolian-German Karakorum-Expedition (Mongolian Academy of Sciences, University of Bonn, German Archaeological Institute) started work in 2000 and focused on the site of Mongol Karakorum. In 2007 the Mongolian-German Orkhon-Expedition was launched to explore the site of the ancient Uyghur capital Karabalgasun (ca. 745–840) and its surroundings (Franken et al., 2020).

The decades of research have yielded a rich knowledge about the sites, their history and the archaeological landscape of the area. In 2011, a museum was opened with support by Japan, to present the findings to the public. However, the presentation in a museum has limitations, as the archaeological heritage of the Orkhon valley is extremely rich but widely dispersed. One of the specialties of the region is, that, due to the sparse settlement and the extensive and gentle land-use by the Mongolian herders, the archaeological sites are generally well preserved in-situ and invite the visitors to explore the heritage. The evolving possibilities of Augmented Reality (AR) applications combined with the availability of cheap, yet powerful handheld devices allow to explore new ways to convey the deep history and archaeological richness of the Orkhon Valley in the museum and right in the landscape, at the sites themselves. However, this is a non-trivial task and the prerequisites and demands have to be considered carefully from the technical and also the curator's side.

This article describes central aspects of a curatorial and technical requirement analysis related to museum AR applications and defines decision criteria with which museums can evaluate the use of AR applications for their exhibitions (see section 3). Before that, basic terminology and theories on the research subjects AR and museums are explained in section 2, which contribute to the further understanding of the article. Finally, a practical consideration and a prototype of a specific AR application in the UNESCO World Heritage Site Orkhon Valley are presented in chapter 4.

2. Theory and Related Work

Next to classes of AR devices and tracking techniques, methods are named that contribute to making AR applications more robust, more real-time capable and more immersive. With regard to the creation of 3D models and their further use in AR applications, photogrammetry and videogrammetry are briefly discussed. Museums are viewed from the perspective of a society that has changed in the course of digital change. This gives rise to challenges that museums must face in order to continue to serve the task of acting as places of education and the mediation of the heritage of mankind and its environment.

[1] UNESCO (2004). Decisions Adopted at the 28th Session of the World Heritage Committee: Suzhou. http://whc.unesco.org/archive/2004/whc04-28com-26e.pdf

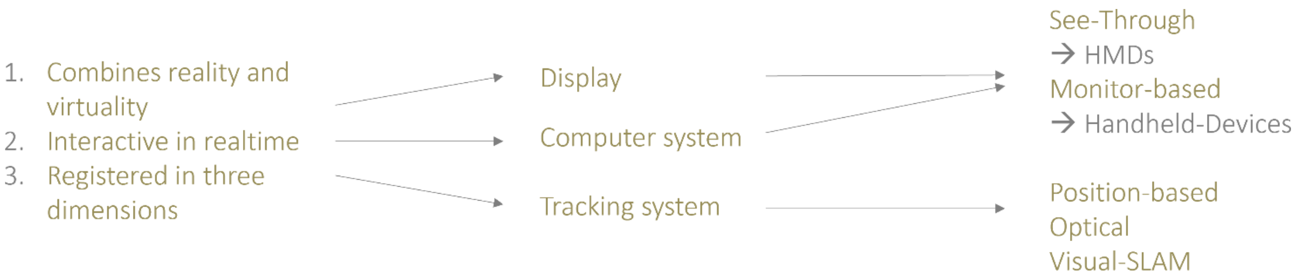

Fig. 1. Defining AR-Systems. According to Azuma (1997), an AR-System has the three characteristics listed on the left-hand side. From these, the components in the middle can be derived (Billinghurst, Clark and Lee, 2015). Milgram, Takemura et al. (1995) categorized them as indicated on the right. (© Lukas Suthe).

2.1 Augment Reality Systems

Representations of reality can be virtually replaced or supplemented with the help of computer-based technologies. One of these technologies is AR, which is increasingly finding its way into our society. Azuma (1997) describes it as follows:

„AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space.“ (Azuma, 1997).

Behind AR experiences or applications are AR systems that differ from each other in certain ways. These are defined and categorized in Figure 1.

Mobile devices combine all three components, which is why AR systems essentially differ in the choice of the AR device and the tracking method, which uses the available sensors as a tracking system. Head mounted displays (HMDs, “AR glasses”) allow AR to be perceived most immersively due to the constant positional relationship between camera and viewer (Dörner et al., 2019), but are still more expensive and not as readily available as smartphones or tablets, which thus have the widest range of applications for AR.

The tracking system ensures the location of the virtual objects in the real world. In an initial registration phase, the position and orientation of the camera or the viewer’s eyes are determined via real anchor points, which are then continuously updated in a subsequent tracking phase. For this article, the markerless model-based tracking method is of relevance, which uses natural feature detection and description algorithms such as SURF (Bay, Tuytelaars, and Gool, 2006), ORB (Rublee et al., 2011), or BRISK (Leutenegger, Chli, and Siegwart, 2011) that detect particular features in the images captured by the camera. At the same time, the AR system has 2D or 3D models of real, size-known objects in the environment that serve as anchors and to which the detected features can be assigned, usually after running a RANSAC procedure (Fischler and Bolles, 1981) to sort out outliers. The further mathematical procedure for camera position and orientation determination and calibration is described for example in Zhang (2000).

Other notable tracking methods are position-based tracking methods that use signals from global navigation satellite systems (GNSS) as anchors, marker-based optical tracking methods that use predefined markers placed in the real environment that are easy for the camera to recognize as anchors, or SLAM techniques (Simultaneous Localization and Mapping) that are capable of creating a map of a completely unknown environment and localizing the sensor used for spatial detection in it.

Another crucial factor for a believable and robust AR experience is the choice of appropriate virtual content, as mobile AR devices have limited computing power, making it inevitable to choose virtual content that continues to ensure real-time, fluid rendering of the AR scene.

2.2 Photo- and Videogrammetry

In recent years, photogrammetry has become more and more established in the everyday documentation of archaeological campaigns on the basis of Structure-from-Motion (SfM) (Luo et al., 2019). Videogrammetry has also been used to some extent in documentation campaigns (Rashidi et al., 2013). Videogrammetry can be seen as an extension of photogrammetry, in which an intelligent image selection is used to extract a set of single images from a video. Various algorithms are available for this task, which have been field of real-time robotics that attempt to solve the min-max problem (Ahmed, 2010).

A very active research focus in this context uses Structure-from-Motion (SfM) and pursues Simultaneous Location and Mapping (SLAM) solutions to localize themselves in self-generated maps or 3D models of an environmental situation. The approach of capturing and processing videos instead of photos has a number of advantages and disadvantages. In our experience with recording data while moving, videogrammetry is the more fault-tolerant, more cost-effective and easier-to-use approach. The software "JKeyFramer", an automatic key frame selection tool, was one of the most important outcomes of the project "Archaeocopter"[2]. This technique was first used during the campaign in Tamtoc/Mexico 2013 (Block et. al., 2015). The biggest disadvantage is certainly the fact that the extracted single photos usually do not have geotags and thus an automatic georeferencing is not easily possible. However, this disadvantage can be solved satisfactorily in combination with pure photogrammetry.

2.3 A Changing Society and an Adapting Museum

A museum is an institution serving and open to the public, which manages the heritage of humanity and its environment for the purposes or goals of education, study and enjoyment[3]. To remain a relevant place of education for the society of the present and the future[4] there are challenges to overcome. One of them is to inspire young generations and individual target groups for the institution of the museum. To achieve this, the museum must be adapted to the needs of contemporary society and the museum's educational target groups. Needs of digital natives and Generation Z, or more specifically the learners of the 21st century, are entertainment, interactivity, own participation and the manipulation of things (Elmqaddem, 2019). Often Museums do not yet meet these conditions. Although the overall statistical survey of museums in Germany for 2017 (Institut für Museumsforschung, 2018) shows that digital media are used more frequently, they are far from being available in all museums. In comparison, the most common sources of information for visitors in the museum continue to be traditional display boards and texts. A intensified digital transformation of the museum, i.e. imparting formats, represents an opportunity to adapt to the mentioned changing needs. The curatorial relevance of digital applications is often recognized, but the current tight museum budgets

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[2] Archaeocopter. http://www.archaeocopter.de

[3] ICOM (2007). Museum Definition: https://icom.museum/en/resources/standards-guidelines/museum-definition/

[4] Deutscher Museumsbund e.V. und Bundesverband Museumspädagogik e.V. (2020). Vision. Bildungsort Museum. https://www.museumsbund.de/wp-content/uploads/2020/10/bildungsvision.pdf

often make it impossible to implement important projects for the digital transformation (Kohle, 2018). Therefore, well thought-out, affordable concepts and innovative technologies are needed to enable as many museums as possible to take advantage of digitization.

3 Museums and Heritage Landscapes as an Application Area for Augmented Reality

AR can be seen as a supportive tool for fulfilling the museum’s educational mission in the age of digital change. The museum’s educational formats, which are enhanced by AR applications, adapt to the needs of a digitally influenced society and offer many opportunities to support sustainable knowledge transfer.

Thereby, AR systems and their applications can be designed differently, as shown earlier, in terms of the choice of the AR device with its available sensors and the tracking system. In addition, the development of an AR application is dependent on basic conditions, requirements and needs of the respective location, if this is defined. In terms of museums as an application area for AR, this means analyzing the curatorial and technical requirements and factors of a museum with its planned AR scenarios.

3.1 Curatorial Requirements

The curator is responsible for the integration and the design of the exhibition with AR as a means of digital change. He must consider and weigh up the curatorial aspects and the technical requirements and development possibilities. A user-friendly, attractive, and suitable AR application from a museum perspective can only be developed in a dialog between these two requirements. Therefore, pedagogical, didactic, and scientific aspects must be included in the decision-making and development process.

The use of computer-based visualizations for the management of archaeological heritage must be treated as a complementary, not a substitute, tool to other, more traditional but equally effective tools (ICOMOS, 2017). Considering this principle and the definition for augmented reality (see section 2.1), which states that AR does not completely replace the real world, but only complements it with virtual objects, it is striking that AR is exactly such a complementary tool and should be used as such. Another factor is the effort involved in modifying an exhibition to be enriched with AR. From a curatorial point of view, changes and effort should be kept to a minimum, since AR should primarily serve museology and museology should not serve AR. Computer-based visualizations, in this case AR, should also normally only be used when it is the most appropriate tool available to achieve a museum’s goal (London Charter, 2009).

Taking this into account, AR can be ideally used, for example, with incompletely preserved exhibits that can be presented to the visitor again in their entirety in this way, for recontextualization or for direct interaction with the real exhibit, which would not be possible in reality for conservation, ethical or physical reasons. The connection of information and virtual visualizations to the real existing objects, which is important for the visitor to understand, can thus be generated, whereby the museum‘s object shouldn‘t be shifted out of focus.

AR is used interactively by the user, increases the attention that is important for the absorption of information, and contributes to the fact that the museum visit is evaluated as an experience, thereby increasing the chance or intention to visit the museum again (Jung and Dieck, 2017). Besides, AR always involves an interplay between entertainment and knowledge transfer, whereby from a curatorial perspective it must be questioned how high the degree of immersion and thus the development effort for an AR scene must be to do justice to the task of truthful knowledge transfer and to fulfil this attractively. Robustness and real-time capability should thus take precedence over high immersion and realism. It must also be taken into account that only truthful information is reproduced and that the AR scene is not enriched with false information for the benefit of entertainment purposes.

The same applies to the 3D content presented in an AR scene, especially for 3D reconstructions. Increasing realism harbors a danger there in particular, as it increases the potential to evoke authenticity and thus misinformation (Hageneuer, 2020). Reconstructions function as a visualized theory that, when miscommunicated in development and use, creates a fictional reality of historical reality (Quick, 2020).

3.2 Technical Requirements

The technical analysis discusses four aspects which influence the decision-making process as well as the selection and development of the AR application significantly: The choice of the AR system, the choice of the tracking method, location-based factors and illumination concepts.

When choosing AR systems, there are advantages and disadvantages of using museum-owned and visitor-owned devices as well as the hybrid form, where both device strategies are combined (see Figure 2). The choice of one of these three device strategies depends in part on a museum's financial resources. Since many visitors own and carry their own AR-enabled devices, the visitor-owned device strategy is advantageous for museums in terms of acquisition costs.

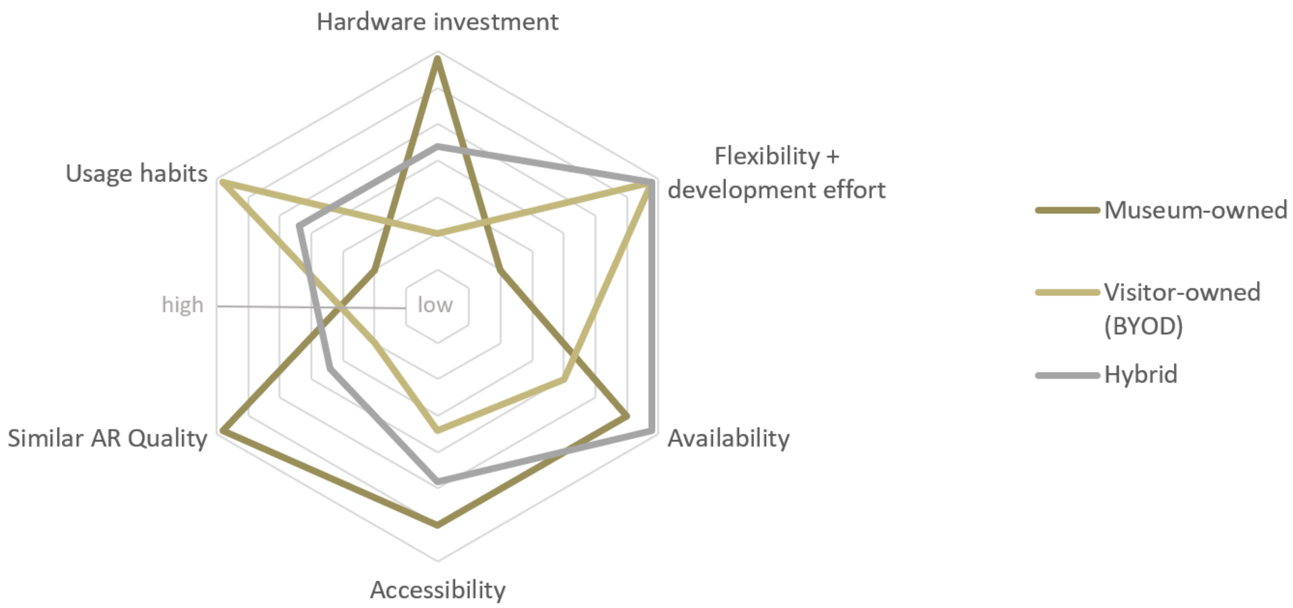

Fig. 2. AR device strategy: Comparison and contrast of the three AR device strategies with each other based on six selection criteria. Hardware investment considers the cost of acquiring devices and setting up the usage infrastructure. The more different end devices are included, the higher the development effort, but also the flexibility of the AR application. Availability says something about how many visitors could have access to the AR application. Accessibility describes how quickly and easily users can start the AR-supported museum visit on average. Different powerful and equipped end devices cause differences in the quality of the AR. The criterion usage habits takes into account the comfort of the familiar operation of a private device carried along. The weighting of the criteria is not always to be considered equally strong and depends partly on the available resources and capacities of the museum. available resources and capacities of the museum. (© Lukas Suthe).

The advantage of the museum-owned device strategy is, among other things, easier application development. Both strategies have disadvantages that can be partially offset with the hybrid device strategy, as far as the visitor is strongly encouraged to use his own device if possible. Each museum must weigh the advantages and disadvantages of each device strategy in the context of its individual resources and available capacities.

Other important factors that contribute to a significantly higher sense of reality and more plausibility in an AR experience are the correct illumination of the virtual content and the correct mutual super-imposition or occlusion of real and virtual objects in the AR scene. If both are taken into account, the degree of immersion for the user is increased here as well.

When it comes to selecting a suitable tracking method, this depends heavily on the particular museum AR scenario and the environment in which it is to be located, and is thus difficult to summarize in this article, which is why it is omitted here. Nevertheless, from a technological point of view, it represents a decisive factor.

Regarding location-based factors, AR represents a virtual extension of the use of the available real space. That´s why an environmental analysis is required, to check which real objects must be integrated, how occlusion will behave and what changes the environment is subject to and would influence the AR experience.

The illumination of museums or museum objects is often steady to the advantage of the AR Scene, as the virtual lighting concept can then be adapted to the real one. If the lighting is changing, illumination analysis and light estimation will become necessary, in order to maintain a believable and immersive AR experience.

4 Experiments and Results

Based on the discussed decision criteria, a potential AR application in the UNESCO World Heritage Site Orkhon Valley is examined as an example, regarding the choice of the tracking method and the choice of the AR system. Further, a workflow is shown for similar AR use cases.

4.1 The Tortoise and the Inscription Stele

For a case study, different scenarios for AR-applications in the Orkhon Valley have been developed. One of this will be presented here. Within the ruins of the ancient city of Karakorum stands a large, finely carved sculpture of a tortoise made of granite (Figure 3). It is situated in front of the remains of the “Great Hall of Karakorum”, a large Buddhist temple and state sanctuary of the Mongol Empire (Franken, 2015). The building was erected during the rule of Möngke Khan (r. 1251–1259) and refurbished several times in the century after. The stone tortoise most likely served as the foundation for an inscription stele commemorating the foundation of Karakorum by Genghis Khan and the building and refurbishing of the temple. The stele itself was destroyed, but several pieces have been recovered, used as spolia in the buildings of the Monastery Erdene zuu, which today occupies the site of the former palace of Karakorum (Hüttel, 2009, pp. 538–548). However, the text of the inscription was preserved in Chinese written sources and on the recovered fragments (Cleaves, 1952). The inscription is one of the most important sources for the understanding of the site and the tortoise is integral part of this heritage. However, most visitors see the tortoise mainly as an ancient piece of art to admire, because they lack the information on its significance and context. An AR-application provides a mean to the researchers and curators to contextualize the stone tortoise with the knowledge about the inscription stele and the history of the monumental temple. Such an application can give the wider public access to the research results and lead to a greater understanding and appreciation of the heritage site.

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Fig. 3. The original stone tortoise in the Orkhon Valley, on which once stood an inscription stele, which described the construction of the city of Kharakhorum and its great temple. It is no longer preserved and only fragments were excavated. (© T. Batbayar).

Fig. 4. On the right is the high-poly model from RealityCapture with around 12 Million vertices and 1.9 GB in file size and on the left the AR-compatible low-poly model with only ten thousand vertices and 1.7 MB in file size (here without the color texture). Both, the vertice count and the file size could be significantly reduced. (© High-poly model: Marco Block-Berlitz/DAI; Low-poly model: Lukas Suthe/DAI).

The situation of the Kharakhorum Museum with the widely distributed open-air historic sites like the stone tortoise around it speak in favour of the usage of the users' own devices. The hybrid strategy with a small range of museum-owned devices is also conceivable for use in the main museum building. In regard to location-based factors, the application "tortoise and inscription stele", where the aim is to clarify the volume and the shape of the stele to the user by a virtual reconstruction on its back, has good AR conditions due to its relatively free position and unimpeded access (as of May 2021). Since the scene is outdoors, light estimation is beneficial to make the AR experience even more immersive and believable. At the choice of the tracking technique, markerless-model-based tracking is justified as a suitable method. However, temporary alterations to the tortoise due to continued use as a sacrificial site or plant growth could be problematic.

4.2 Augmented Reality Assets using Videogrammetry

Videogrammetry and photogrammetry are excellent technologies to create precise 3D models for AR, either to place them as virtual objects in the AR scene or to use them as tracking anchors. Especially for markerless-model-based tracking techniques, it is crucial to have a preferably identical 3D model of the desired anchor.

In the case of the previously described application, videogrammetry was chosen and it was sufficient to extract keyframes out of a simple smartphone recorded video. With these keyframes, a 3D model[5] could be calculated, using the software *RealityCapture*[6]. Using the right input material, these 3D scans are mostly made of an over-dense polygon mesh and are not directly suitable for AR, especially mobile AR. To achieve AR-capability, unrelevant parts of the generated high-poly model were removed and the mesh was completely remeshed and cleaned up. To ensure that the high level of detail is not lost but the number of polygons can still be significantly reduced, normal baking was applied, to have a low-poly model and a detailed normal map as a result (see Figure 4). For this step, the open-source 3D software *Blender*[7] was used. The original 3D model is available online at the object database idai.objects[8] of the German Archaeological Institute.

[5] https://arachne.dainst.org/entity/7084504

[6] https://www.capturingreality.com/

[7] https://www.blender.org/

[8] https://arachne.dainst.org/

4.3 Adding Augmented Reality Functionality

The app development was done in the cross-platform game engine Unity, which is compatible with various AR SDKs (Software Development Kits) and offers easy, simultaneous development for at least iOS and Android. The core functionality, the desired model-based markerless tracking, is provided by the *Vuforia-SDK*[9]. Therefore, a model-target, in this case the AR-optimized tortoise model, has to be generated and added with the *Vuforia Model Target Generator*[10].

Fig. 5. Screenshot of the experimental version of the AR application for the use case: "Tortoise and inscription stele". Next to the pure visualization of the stele, the user shall also have access to text overlays and a translator function to read the inscription. (© Lukas Suthe).

Fig. 6. Result of the tracking test. Despite various changes on the turtle, it stays easily identifiable as a 3D anchor every time and the tracking remains stable. The first changes were ribbons around its neck (left), the next color changes (middle) and strong direct light, representing the sun (right). (© Lukas Suthe).

[9] https://developer.vuforia.com/downloads/SDK

[10] https://developer.vuforia.com/downloads/tool

4.4 Prototype and Checking Detected Challenges

Until now it was not possible to develop, test and evaluate the application directly on site in Mongolia, which is crucial especially with this location-based AR, so the local conditions were simulated and an available much smaller turtle model was used as a prototype (see Figure 5).

It was tested whether the result of the theoretical analysis also confirmed in practice or whether the tracking despite changes remains stable on the tortoise. This can be confirmed in the evaluation (see Figure 6). Both the analysis and the experimental implementation help to plan a real implementation on site and create a basis for it.

5. Conclusion and Future work

Overall, it is shown that AR can meet the needs of the digital generation and can therefore be a suitable tool for achieving museum educational goals. Dealing with the topic of museum AR applications ultimately requires an interdisciplinary analysis for each museum in order to be able to individually weight the decision-making criteria for AR applications based on the technical quality, the educational mandate and the given resources.

Not only in relation to the UNESCO World Heritage Orkhon Valley, but also to other heritage landscapes and museums, it should be noted that the presented workflow can be applied to other sites of this culturally and historically rich landscape in and around Kharakhorum to bring them together in an all-encompassing AR application, which helps to convey its deep history and archaeological richness.

As an outlook, it should be added that, in addition to curatorial and technical requirements, user feedback and evaluations through usage tests and the like should also be taken into account to an even greater extent and incorporated into the development process at an early stage, but this article limits itself to the curator´s and technician´s point of view.

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