Applications of Augmented and Virtual Reality at Museums and Archaeological Parks to Improve Sustainability

by

Nikolay Sargsyan

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Approved by

Cheryl D. Seals, Chair, Professor and Chair of Computer Science and Software Engineering
Hari Narayanan, John H. and Gail Watson Professor and Chair of Computer Science and Software Engineering
Gerry Dozier, Professor of Computer Science and Software Engineering
Jakita O. Thomas, Philpott-WestPoint Stevens Associate Professor of Computer Science and Software Engineering
Alex Benitez, Director, Moundville Archaeological Park

Abstract

Augmented and Virtual Reality are relatively novel technologies that have gained popularity during the past decade. Virtual Reality allows one to be immersed in virtual worlds, while Augmented Reality combines virtual and real worlds in a see through device, e.g. a camera-enabled smartphone. Today Augmented and Virtual Reality technologies are widely researched and applied in various fields, including non-conventional and informal educational settings.

Museums are locations renowned for informal education. Keeping a museum up-to-date with the advancement of multimedia technologies is beneficial for both museums and visitors. Improved interactivity and better informational systems installed at a museum can improve visitor experience and learning. As such, visitor attendance may be increased and on-site behaviour affected positively, growing museum sustainability.

This research discusses the effect of gamified Augmented and Virtual Reality museum experiences on museum sustainability via a case study at the Moundville Archaeological Park. The prospects of monetizing gamified Augmented and Virtual Reality museum experiences are explored. The effects of gamified Augmented and Virtual Reality museum experiences on visitors' educational, entertainment, esthetic, and recreational experiences are explored. The perception of of gamified Augmented and Virtual Reality museum experiences by the museum internal and external stakeholders is explored.

Additionally, this research discusses a case study at the Jule Collins Museum of Fine Art illustrating the applicability of utilizing Augmented Reality headset camera to analyze museum visitor experience as a substitute to more conventional but significantly more expensive specialized eye-tracking headsets.

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Chapter 1

Introduction

1.1 Museum as an Informal Learning Environment and Museum Sustainability

In his fundamental work *Learning in the Museum*, George E. Hein defines informal learning in museums as self-directed learning taking place in a museum environment contrary to curriculum-based learning taking place in classrooms [44]. He identifies four educational methods that happen in a museum: didactic, or expository education, stimulus-response education, discovery learning, and constructivism. Didactic and stimulus-response methods are focused on providing prepared, sequential information to the learner. Didactic method underlines the ”true” nature of the received knowledge while stimulus-response method leaves the interpretation open. Museums providing didactic, expository, and stimulus-response educational settings feature sequential, labeled exhibitions. Discovery learning views learning as an active process where the learner interacts and explores the given material, with a ”true” interpretation being provided. Hence, museums providing discovery learning feature exhibitions that allow exploration and interaction with exhibits and workshops. Unlike discovery learning, the constructivist method accepts multitudes of conclusions and assumes even more interactive, explorative and engaging exhibitions present in the museum. George E. Hein sees the future of the museums in providing discovery and constructivist learning while stressing that, as different visitors have different learning habits, a museum must feature a diverse set of knowledge mediums to serve a broader audience.

Izabela Luiza Pop and Anca Borza in their work *Factors Influencing Museum Sustainability and Indicators for Museum Sustainability Measurement* present the evaluation of museum

functions. The traditional goal of collecting, preserving and researching exhibits is today replaced by the modern concept of knowledge and education delivery. Finally, the post-modern museum is a sustainable museum that adds educational and entertainment value, and is economically and commercially successful [82]. Nick Merriman identifies the museum sustainability dimensions as social sustainability, economic sustainability, and environmental sustainability. He stresses that a fully sustainable museum must fulfill all three dimensions [62]. Social sustainability can be interpreted as the value added to the society, such as informal and lifelong learning environments [82]. Economic sustainability is the financial stability of a museum. Environmental sustainability can be disclosed as the contribution of a museum to the overall preservation of the environment, be it preserving artifacts and landscapes, using renewable power sources, decreasing air pollution, or similar [62].

Katja Lindqvist defines the museum stakeholders as *"as groups and actors that influence or depend on the decisions of museums [and] include owners, governments, grant givers, visitors/customers, the general public, donors, friend associations, sponsors, and providers of services and goods used by the museum"* [55]. In the current work, we will identify the members of museum staff and administration, regardless of their job origin, as internal stakeholders, and all kinds of visitors and the general public as the external stakeholders.

1.2 Augmented and Virtual Reality

The first Augmented and Virtual Reality system was created by Ivan E. Sutherland in the 1968 [99]. It was in the form of a headset supported by a mechanical stand. It could show only primitive wireframes due to low computational power available at the time.

The term "Virtual Reality (VR)" started to appear in different theoretical research from the beginning of the 20th century, and was first extensively researched by Jaron Lanier [53]. Henry Fuchs and Gary Bishop define Virtual Reality as *"Real-time interactive graphics with three-dimensional models, combined with a display technology that gives the user the immersion in the model world and direct manipulation"* [29].

The term "Augmented Reality (AR)" was first coined by P. C. Thomas and W. M. David in 1992 [101]. Klopfer, et al. define Augmented Reality as a technology *in which a real world*

context is dynamically overlaid with coherent location or context sensitive virtual information, and that *provides users technology-mediated immersive experiences in which real and virtual worlds are blended* [48] [49] [50].

1.2.1 Technology Overview

Both Augmented and Virtual Reality devices perform position tracking based on the Inertial Measurement Unit (IMU) data and the mapping of the real-world environment through one or multiple cameras. Some devices also utilize external infrared stations to increase the tracking precision.

Following techniques are being used in Augmented Reality to annotate the real-world objects with virtual data:

- *Location-Based*. With this technique, the AR content is triggered based on the user's physical location. The location tracking can be performed via GPS or indoor location tracking systems such as Bluetooth beacons, e.g. this approach is used in the notorious Pokemon Go game [71].

- *Markers-Based*. Here, predefined visual markers are being used to trigger the AR content.

  - A QR code, or a barcode, or an equivalent can be used as a marker.
  - Natural Feature Tracking (NFT) can be used to turn any 2D image with enough detail into a marker.
  - Image classifiers can be used to recognize objects.

  Virtual data may be strictly anchored to the marker, or the marker can serve just as a trigger.

- *Markerless*. With this approach, virtual content is either anchored to a plane (e.g. tabletop or a floor) or does not have an anchor and can be moved around freely. Applications using NFT can also be considered markerless as they may not require a specific marker to be used and therefore may provide a more natural flow of interaction.

Today, many different consumer devices exist for Virtual Reality experience.

Modern smartphone devices have enough computational power and sensory precision to run VR applications. They can be used both standalone and as VR headsets when paired with devices like Google Cardboard [36], Merge Cube Glasses [61], or Samsung Gear VR [91]. These kind of devices rely on either the user tapping the smartphone screen or tracking the user gaze direction as a means of interaction, but can also be paired with different controllers.

Another type of devices are VR headsets that must be paired with a computer. They also optionally utilize external tracking stations for precise room-scale tracking. Examples of such devices that are in a different price range and with different levels of tracking and interaction quality are Oculus Rift [76] and devices of the HTC Vive series [110], with HTC Vive series being both more advanced and expensive.

Finally, standalone VR headsets exist such as Oculus Go [74] that has a very basic level of immersion and interaction, and Oculus Quest 2 [75] that provides a fully immersive experience. These devices utilize different types of handheld controllers for interaction. 3rd party hardware such as Leap Motion by Ultraleap [105] is capable of recognizing hand gestures and can be paired with a VR headset to allow a more natural interaction. Currently, the Oculus Quest 2 is the only consumer VR headset that supports hand gesture interaction without 3rd party hardware.

AR headsets can be divided into two categories: smartglasses and Mixed Reality headsets.

Smartglasses do not provide a fully immersive Augmented Reality experience. Rather, they offer users an efficient medium for instant access to information without the need to interact with physical media, and are also capable of annotating real-world objects with virtual data. Smartglasses utilize voice commands and a built-in touchpad as a means of interaction; some can be paired with a smartphone wirelessly. Examples of smartglasses are the Google Glass [35] and the Epson Moverio smartglasses series [66] that are made for mainly corporate usage, and consumer-oriented Vuzix [111] and North [73] series smartglasses.

Mixed Reality headsets, as the name implies, provide full immersion, ”mixing” the real and virtual worlds. Mixed Reality interaction is more natural and combines hand gestures with

voice commands. Currently, only the Hololens series by Microsoft [63] and Magic Leap [58] Mixed Reality headsets exist and are mainly targeting developers and corporate users.

For regular users, smartphones are the main device to get an Augmented Reality experience. With the camera being enabled, smartphones can be used as handheld see-through devices. The computational power of contemporary smartphones allows for camera and sensory tracking and runtime feature recognition. The interaction patterns are the same as with regular smartphone applications, although gaze direction can also be used as a means of interaction. Solutions that allow users to turn their smartphones into an AR headset also exist, but they did not gain much popularity due to limited functionality [6] [61].

1.2.2 Augmented and Virtual Reality in Museums

Shaorong Tu identifies the trends of Augmented and Virtual Reality in museums as the reproduction of cultural heritage and storytelling [104]. Panayiotis Kyriakou and Sorin Hermon state that *"using Augmented Reality, we can bring the digital entity into the physical space of the museum and therefore to have a virtual museum in a physical museum"* [52].

In her overview of applications of Augmented Reality in the museums, Mandy Ding highlights the value that an AR smartphone-based application can add to an art or a natural history museum. She indicates that AR apps *invite visitors to step inside the artworks by themselves* and *provide great opportunities for these types of museums to bring still works to life and ignite visitors' imaginations* [23]. She lists the development costs, lack of strong internet connection and lack of proper advertisement for museum AR apps as existing issues for applying Augmented Reality to a museum exhibition.

Nilam Desai, in her analysis of existing applications of Augmented Reality for history recreation, stresses the capabilities of AR to recreate the broken and lost artifacts by either presenting those as virtual objects or augmenting existing exhibits with virtual components [19]. Discussing the possible applications of Augmented Reality in education, Steve Chi-Yin Yuen, Gallayanee Yaoyuneyong, and Erik Johnson underline the value of discovery-based learning and how it can be effectively implemented with Augmented Reality technologies. They specifically mention the applicability of discovery-based learning through interactive virtual overlays

in historic sites [114]. Exploring the possible applications of Augmented Reality in the tourism field, Anand Nayyar, et al. highlight that Augmented Reality has the potential to add another layer of entertainment to an attraction [69]. According to findings by Hyunae Lee, et al. [54], Timothy Jung, et al. [45], and Juno Rae and Lizzie Edwards [87], the above-said can also be stated for the Virtual Reality.

It is interesting to know how Augmented Reality contributes to the memorizing of information, hence contributing to learning and knowledge retention. Nickolas D. Macchiarella and Dennis A. Vincenzi arranged a study where presentation, video, AR and interactive AR approaches were compared when teaching undergraduate students about pump maintenance [57]. They discovered that students who learned with AR did not score significantly higher on the immediate-recall and long-retention-recall tests than students using traditional educational media, but their scores for both tests were closer than for other students, suggesting that utilizing AR contributed to knowledge retention. Phil Diegmann, et al., in their analysis of the benefits of Augmented Reality in education, list a set of case studies that also indicate better knowledge retention, including some case studies in museum environments [22]. In a series of experiments on informal learning using an AR app in a match exhibition, Peter Sommerauer and Oliver Müller also indicate that Augmented Reality positively affects short-term memory [96]. However, they found that utilizing AR is not necessarily more effective for long-term memory [97]. For a piece of knowledge to be transferred from the short-term memory storage to the long-term memory storage, it must be rehearsed, semantically organized and integrated with prior knowledge or experience. Peter Sommerauer and Oliver Müller assume that in their case the designed AR app had not supported any of these transfer mechanisms.

Eleanor Cranmer, et al. explore the effect of Augmented Reality on museum sustainability in a series of interviews with museum stakeholders [15] [16]. Regarding social sustainability, it was suggested that utilizing Augmented Reality technologies can add a new layer of learning and entertainment, increase visitor numbers, attract modern visitors and youth ensuring the longevity of the museum. For economic sustainability, the museum stakeholders identified the additional revenue from increased visitor numbers and from providing Augmented and Virtual Reality experiences as an additional service and increasing the time visitors may spend at the

museum hence increasing chances that the museum stores will be visited. The advantages of Augmented Reality for environmental sustainability can be expressed as the exhibit and site preservation by substituting real-world alteration and interaction with a virtual one. It also must be noted that Augmented Reality was viewed as a complement, not a substitute for the guided tours by the interviewed stakeholders. M. Claudia tom Dieck and Timothy Hyungsoo Jung conducted a similar set of interviews with museum stakeholders receiving similar results [21]. Notably, both young and senior visitors showed interest in using an Augmented Reality application as a museum guide. The research by M. Claudia tom Dieck and Timothy Hyungsoo Jung also exposed an interest by all of the stakeholders towards a gamified museum experience.

1.3 Gamification

The terms "gamification" and "serious games" had emerged in the second half of the 20th century and gained acclaim in the recent decade, but the phenomena itself predates historical record [70]. Deterding, et al. define gamification as *"the use of game design elements in non-game contexts"*, and serious games can be defined as *"games for purposes other than entertainment."* [20]. Under game elements, we understand a set of rules that player(s) and other game entities must follow, and a set of goals and objectives to achieve. The gamification often utilizes virtual game-like incentives such as achievement badges, coins, and others to encourage the player. In certain gamification scenarios, these virtual incentives can be exchanged for real-world values. Tara J. Brigham gives a different definition of gamification by stating that *Unlike a game, gamification is not a self-contained unit; it does not have a clear beginning, middle, and end. Gamification uses game-based elements and strategies to increase engagement, motivation, learning, and even solve problems* [13].

It is crucial to understand that an interactive AR or VR system present in a museum is not necessarily a gamified experience since it may lack game elements. Ioannis Paliokas and Stella Sylaiou in their review of gamified and serious game experiences in museums through 2009-2015 summarize that gamification increases the learning outcomes with the visitors and their sense of ownership regarding the museum artifacts but also complain that existing research fails to provide clear definitions and measures for the learning effect [80].

Based on the rule patterns defined by Damien Djaouti, Julian Alvarez, and Jean-Pierre Jessel [24], Ioannis Paliokas and Stella Sylaiou indicate that ”Move” and ”Select” patterns are the most widespread within museum gamified experiences, followed by the ”Manage” and ”Match” patterns, and with ”Destroy”, ”Shoot” and ”Random” patterns being rarely used.

The list of game rule patterns defined by Damien Djaouti, Julian Alvarez, and Jean-Pierre Jessel is: Avoid, Match, Destroy, Create, Manage, Move, Random, Select, Shoot, White.

In this work, we will use the terms ”gamification” and ”serious games” interchangeably as our approach merges both serious games and gamification.

1.4 Eye-Tracking and Visitor Experience Evaluation

As with any educational and entertainment product or service, it is crucial to evaluate the user experience and learning. For museums, the success has been traditionally measured in ticket sales and visitor interviews and reviews. The first systematic approach was introduced by the acclaimed museum consultant Beverly Serrell [94]. She researched the connection between the attention, or diligence, of the visitor, and their behavior patterns inside the museum, such as the time spent by each exhibit and the total stops at exhibits. Her research indicated that visitors taking longer stops at each exhibit also tend to take total more stops at the museum and receive better learning experience. Beverly Serrell's research spawned a set of similar research looking at different aspects of visitor attention and behavior relation and proving the direct correlation of the time spent at an exhibit, number of stops at all exhibits, and positive visitor experience and learning.

Previously, visitor behavior data was obtained by observing visitors and taking notes on their behavior. Currently, such observations can be performed with external and head-mounted cameras. Eye-tracking technologies have seen great advancement in the last decade. Head-mounted eye-tracking glasses have become much smaller and capable of standalone operation, which enables the technology to be applied in field studies. Specifically, eye-tracking technology can assist in measuring the time the visitor spent by a single exhibit and the pattern the visitor examines that exhibit with, as opposed to external cameras and visitor observations

where museum visit pattern can be easily derived, but determining the exhibit examination pattern by a visitor is challenging.

1.4.1 Technology Overview

Eye-tracking devices were developed to track the movement of the human eye, map it into the surrounding environment, thus providing the eye-sight direction data. Two types of eye movements are being studied with eye-tracking devices: *saccades*, the rapid movements of eyes, and *fixations*, when the human gaze is focused and relatively motionless. The processing of visual data by humans takes place during fixations. The sequence of saccades and fixations is named a saccadic eye movement [12].

Stationary eye-tracking devices exist that are usually used in laboratory settings. They are put along with the object under consideration in front of the experiment participant. For example, such a device can be attached to a computer screen to explore how the participant is viewing and interacting with a web site present on the screen. Regarding the field of museum science, wearable eye-tracking glasses are of more value, since they do not necessarily require a laboratory setting and provide museum visitors' point of view data. Today, such devices do not require a wired connection to a computer to be able to operate wirelessly or completely standalone. This provides more movement freedom to a visitor, which is a plus considering that one must not artificially limit a museum visitor's actions during a visitor study. Research on software solutions to allow eye-tracking with regular web cameras also exists, such as one by Kyle Krafka, et al. [51].

1.4.2 Eye-Tracking in Museums

Daniel Wessel, Eva Mayr, and Kristin Knipfer [113] summarize the following four main advantages of eye-tracking technology over visitor interviews, surveys, and external observation. Eye-tracking provides a possibility for *non-reactive measurements* while visitor surveys and

interviews may be reactive and opinionated. Unlike external observations, be it with or without using recording technologies, eye-tracking data is easier to *process statistically*. As eye-tracking is the record of visitors' point of view experience, it has more *data richness* and *data validity*.

Very limited research also exists on building museum guides where the information trigger is the visitor gazing on an exhibit [65] [102].

Albeit the existing research clearly proves the usability of the eye-tracking glasses for museum visitor experience and behavior evaluation, a set of limitations for this technology exists. The core limitation is the fact that eye fixations on a specific area do not necessarily indicate attention paid to that area. And vice versa, the visitor may pay attention to an object without focusing eyes on the object. This leads to the necessity of combining eye-tracking data with visitor interviews and surveys. Aga Bojko [12] suggests applying a retrospective protocol for general eye-tracking research since requiring the participant to comment on the actions during the experiment may affect participants' behavior and distort gathered data. Kira Eghbal-Azar and Thomas Widlok [26] suggest using visitor retrospective reporting with cues on visitor's actions as a method to gather additional insight that can support the analysis of the eye-tracking data, using the eye-tracking footage itself as a cue. Daniel Wessel, Eva Mayr, and Kristin Knipfer [113] utilized visitor exit interviews with no cues.

Another limitation to apply eye-tracking glasses at a museum or an archaeological park is the high prices for this technology. Eye-tracking glasses hardware alone can cost more than $10000 [28], and prices for data processing tools must also be considered. More affordable, static, non-wearable eye-tracking solutions also exist. Due to technological limitations, they are suitable for lab experiments, but not for use in the museums.

The issues with calibrating eye-tracking glasses in non-laboratory settings and the possible impact on the collected data accuracy must also be taken into consideration.

Using eye-tracking and head-mounted cameras in museums also raises ethical concerns because of possible privacy violations in case of intended or unintended malicious use of recorded materials.

Studying the visitor behavior patterns, exploring their learning and experience does not only assist evaluating the designed system, but also provides visitor personas.

1.4.3 Visitor Tracking in Museums with AR headsets

AR headsets can be used to gather and analyze the visitor experience by recognizing visitor patterns and measuring the attention towards exhibits. Hololens 2 by Microsoft [63] and Magic Leap One by MagicLeap [58] are the only available headsets that feature eye-tracking technologies. The eye-tracking in these devices is tuned specifically to map the user's gaze direction within the virtual world and is not readily suitable for real-world behavioral research purposes requiring custom setup and plugins [9] [46]. Unlike the eye-tracking headsets dedicated to behavior analysis that track the gaze of both eyes, Hololens 2 and Magic Leap One report only the estimated intersection of the gaze. The dynamic environment of a visitor traversing through a museum exhibition poses additional challenges for eye-tracking and can affect its accuracy since the eye-tracking works the best in calibrated static environments. The eye-tracking also comes with a price tag, e.g., the Lynx R-1 MR headset that is currently under development by Lynx [56] has reported a price drop of about $500 after the eye-tracking feature was removed [38].

With the current limitations of eye-tracking inside AR headsets, it is worth investigating the headset cameras' capability to track the visitor's attention. We will call this method "head-tracking". It must be mentioned, that both head-tracking and eye-tracking technologies are sometimes referred to as "gaze tracking" in literature and technology.

As human eyes have a significant level of independent mobility, human head and eye directions do not necessarily correlate [37].

Under natural conditions, the eye and head directions co-occur with fixation rather saccade movement of eyes, with head movement compensating eye saccades [25].

Bernard Marius 't Hart, et al. [59] note that it is wrong to assume the eye gaze is centered during fixation, although they measure eye and head direction deviation during observation tasks in natural settings small enough to consider the eye gaze "centered", but underline that the eye and head correlation highly depends on the actual environment.

Clara Schmitow, et al. [93] summarizes that eye and head directions are more likely to co-occur in horizontal planes while deviating in vertical planes, and rarely co-occur when the head is extremely rotated regarding to the body. They recap that head-mounted cameras can be used to infer attention direction.

Francis Quek, Roger Ehrich and Thurmon Lockhart [86] argue that eye and head direction deviation is more likely to occur in social environments, when human behavior is affected by socio-cultural habits and requirements. While in an observation task both the eye and head directions, and the eye direction and the body stance can be co-aligned.

Further, Ali S. Razavian, et al. [88] propose a machine-learning approach to automatically detect salient exhibits by measuring the time and location they appear in the footage recorded with a head-mounted display, thus measuring the time and attention paid to the exhibits by the visitor. A visitor was considered to have paid attention to an exhibit when it was focused on the central part of a video frame. A sequence of such frames was named a focus shot. The total length of focus shots for an exhibit was used to determine the attention level of the visitor for that exhibit.

1.5 Museum Visitor Personas

Personas are a generic representation of the potential users of a system. Defining and understanding personas helps to build more usable and useful systems.

John H. Falk identifies the following five museum visitor personas [27]. Explorers visit museums to satisfy their curiosity and generally have an interest in the field; they seek knowledge. Experience seekers, on the other hand, seek more pleasure than knowledge. Facilitators visit to support other people. Examples of facilitators are parents and teachers taking children to a museum. Professionals and hobbyists visit museums for a specific interest. Rechargers are hoping to relax and recharge their energy.

Eliséo Véron, and Martine Levasseur identify the following four exploration styles for museum visitors [109]. Ants closely view almost all exhibits and follow the defined path. Fish

still view most of the exhibits but does that from a distance without getting into detail. Butterflies view most of the exhibits but do that with no order and frequently changing direction. Grasshoppers closely view only specific exhibits and ignore most of the others.

[90] Maria Roussou, et al. performed research on visitor personas at Acropolis Museum, Greece and Cité de l'Espace, France, to develop personalized mobile app experiences for those museums. The teenage and young visitors were characterized as wishing for more interactivity and technology features, kids were characterized as finding the museum boring. Adults were viewed as enjoying the museum and willing to introduce it to a younger generation. Museum staff personas were characterized as willing to incorporate new technologies.

Stefano Mastandrea, Gabriella Bartoli, and Giuseppe Bove researched visitor personas in two different art museums and found that, while other motives for a visit may differ, visitors in both museums indicated *desire for cultural enrichment* and *to see the artworks in the original* [60]. Jens Keil, et al. suggest using different scenarios for different visitor personas [47]. Such, in their AR museum guide they have implemented two separate game experiences targeting child and adult personas.

1.6 Area of Research

Eleanor Cranmer, et al. illustrates that sustainability is indeed viewed as a benefit that Augmented and Virtual Reality can introduce to a museum [15] [16]. Hence, applying Augmented and Virtual Reality at a museum supports the statement by Izabela Luiza Pop and Anca Borza, as well as Nick Merriman [82] [62] that sustainability is the function of a post-modern museum. Although today there is a notable amount of research discussing applications of Augmented and Virtual Reality in museums and archaeological parks, there is no case-study research that directly explores Augmented and Virtual Reality technologies for museum and archaeological park sustainability.

For post-modern museum, George E. Hein has proposed that the museum of the future must promote discovery and constructivist learning [44]. Steve Chi-Yin Yuen, Gallayanee Yaoyuneyong, and Erik Johnson indicate that Augmented Reality provides such learning [114],

and a handful of case studies support this []. However, only few studies on Augmented and Virtual Reality applications in museums for better learning exist that actually assess the knowledge gain in comparison with the traditional method [97] [33].

Despite the listed benefits that AR and VR solutions add to museums, in 2017 just over 1% of all museum in the U.S. were considering to utilize smartphone-based AR systems, according to the research by Mandy Ding [23]. The vast majority of the research on applications of Augmented and Virtual Reality in museums and archaeological parks takes place in the European and Eastern countries.

The existing research on applying eye-tracking glasses and head-mounted cameras to analyze museum visitors' experience provides evidence that footage from a head-mounted camera can be used to track visitors' attention [2] [113] [30] [26] [68] [88]. However, the existing research does not specifically focus on the viewpoint of utilizing AR and MR headsets to track visitors' attention. The existing research also features issues such as the lack of an exhibition with diverse content and visitor exit surveys to verify results.

Taking into account these knowledge gaps, we seek to apply a set of Augmented and Virtual Reality solutions at the Moundville Archaeological Park, Alabama, and Jule Collins Smith Museum of Fine Arts, Alabama (Section 4.2) with the main focus on museum sustainability:

- *Museum and archaeological park sustainability.* As discussed by Izabela Luiza Pop and Anca Borza, and Nick Merriman, sustainability is the function of a post-modern museum [82] [62]. Eleanor Cranmer has provided a theretical justification for the sustainability benefit from Augmented and Virtual Reality [15] [16], and some of the research on applications of Augmented and Virtual Reality at museums support some of Eleanor Cranmer's findings REFERENCES_HERE for social and environmental sustainability. We propose to perform a deeper research on benefits of Augmented and Virtual Reality for social, economical and environmental sustainability.

  - *Social Sustainability.* We intend to perform a more in-depth research on the effects of Augmented and Virtual Reality to the visitor knowledge gain at the museum and its retention by comparing visitors AR/VR and traditional self-guided tours.

We intend to measure the entertainment and amusement value that Augmented and Virtual Reality brings to the site.

  - *Economical Sustainability.* We aim to explore the means that Augmented and Virtual Reality can financially benefit a museum by exploring AR and VR apps as a potential added service and the possibilities of an AR guide to redirect visitors to the museum store. We intend to measure the willingness to revisit the site by visitors who used AR/VR and traditional self-guided tours.
  - *Environmental Sustainability.* The perceived value of the applied Augmented and Virtual Reality solutions for the environmental sustainability will be measured through stakeholder surveys and interviews.

- *Applicability of head-tracking for museum visitor experience analysis.* We intend to evaluate the applicability of head-tracking the museum visitor experience using an AR headset in a diverse museum environment.

- *Framework of how to apply AR/VR technologies at an archaeological park.* As we expect to apply a set of Augmented and Virtual Reality solutions at the Moundville Archaeological Park, we intend to compile the received experience into a set of guidelines and practices providing a framework for applying Augmented and Virtual Reality at museums and archaeological parks.

1.7 Key Terms

- Virtual Reality (VR) – the computer-generated simulation of a three-dimensional environment that can be interacted with in a seemingly real way.

- Augmented Reality (AR) – a technology that superimposes a computer-generated multimedia on a user's view of the real world, thus providing a composite view.

- Mixed Reality (MR) – elaborate version of Augmented Reality. Physical and digital objects co-exist and interact, and user interaction is a hybrid of reality and virtual reality.

- Gamification – the application of typical elements of game playing (e.g. point scoring, competition with others, rules of play) to other areas of activity.
- Eye-Tracking – the recording and study of the movements of the eyes in following a visual stimulus, used as a diagnostic procedure or a means of evaluating and improving the visual presentation of information.
- Head-Tracking – the recording and study of the movements of the head in following a visual stimulus, used as a diagnostic procedure or a means of evaluating and improving the visual presentation of information.
- Exhibit Focus Shot – A frame in a video footage, where the exhibit is centered in the frame
- Internal Museum Stakeholders – museum staff and administration, regardless of job origin.
- External Museum Stakeholders – all kinds of museum visitors.
- Discovery-Based Learning – an educational method that views learning as an active process where the learner interacts with and explores the given material. In the current work, we will also understand constructivist learning under discovery-based learning for simplicity of the terminology.
- Museum Social Sustainability – can be interpreted as the value added to the society such as informal and lifelong learning environment, as well as the positive relations built with the museum stakeholders and the local community.
- Museum Economic Sustainability – the financial self-sustainability of the museum and its positive effect on the local economy.
- Museum Environmental Sustainability – the role of the museum in global environmental sustainability as well as sustaining the local environment: natural and historical landscapes, artifacts, etc.

- Museum Sustainability – combination of social, economic and environmental sustainability.

Chapter 2

Research Problem

2.1 Visitor Head-Tracking in Museums

We have introduced a set of limitations for the eye-tracking technology. The limitations concerning the visitor attention span at an exhibition are similar to those of head-tracking. A set of research illustrates the co-alignment of head and eye directions. Currently, eye-tracking technology is not widely affordable. The research on applying eye-tracking and head-tracking technology for museum visitor studies is limited to picture galleries.

It is feasible to research the possibility to gather insight into visitor experience in a diverse museum environment by utilizing the built-in camera of an AR headset lacking eye-tracking.

2.2 Applications of AR/VR to Improve Museum Sustainability

Augmented and Virtual Reality solutions can contribute to all three aspects of museum sustainability: social, economic, and environmental. Augmented and Virtual Reality perfectly fits the concept of the discovery-based museums.

The examination of the research and literature on the effect of Augmented and Virtual Reality for museum sustainability did not show any examples of case-study research that views the performed work from the standpoint of museum sustainability, or adequately covers all of the aspects of museum sustainability.

It is feasible to perform a more in-depth research on effect of Augmented and Virtual Reality applications on the three dimensions of museum sustainability.

2.2.1 Social Sustainability

Providing educational and recreational value is the core part of the social sustainability. There is almost no case study research that looks into the perceived value of the Augmented and Virtual Reality solutions by museum internal stakeholders.

2.2.2 Economic Sustainability

The increase of the museum revenue positively affects its economic sustainability. We failed to find a case study that researches the effect of Augmented and Virtual Reality solutions in museums on the Economic Sustainability of the museum. Only a few case studies discussed the possible increase in visitor numbers with no further implications.

2.2.3 Environmental Sustainability

The contribution of Augmented and Virtual Reality in this aspect of museum sustainability mainly falls in the domain of preserving the original artifacts and landscapes by substituting real-life alterations with virtual entities. We found no case studies discussing the contribution of Augmented and Virtual Reality to the environmental sustainability of museums.

Chapter 3

Literature Review

3.1 Visitor Tracking in Museums

The article search was performed with the following keywords: ”eye tracking”, ”camera tracking”, ”museum visitor experience”.

Al-Baddai, Saad, Barbara Ströhl, Elmar W. Lang, and Bernd Ludwig. ”Do Museum Visitors See what Educators Want Them to See?.” Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization. 2017. [2]

Art appreciation can be an art on its own. To understand an art exhibit in its original cultural context, art specialists develop museum self-guiding media to direct visitor attention towards areas of interest of an art exhibit to ensure better understanding of it. Al-Baddai, Saad, Barbara Ströhl, Elmar W. Lang, and Bernd Ludwig questioned if the museum visitors actually follow the given instructions and if the museum self-guiding media is effectively educating visitors.

The researchers examined visitor behaviour at the Alte Pinakothekin (Munich, Germany) and the Kunstforum Ostdeutsche Galeriein (Regensburg, Germany) art galleries. For some of the paintings displayed at these art galleries the ROI for visitors with an audio guide were identified.

Visitors were asked to wear SMI 30Hz eye-tracking glasses during the visit. Later, the data from the eye-tracking glasses were processed and the actual visitor eye focus areas (AOF, aka area of focus) were matched against the ROI. Analysis showed that 23.68% of ROI were missed by visitors, while 43.42% of AOF were not marked as ROI by experts. Therefore, the audio guide failed to direct visitor attention to a significant portion of the ROIs.

As some other research suggests, eye focusing is not a solid indicator of attention. Taking this into account, the ROI and AOF measurements using an eye-tracking glasses may not be exact. Nevertheless, this research illustrates that eye-tracking data can serve as a strong basis for guide improvements.

While this research does a good job of applying eye-tracking to analyze how visitors explore picture galleries (2-dimensional exhibits), visitor behavior during the exploration of 3-dimensional exhibits (e.g. pottery, statues, 3-dimensional models) may be different. (3-dimensional exhibits provide different challenges)

The work by Al-Baddai, Saad, Barbara Ströhl, Elmar W. Lang, and Bernd Ludwig is centered around a scenario that is impossible to cover using head-tracking because it does not define the visitor's eye focus, hence serving as an illustration of limitations of head-tracking.

Wessel, Daniel, Eva Mayr, and Kristin Knipfer. "Re-viewing the museum visitor's view." Workshop Research Methods in Informal and Mobile Learning, Institute of Education, London, UK. 2007. [113]

This research focused on exploring the advantages of eye-tracking over visitor interviews, surveys. The data obtained from the eye-tracking device were analyzed, with visitor exit interviews to support the analysis since eye-tracking data does not provide a full description of the visitor's mental and cognitive processing of the exhibition. Artificial poster exhibition was created for the purposes of the research, with data being categorized by concept. The researchers had utilized ASL Mobile eye tracker.

Same as in similar researches, it was found that visitors first scan the exhibition as a whole and then proceed with scanning of individual the exhibits based on their conceptual belonging.

Daniel Wessel, Eva Mayr, and Kristin Knipfer validated the applicability of eye-tracking technologies used along with exit interviews to derive visitor behavior data. However, the research only presents the evaluation and results of the original exhibition without an attempt to discuss improvements to and reevaluate the exhibition based on gathered data.

An artificially modeled exhibition can be advantageous when researching patterns of human behavior, as it provides a better controlled testing environment. It is also easier to restructure an artificial exhibition to test new configurations based on eye-tracking data analysis, while changing an exhibition in an actual museum may rise logistical, technical, and ethical issues.

The use of an artificially created exhibition can also be considered the main disadvantage of this research. When applying the analysis results, artificial exhibitions may fail to illustrate the potential limitations on exhibition alterations that naturally occur in a real museum, such as space and the range of acceptable methods to handle an exhibit. Therefore, artificially created exhibitions and lab environments cannot fully explore the issues that occur in real museums. It must also be mentioned, that Daniel Wessel, Eva Mayr, and Kristin Knipfer have used only poster presentations (2-dimensional exhibits) in this research. The visitor behavior patterns may differ when examining 3-dimensional exhibits such as pottery and statues.

With the proposed research, we skip the step of exploring visitor behavior with an artificially set up exhibition, since our goal is to explore the collection and application of eye-tracking data in a specific setting, not the exploration of human behavior.

Gehle, Raphaela, Antje Amrhein, Maximilian Krug, and Karola Pitsch. "Towards Using Eyetracking Data as Basis for Conversation Analysis on Real-World Museum Interaction." SAGA-International Workshop on Solutions for Automatic Gaze Data Analysis: Proceedings. 2015. [30]

This short paper examines a different scenario of a museum visit. Here, visitors do not perform a self-guided tour but are accompanied by a professional guide. The professional guide was wearing eye-tracking glasses to evaluate the social interaction between the guide and the visitors and the interconnection of social interaction with the visitor and exhibition interaction. Besides, two external cameras were deployed in the exhibit room. The results of the experiment indicate that it was impossible to restore the interaction pattern between the guide, visitors, and the exhibition based on the data from the eye-tracking glasses only. The analysis was possible only when the data from eye-tracking glasses and external cameras were correlated and studied as a whole. The researchers used SMI Version 1 eye-tracking glasses for this study.

As the proposed research aims to develop an Augmented Reality smartphone-based guide for the Moundville Archaeological Museum, the experiment by Raphaela Gehle, Antje Amrhein, Maximilian Krug, and Karola Pitsch provides valuable insight on possible limitations when applying eye-tracking technologies to evaluate the AR guide-visitor-exhibition interaction.

Eghbal-Azar, Kira, and Thomas Widlok. "Potentials and limitations of mobile eye tracking in visitor studies: Evidence from field research at two museum exhibitions in Germany." Social science computer review 31.1 (2013): 103-118. [26]

Kira Eghbal-Azar and Thomas Widlok extracted exhibition observation patterns using eye-tracking glasses.

Two exhibitions were used for testing. One was set up in Linden-Museum Stuttgart, Germany, with ASL MobileEye being used. The second one was the LiMo museum in Marbach, Germany, with Locarna PI Mini eye-tracking glasses being used. Only new visitors who had never been at the museum before were considered to participate in the experiment.

The following observation patterns were found. Insight, as the name implies, is the pattern of the visitor "getting into" the exhibit. A body and head motion towards the exhibit happens before an eye movement is performed during an insight. Changing perspective is a pattern that occurs when a visitor views an exhibit from different perspectives. It is accompanied by head and body movements. The backward gaze is a pattern that visitors apply to re-orient themselves in the museum environment. It includes eye and head movement combinations, sometimes along with body movements. The social gaze is a pattern that is directed to other persons in the environment. This pattern can include only eye motion or a combined eye and head movement.

For the proposed research, the fact that Kira Eghbal-Azar and Thomas Widlok indicate the head movements accompanying the visitor patterns may help to interpret the recorded footage.

Naspetti, Simona, et al. ”Automatic analysis of eye-tracking data for augmented reality applications: A prospective outlook.” International Conference on Augmented Reality, Virtual Reality and Computer Graphics. Springer, Cham, 2016. [68]

Similar to [2], this work is another example of successfully applying eye-tracking technology to determine how visitors process paintings in a gallery. Naspetti Simona, et al. used a Tobii Eye-Tracker X2-60 glasses to record visitor experience and the Imotions® Attention Tool software (vers. 5.7) to process the recorded footage. Slides presenting three famous paintings preserved at the National Gallery of Marche, including ”The Ideal City” by an unknown author (1480-1490), were used to research picture-exploration patterns. The experiment was set in laboratory conditions, not an actual museum. For each painting, areas of interest (AOI) were defined. For the ”The Ideal City”, the areas of interest were in actual use by an augmented reality guide application used at the National Gallery of Marche.

The experiment consisted of two tasks. For the first task, participants were shown a slide with a painting reproduction and description text and asked to observe it freely. For the second experiment, the reproduction of the ”The Ideal City” painting was shown with highlighted areas of interest and the visitors were ”asked to observe the reproduction as if they were at a museum”. The AR app was not used during the experiment. The AOIs were highlighted by drawing a red square around them on the slide. The fixation and time spent at each AOI were measured, indicating much better results when AOIs were highlighted in the painting. A Markov chain was also derived to illustrate the attention scheme over the AOIs. An exit survey was performed with the participants, where their attitude towards the art and paintings, in general, was measured.

Albeit obvious limitation of using a laboratory setting with slides instead of actual paintings and participants being ”asked to observe the reproductions as if they were at the museum”, Naspetti Simona, et al. voice two points that co-align with our research. First, the usability of the AR guide used at the National Gallery of Marche was indirectly evaluated. Secondly, the exit survey focused not on the participants explaining their behavior when observing art but the general attitude and interest of the participants towards art. Compared to other similar work in

the field, both these points make this research closer to our goal of evaluating visitor learning and using the collected data to build an AR museum guide that can improve visitor learning.

Razavian, Ali S., et al. "Estimating attention in exhibitions using wearable cameras." 2014 22nd International Conference on Pattern Recognition. IEEE, 2014. [88]

The research performed by Ali S. Razavian, et al. explore the possibilities of utilizing a head-mounted camera to track visitors' attention level in an exhibition, differentiating this work from the overwhelming majority of similar research focusing purely on eye-tracking technologies.

A photo-exhibition was created in a two-room area for the experiment. Participants were asked to attend the exhibits while wearing a head-mounted camera. A classifier was then trained to recognize the photos appearing in a video frame under different perspectives. This classifier was successfully used to determine the position of the exhibit in a video frame and the time it remained there. A visitor was considered to have paid attention to an exhibit when it was focused in the central part of the video frame. A sequence of such frames was named a focus shot. The time an exhibit spent being focused was used to determine the attention level of the visitor for that exhibit.

Albeit successfully deriving the attention level for each exhibit, this work discovered the following issue that is also applicable to the proposed research. It is hard to determine the salient item if two or more of them appear simultaneously in one frame and head movement is smooth between them. This issue does not occur with eye-tracking technology. Another issue was also mentioned. An exhibit was inaccurately detected if it was at the boundaries of a focus shot or it was larger than the camera's field of view in a frame. The first issue can be omitted as we can consider that eye saccades and eye-head co-alignment happen here, with no cognitive processing of the exhibit taking place. The second is purely an issue of the classifier and will not occur during a manual evaluation of the video footage.

In the context of the current research, this work is a valuable example of a successful attempt to use a head-mounted camera to measure visitor's attention levels. In comparison with our research, Ali S. Razavian, et al. used an artificial exhibition featuring only photos. The findings were not supported by an exit survey or applied to improve the exhibition in

any way. Unlike the proposed research, Ali S. Razavian, et al. automated the process of extracting visitor attention levels from the video footage. It is more challenging to train a classifier for a diverse exhibition that can include both wall-mounted paintings and pictures, and 3-dimensional exhibits such as statues and pottery. This is an interesting proposition of a framework that will allow streamlining such a process for museums and can greatly benefit visitor evaluation. Although valuable, this problem is out of the scope of our research.

Barz, Michael, et al. "Automatic recognition and augmentation of attended objects in real-time using eye tracking and a head-mounted display." ACM Symposium on Eye Tracking Research and Applications. 2021.

In their work, Michael Barz, et al. present a system that can track visitor attention using the eye-gaze feature of a Microsoft Hololens 2 headset. In their experiment, the physical objects were annotated with virtual labels whenever a fixated gaze was detected.

Although Michael Barz, et al. performed testing only inside a controlled laboratory environment, their experiment provides a ground for a new, real-time, gaze-guided level of AR interaction in museums. In terms of visitor experience tracking, the system designed by Barz, et al. can allow to detect eye gaze focus shots in real time.

3.2 Augmented and Virtual Reality in Museums

The article search was performed with the following keywords: "augmented reality", "virtual reality", "museum sustainability", "museum gamification".

Jung, Timothy, et al. "Effects of virtual reality and augmented reality on visitor experiences in museum." Information and communication technologies in tourism 2016. Springer, Cham, 2016. 621-635. [45]

Timothy Jung, et al. explored the applications of the augmented and virtual reality systems in a museum from the standpoint of the Experience Economy. The Experience Economy is a concept that was first introduced by Joseph B. Pine and James H. Gilmore [81] and suggests four dimensions of visitor experience: entertainment, education, esthetic, and escape experience.

The research was performed in the Geevor Tin Mine Museum, in Cornwall, United Kingdom. An AR smartphone application was used to overlay text, image, video, and 3d animation content over the exhibits in the museum. The visitors were free to download and install the AR application on their smartphones. A VR application designed for the Samsung Gear VR was used to provide the visitors an experience of a lift ride down the mining shaft.

163 visitors of the Geevor Tin Mine Museum agreed to participate in the experiment. After using the AR and VR applications, they were asked to complete an exit survey. The survey consisted of 47 questions with a 1-7 Likert scale, each exploring one of the Experience Economy dimensions for the AR or the VR application. The analysis of the survey data revealed that the entertainment experience contributed the most to the four dimensions of the Experience Economy. It is also notable that Augmented Reality got a slightly lower score for entertainment and higher for education. This may correspond to the way these technologies were used in the Geevor Tin Mine Museum. The scores expressing visitors' intent to revisit the museum were also low for both technologies.

The limitations of the work performed by Timothy Jung, et al. in comparison to the proposed research are the following: although the exit survey for the experiment participants included questions on education, their overall educational experience was surveyed with no attempt to measure the actual knowledge gained and compare it to the knowledge gained by the regular visitors of the Geevor Tin Mine Museum. The same can be said about the other parameters the exit survey measured.

Regarding the proposed research, the work by Timothy Jung, et al. provide a set of questions that, with slight modifications, can be included in the exit survey for the Moundville Archaeological Park visitors.

The discusses AR and VR applications contributed to the social and environmental sustainability of the Geevor Tin Mine museum, but no research was performed towards economic sustainability.

Lee, Hyunae, et al. ”Experiencing immersive virtual reality in museums.” Information & Management (2019): 103229. [54]

Hyunae Lee, et al. also researched the VR lift ride application designed for the Geevor Tin Mine museum from the standpoint of Experience Economy. Unlike the research by Timothy Jung, et al. [45], this experiment was conducted not in the Geevor Tin Mine museum itself but on the premises of The Museum of Science and Industry in Manchester, UK.

269 visitors agreed to participate in the research. The post-survey results indicate that participants agreed on the value of the VR application as an educational and entertainment medium. The analysis of the retrieved data indicated the positive effect of the VR application on the dimensions of the Experience Economy and overall museum experience. The research also indicated positive feedback on the intent to visit the actual Geevor Tin Mine Museum, which supports similar hypotheses of the proposed research.

Although only the Social Sustainability of the Geevor Tin Mine museum VR application was discussed in this work, it also clearly contributes to Economic Sustainability.

Miyashita, Tsutomu, et al. ”An augmented reality museum guide.” 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality. IEEE, 2008. [64]

Tsutomu Miyashita, et al. researched the usage of an Augmented Reality system as a guide for a museum. The research was performed at The Louvre - DNP Museum Lab (LDML) which is an experimental museum composed of three main spaces (Presentation Room, Information Space, Theater) and a Lobby. The museum is maintained by the Musée du Louvre and DNP Digitalcom Co., Ltd.

The developed Augmented Reality system performed two tasks. First, it introduced a virtual balloon that was guiding visitors through the museum. Next, it augmented the ceramic exhibits of the museum driving visitor attention to the points of interest on the ceramic. The researches used a custom build tablet-like device for the first task and a stationary holographic system for the second.

The stationary Augmented Reality system was used by 330 people, and the Augmented Reality navigation system was by 25 people. Exit interviews were conducted with the visitors

participating in the research. Although the experiment participants described their experience as ”delightful” and ”motivating to explore”, a set of issues were discovered. The majority of them relate to the technological limits of the designed system, and the fact that the museum was poorly illuminated. Hence, they do not apply to the proposed research. The interviews found out that visitors do not tend to move or continue interaction with the Augmented Reality holograms due to a lack of previous experience with Augmented Reality. This must be considered when building the Moundville AR guide.

The exit interviews provide points in support of the proposed research. First, it is indicated that visitors examined the exhibits more thoroughly with the Augmented Reality system. This supports the hypothesis that the Moundville AR guide can improve visitor learning. Second, Tsutomu Miyashita, et al. justify the use of the balloon as an Augmented Reality guide by stating that, with the visitor location tracking not being precise, using an object with perceived floating nature can hide the tracking mistakes.

The learning of the visitors was not measured in this research, and nor was the visitor experience matched with a control group not using the Augmented Reality system.

The system designed by Tsutomu Miyashita, et al. contributed to the social sustainability of the LDML, but no exploration was performed towards economic or environmental sustainability.

Blanco-Pons, Silvia, et al. ”Design and implementation of an augmented reality application for rock art visualization in Cova dels Cavalls (Spain).” Journal of Cultural Heritage 39 (2019): 177-185. [10]

The preserved prehistoric rock art is mostly faint and barely noticeable. While a specialist can locate and explore rock art with ease, the rock art details often escape from the sight of a common visitor.

In this work, Blanco-Pons Silvia, et al. explore the possibility of using an Augmented Reality smartphone app to visualize prehistoric rock art. The visitors were able to hover their smartphones over a rock art painting and see the enhanced virtual image of the rock art being displayed over the painting along with an informative text.

The research was performed at the Cova dels Cavalls rock-shelter, Spain. Unity and ARToolkit (the predecessor of ARToolkitX) was used to build the app for both Android and iOS smartphones. The app was tested by 11 volunteers. The surveys indicate that the AR app made the drawing easier to be recognized, improved the visualization of the paintings, and overall enhanced the visitor experience. The surveys also indicate that it took a long time for the app to recognize the rock art painting, and the virtual content was not always stable and correctly positioned. The reason for this is the lack of trackable features of a fainted rock art painting.

Although there are no rock art paintings at the Moundville Archaeological Park museum, it features a set of disks and palettes with carvings that are on the same level with the rock art from the standpoint of having trackable features. This makes the work performed by Blanco-Pons Silvia a valuable example for the proposed research. This work illustrates that Augmented Reality can be successfully applied to a case that, by a first glance, may lack attributes required for successful natural feature recognition.

The learning of the visitors was not measured in this research, and nor was the visitor experience matched with a control group that had not used the Augmented Reality application.

The application designed by Silvia Blanco-Pons, et al. clearly contributed to the social and environmental sustainability of the Cova dels Cavvals, but no work was performed toward economic sustainability.

Hammady, Ramy, Minhua Ma, and Nicholas Temple. "Augmented reality and gamification in heritage museums." Joint International Conference on Serious Games. Springer, Cham, 2016. [41]

In this work, Ramy Hammady, Minhua Ma, and Nicholas Temple discuss applications of the Augmented Reality in the Egyptian Museum in Cairo, Egypt. Specifically, an AR game "Horus" is proposed to educate visitors in Egyptian mythology. The game explores the legend of Osiris and Horus and combines 2D video materials telling the story with a AR 3D shooting minigame where the visitor must shoot monsters spawned by Horus.

No evaluation or testing results were discussed for the implemented game.

In the context of the proposed research, the game mechanics of the ”Horus” must be considered. Unlike similar research that utilizes quiz and puzzle game mechanics, ”Horus” is based on a shooter game mechanics and hence may be more appealing for the young audience. Ramy Hammady, Minhua Ma, and Nicholas Temple discuss the social sustainability aspects of ”Horus”, but no attempt was performed to discuss the aspects of the economic and environmental sustainability.

Hammady, Ramy, Minhua Ma, and Anna Powell. ”User Experience of Markerless Augmented Reality Applications in Cultural Heritage Museums:‘MuseumEye’as a Case Study.” International Conference on Augmented Reality, Virtual Reality and Computer Graphics. Springer, Cham, 2018. [42]

In this work, Hammady, Ramy, Minhua Ma, and Anna Powell had implemented an Augmented Reality guide dubbed ”MuseumEye” for the Leeds Museum, UK and The Egyptian Museum, Cairo.

The ”MuseumEye” smartphone application utilizes Bluetooth beacons for indoor positioning along with Simultaneous Localization and Mapping (SLAM) tracking to identify the current position of the visitor. Based on the location, the visitor is prompted to view a 3D artifact replica and audiovisual educational materials that supplement the context of the surrounding exhibition. The application was developed with Unity using Open CV and ARCore.

In related work, Ramy Hammady, et al. discuss the version of the ”MuseumEye” for the Hololens Mixed Reality headset. Similar positive feedback was registered among participants. Compared to the smartphone version, the visitors who experience the ”MuseumEye” through the Hololens Mixed Reality headset were more impressed and engaged.

Based on the experiment with 20 participants, the application was found useful in guidance, visually attractive, and ”interesting in a museum”. Thus the effect of the ”MuseumEye” application on social sustainability was explored, but the economic and environmental sustainability were neglected, even though both versions of the ”MuseumEye” contribute to environmental sustainability.

Varinlioglu, Guzden, and Suheyla Muge Halici. ”Gamification of Heritage through Augmented Reality.” (2019). [108]

Guzden Varinlioglu and Suheyla Muge Halici considered the issue of preserving and researching cultural heritage while ensuring access to it for regular visitors in an active excavation environment. Their approach was to provide a gamified AR smartphone app that will both display the virtual replicas of excavated artifacts and engage visitors in a treasure hunt game. The research was performed in the ruins of ancient Greek city Teos, modern Turkey.

The developed AR guide, dubbed TeosGO, was designed as follows. The player location is being constantly tracked, and the player receives notifications on a historical artifact nearby when entering certain locations in the site. Using provided tips, the player finds the virtual artifact and can interact with it to get more educational information. The player is also opted to pass a quiz about the artifact. The player is awarded virtual coins for finding artifacts and solving quizzes. The artifacts, educational materials, and awards can be shared via social platforms. Since the game operates outdoors and visitors can view the real-life runs of Teos from different angles, Guzden Varinlioglu and Suheyla Muge Halici used a model-based tracking technology as opposed by a more widespread 2D marker recognition technologies.

A limitation of this research is that only preliminary research was performed by archaeology and software professionals. No actual evaluation with visitors was conducted.

As in the proposed research, we also intend to apply treasure hunt game mechanics, the research by Guzden Varinlioglu and Suheyla Muge Halici is a valuable example of the validity of such an approach. This research also directly contributes to the environmental sustainability of the Teas archaeological site as no actual modifications of the site were required for a guided tour. Unlike the proposed research, Guzden Varinlioglu and Suheyla Muge Halici did not further capitalize on the gamification of the AR guide by linking the coins collected in the game into real-life incentives and contributing to the economical sustainability of the site.

Noreikis, Marius, et al. ”Effects of Gamified Augmented Reality in Public Spaces.” IEEE Access 7 (2019): 148108-148118. [72]

In this research Marius Noreikis, et al. considered an AR guide that both invites the participants to explore an exhibition and engage in social interaction. The research was performed at the Heureka science center, in Finland.

An application named ARQuiz was developed to be used with smartphones. To track the current location of visitors, the video footage captured with the smartphone camera was streamed to a server where it was matched towards the anchor markers. The ARQuiz displayed 3D virtual question marks in locations where quizzes were set up. The quizzes required knowledge only about the adjacent exhibitions thus engaging visitors to explore these exhibitions. Visitors were also able to leave messages in the virtual space and answer messages left by other visitors participating in social interaction.

Although the possibility to use the designed application to enhance visitor learning is proposed, this research does not explore and analyze the ARQuest application from the learning standpoint, only the social aspect is being analyzed.

The research by Marius Noreikis, et al. contributes the social sustainability at the Heureka science center by improving the visitor experience, but the economical and environmental sustainability was neglected in this research.

Rae, Juno, and Lizzie Edwards. ”Virtual reality at the British Museum: What is the value of virtual reality environments for learning by children and young people, schools, and families.” Proceedings of the Annual Conference of Museums and the Web, Los Angeles, CA, USA. 2016. [87]

Juno Rae and Lizzie Edwards researched the possibility of recreating a prehistoric environment using existing scientific findings to engage the visitors with preserved relics and also provide family-friendly entertainment medium. The experiment was performed in the British Museum, London, UK. Samsung Gear VR headset was used.

A bronze-age settlement was recreated in VR that illustrates how people lived in that period. No scenario was applied in the game. The player started the experience in a roundhouse

and was able to move within the settlement. Virtual replicas of actual exhibits were put inside the roundhouse among other household items typical for the bronze age. The player was able to interact with the exhibit replicas to gain more information about them. A museum curator was present to guide the player and answer questions.

The visitors of the British Museum found the application engaging. No in-depth surveying or interviews were conducted.

The experiment by Juno Rae and Lizzie Edwards contributed to the social sustainability of the British Museum, but no attempt was performed to discuss the aspects of economic and environmental sustainability.

Ghouaiel, Nehla, et al. "Mobile Augmented Reality in Museums: Towards Enhancing Visitor's Learning Experience." International Journal of Virtual Reality 17.1 (2017): 21-31. [33]

Nehla Ghouaiel, et al. implemented and explored an Augmented Reality smartphone guide dubbed M.A.R.T.S (Mobile Augmented Reality Touring System) in the Basque Museum, in Bayonne, France. A custom-built NFT module was used along with OpenGL. This is a rare example when the actual knowledge gain between different guide mediums was measured.

M.A.R.T.S. application offers visitors three types of functionality. First, it displays text information about an exhibit when hovered over it. Second, it can display the points of interest in the exhibit to correctly direct the visitors' attention when exploring the exhibit. Third, it can superimpose a damaged exhibit with a 3D virtual reconstruction of that exhibit.

M.A.R.T.S. was compared against a self-guided tour where visitors relayed solely on the exhibit labels, and with an audio-guided tour. 17 visitors participated in the research. For each participant, the exhibits in the museum were randomly divided into three sets, each set being viewed by one of the guide mediums. Surveys and interviews were conducted afterward, including a quiz assessing participants' knowledge about the Basque culture presented in the museum. Those participants who used the M.A.R.T.S. application received a slightly better score on the quiz. Overall, the participants found M.A.R.T.S. as an adequate learning tool that can improve the visitors' perception of the Basque culture and that it makes the exhibition

more captivating. The participant surveys also indicate that there was no difference in acquired skills and willingness to continue research on Basque culture between the three mediums. Remarkably, the audio guide received slightly higher usability rating which Nehla Ghouaiel, et al. justify by visitors more willing to hear for information instead of reading it and that they tended to keep their smartphones in the pockets.

Compared to the proposed research, this work successfully implements a similar evaluation approach of visitors' knowledge gain, illustrating its viability. It also presents results that our findings can be compared against.

The research by Nehla Ghouaiel, et al. explores mainly the social sustainability aspects of the M.A.R.T.S. although the application also contributes to the environmental sustainability of the Basque Museum. No work was done toward economic sustainability.

Chapter 4

Method

4.1 Research Approach

4.1.1 Visitor Head-Tracking in Museums

The evaluation of the visitor head-tracking in museums was implemented in three steps:

1. Assessment of the museum exhibits;
2. Assessment of the museum-specific questions about visitor behavior;
3. Visitor experience evaluation at the museum using head-tracking technology; supported with an exit interview.

4.1.2 Applications of AR/VR to Improve Museum Sustainability

The evaluation of the effect of AR/VR applications on museum sustainability was implemented in five steps:

1. Assessment of the museum exhibits;
2. Development of an Augmented Reality experience for the museum;
3. Development of a Virtual Reality experience for the museum;
4. Linking of AR/VR experiences with the museum store via gamification, serving a museum store discount as the gamification incentive;
5. Evaluation of visitor experience with the developed AR/VR experiences via exit surveys.

Additionally, the following was performed:

- Conducting online public surveys to assess best museum store discount;
- Conducting online public surveys to assess the general public opinions of Augmented and Virtual Reality applications at museums;
- Conducting online surveys with museum workers to assess the general museum worker opinions of Augmented and Virtual Reality applications at museums;

4.2 Research Sites

The following two museums were part of the research.

4.2.1 Moundville Archaeological Park

Moundville Archaeological Park [112] was selected as the primary location for development and evaluation of Augmented and Virtual Reality applications. It is located near the city of Tuscaloosa, in Alabama, US. One of the largest known pre-Colombian era cities was once located on the park territory. It was the capital of a powerful chiefdom of Native American Mississippian culture. The park features the remnants of the mounds that once served as a temple and chief housing ground. The Jones Archaeological Museum located in the Moundville Archaeological Park showcases the exhibits discovered during the excavations

This location was selected because it features:

1. A rich collection of various artifacts displayed in the museum building, hence providing a research ground for informational and navigational Augmented Reality applications at the museum,
2. Exhibits recreating the indigenous inhabitants of the Moundville performing daily routine, thus providing another possible layer of Augmented and Virtual Reality interactivity to be installed,

3. An archaeological site that was not fully preserved, providing a possibility to exploit Augmented and Virtual Reality as a tool to augment the site to present its original historical appearance,

4. As only the mound structures of the original Native American city are preserved, it is reasonable to employ Augmented and Virtual Reality to allow visitors to explore the Moundville in its original historical appearance,

5. There are no exhibitions at the park that tell the story of excavations. This provides the possibility to recreate a part of the park heritage completely by the means of Augmented and/or Virtual Reality,

6. Promoting and educating Moundville Native American heritage, arts and crafts, serving as a site for informal education about Native American culture,

7. The museum features a souvenir shop and a food court located at the museum,

The Moundville Archaeological Park has about 40000 visitors per year. Hence, sufficient participants can be recruited for the research.

Due to time and resource constraints, this research mainly focused on points 1, 4, 6, and 7.

As significant excavations at the Moundville Archaeological Park took place before the establishment of the archaeological park, the Moundville Archaeological Park does not own all of the exhibits present in its museum. Some of them are part of other museums and collections, landed to the Moundville Archaeological Park for display, and some are disputed by the local Native American tribes descending from the Moundville people. The Table 4.1 provides the list of exhibits accepted to participate in the research. The locations of the selected exhibits within the museum can be found in the Figure 4.1.

The Moundville Archaeological Park does not own the merchandise in the souvenir shop. Hence, it was decided to limit the research to the snacks and drinks of the museum food court.

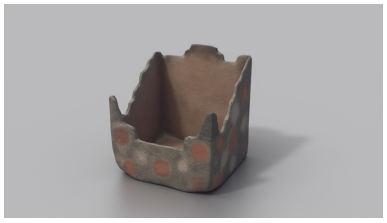
4.2.2 Jule Collins Smith Museum of Fine Art

Jule Collins Smith Museum of Fine Art was selected as the primary location for the evaluation of the head-tracking. It is located in the city of Auburn, in Alabama, US. The Jule Collins Smith Museum features a wide range of art in its exhibition, including paintings, posters, photography, video materials, sculptures, clothing, furniture, chandelier, and an AR-enabled exhibit. At the moment of the experiment, there were over 100 exhibits on display in the museum. Some were displayed standalone, and some were united into installations.

18 individual exhibits and exhibit installations were selected to be included in the experiment. As the exhibits at the Jule Colins Smith Museum of Fine Art are not owned by the museum, it was advised by the museum curators not to publish any imagery of these exhibits to avoid potential copyright violations. The list of these exhibits can be found in the Table 4.2. The locations of the selected exhibits within the museum can be found in the Figure 4.2.

Table 4.1: The list of exhibits at the Moundville Archaeological Park museum included in the experiment (total of 6).

Exhibit Code	Name	Exhibit Photo	Exhibit Model Render
M1	Bat Effigy Bowl		
M2	Caddoan Style Ceramic Bottle		
	Continued on next page		

M4	Human Effigy Bowl		
M6	Lipped Ceramic Vessel		
M7	Stepped Square Vessel		
M8	Stone Pendant		

4.3 Research Questions

4.3.1 Visitor Head-Tracking in Museums

Our research aims to cover the following questions regarding the applications of the head-tracking technology at museums:

Table 4.2: The list of exhibits and installations at the Jule Collins Smith Museum of Fine Art included in the experiment (total of 18) with descriptions.

Exhibit Code	Type	Exhibit Description
A1	Painting	A painting of the museum founder.
A2	Glass figure	A glass figure attach to the wall, with a large description text.
A4	Sculpture, Freestanding	A lightweight circular sculpture with leafs.
A10	Painting, AR-enabled	A modern art painting accompanied by a QR code. The visitors are prompted to scan the QR code, download the associated app, and engage into an AR experience with the painting.
A11	Installation, Wall-sized	An art installation of books occupying a whole wall.
A16	Clothing	A manikin wearing the exhibited clothing piece.
A20	Installation, Table	A table with an installation of books on it.
A24	Informative texts, Wall-sized	A set of descriptions of the current exhibitions and the artists behind it. Occupies half of the wall in height and width.
A27	Installation, Room-Sized	A room with an installation depicting process of creation of electric guitars on it's walls. The walls were divided into 3 logical sections, each section was treated as an individual exhibit (A27-A, A27-B, A27-C).
A31	Installation, Paintings, Two	Two paintings (A31-A, A31-B) next to each other, sharing a common theme.
A32	Painting	A large painting.
A38	Blanket	A large blanket hanging on a wall, with artistic paintings
A49	Sculpture, Freestanding	A modern art sculpture, requiring to get very close to it for a full experience.
A51	Sculpture, Under glass	A sculpture of a human hand.
A55	Installation, Paintings, Three	Three paintings (A55-A, A55-B, A55-C) next and under each other, united by a single theme.
A58	Installation, Furniture, Table and Chair	Two pieces of concept furniture, a table (A58-A) and a chair (A58-B).
A59	Chandelier	A huge chandelier spanning 2 floors, hanging from the ceiling.
A60	Poster, Wall-sized	A large poster occupying a whole wall.

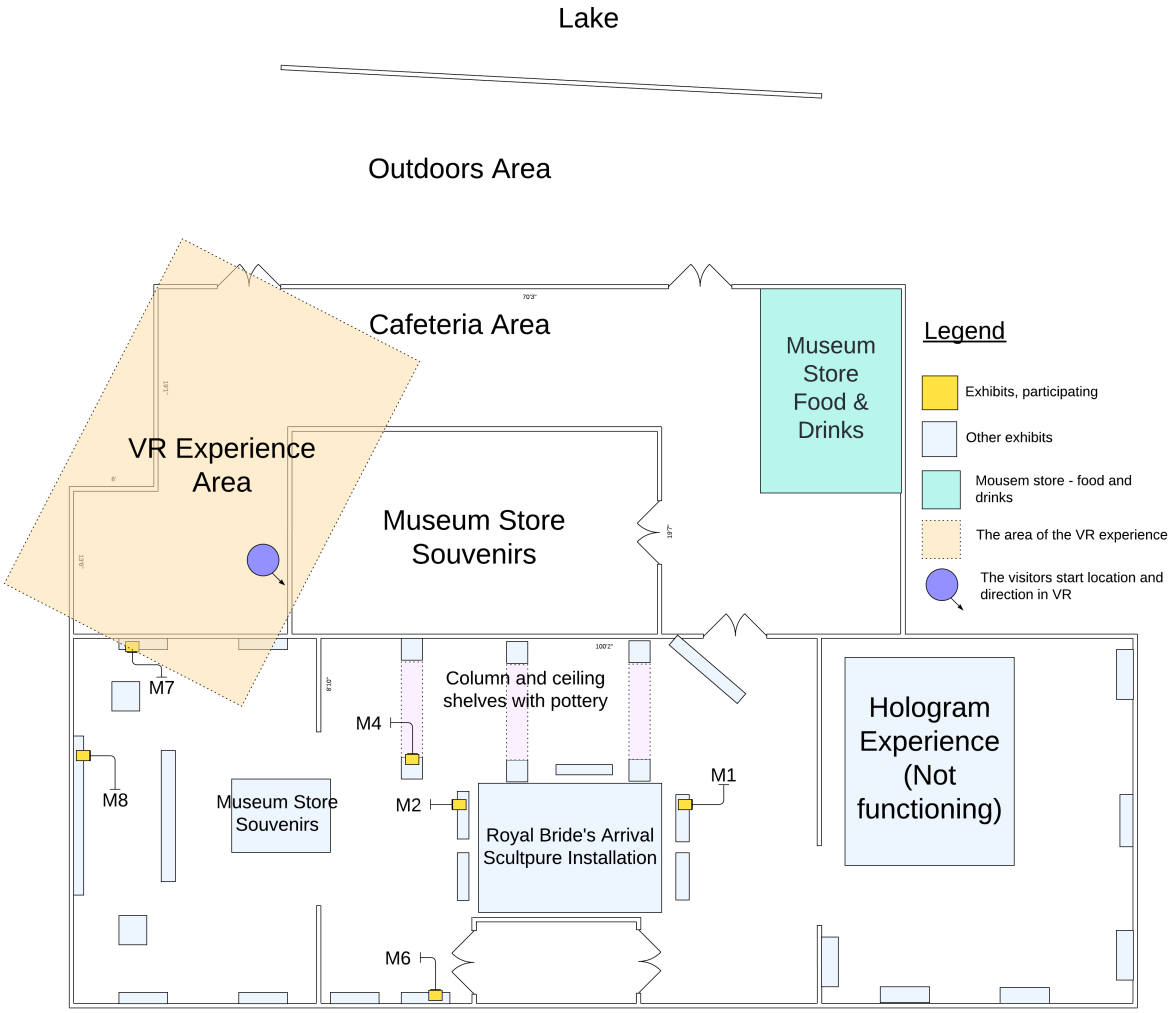


Figure 4.1: Schematic representation of the floor plan with the exhibit locations at the museum of the Moundville Archaeological Park.

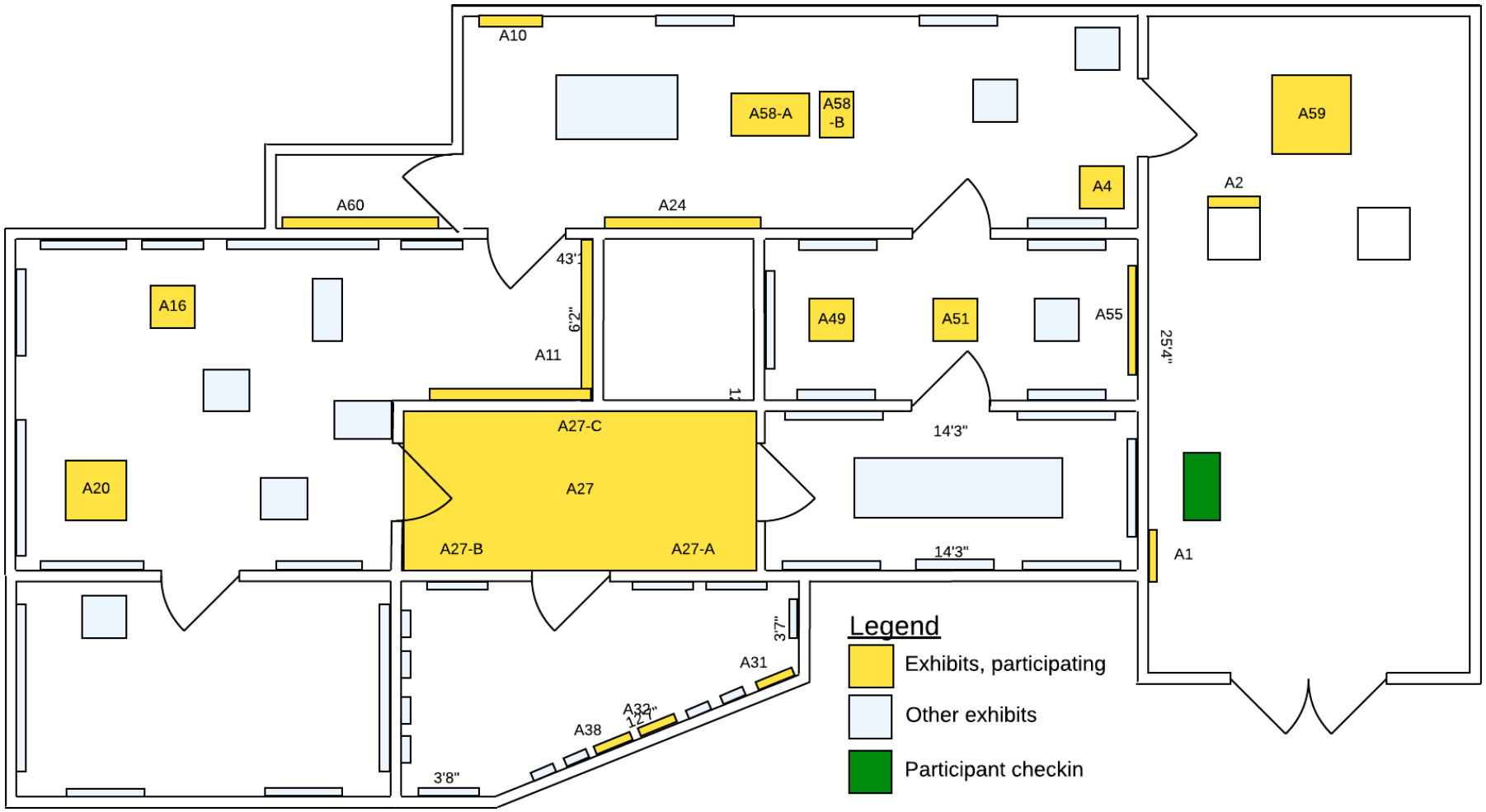


Figure 4.2: Schematic representation of the floor plan with the exhibit locations at the Jule Collins Smith Museum of Fine.

1. *How are the museum stakeholders' expectations of visitor experience different from the actual visitor experience derived from the head-tracking data and visitor exit surveys?*
2. *Can we correlate the visitor exit survey results with the head-tracking data?*
3. *Are the visitors concerned with their privacy when using AR headsets to evaluate their experience during a museum visit?*
4. *Is visitor experience obstructed by using AR headsets during a museum visit?*
5. *What are possible limitations of using head-tracking in museums?*

Additionally, with the input from the curators of the Jule Collins Smith Museum of Fine Art, the following questions about the quality of the current exhibition were identified with a request to answer these questions using the head-tracking technology:

1. The museum exhibition halls are interconnected, creating a loop. No signage of which direction to start from are provided to the visitors. Is there a preference in the start direction among the visitors?
2. Do visitors engage with the AR experience of exhibit A10?
3. Do visitors pay attention to exhibit A24?
4. Do visitors pay attention to the installation A27?
5. What part of the installation A27 is the most popular among the visitors?
6. Do visitors have a preference between the two paintings in the installation A31?
7. The exhibits A32 and A38 are next to each other and share a similar color pattern. Exhibit A38 is the first to be viewed when entering the exhibition hall. Is exhibit A32 neglected?
8. Do visitors pay attention to exhibit A59?
9. Do visitors pay attention to exhibit A60?

4.3.2 Applications of AR/VR to Improve Museum Sustainability

The proposed research aims to cover the following questions regarding the applications of Augmented and Virtual Reality to improve museum sustainability:

1. *How do Augmented and Virtual Reality experiences affect the visitor experience as perceived by the museum internal stakeholders?*
2. *How do Augmented and Virtual Reality experiences affect the visitor experience as perceived by the museum external stakeholders?*
3. *How can the development of Augmented and Virtual Reality experiences be funded as perceived by the museum internal stakeholders?*
4. *How can the development of Augmented and Virtual Reality experiences be funded as perceived by the museum external stakeholders?*
5. *How do gamification affect the visitor experience as perceived by the museum internal stakeholders?*
6. *How do gamification affect the visitor experience as perceived by the museum external stakeholders?*
7. *Will Augmented and Virtual Reality experiences expand the knowledge that the visitor gets from the museum?*
8. *Will Augmented and Virtual Reality experiences provide entertainment for the visitor?*
9. *Can gamification be monetized by the museum?*
10. *Will Augmented and Virtual Reality experiences increase chances for a visitor referral?*
11. *Will Augmented and Virtual Reality experiences increase chances for a revisit?*
12. *Can Augmented and Virtual Reality experiences be directly monetized by the museum?*
13. *What are the target age groups for the Augmeted and Virtual reality in museums as perceived by the museum internal stakeholders?*

14. *What are the target age groups for the Augmeted and Virtual reality in museums as perceived by the museum external stakeholders?*

15. *Can 3D models susbsitute unavailable exhibits as perceived by the museum internal stakeholders?*

16. *Can 3D models susbsitute unavailable exhibits as perceived by the museum external stakeholders?*

17. *What is the contribution to the environmental sustainability impact of the Moundville AR guide and the Moundville VR game as perceived by the museum internal stakeholders?*

18. *What is the contribution to the environmental sustainability impact of the Moundville AR guide and the Moundville VR game as perceived by the museum visitors?*

4.4 Research Hypothesis

4.4.1 Visitor Head-Tracking in Museums

We aim to illustrate the applicability of measuring visitors' attention using an AR headset camera.

Hypothesis 1 (H1): *There is a correlation between the time spent at an exhibit derived from the headset camera footage and the visitor's self-assessment of the attention paid to the exhibit.*

Hypothesis 2 (H2): *The AR camera can detect the AOI within an exhibit that a visitor paid the most attention to.*

Wearing an AR headset may alter the visitor's behavior due to expectations of virtual interaction. Visitor behavior could have been affected because they knew it was being recorded.

Hypothesis 3 (H3): *Wearing AR headset affects the visitor behavior.*

Given the weight and form factor of modern AR headsets and the presence of the virtual user interface, they may annoy the visitors and obstruct them from their experience.

Hypothesis 4 (H4): *The AR headset does obstruct the visitor experience.*

Usage of AR technologies is known for personal privacy violation concerns. Privacy violation concerns may hinder the adoption of AR technologies in museums.

Hypothesis 5 (H5): *The museum visitors do not have privacy concerns associated with AR headset camera.*

4.4.2 Applications of AR/VR for Museum Sustainability

Museum Economic Sustainability

Hypothesis 6 (H6): *Museum visitors who used the AR and VR experience are more likely to revisit the museum.*

Hypothesis 7 (H7): *Museum visitors who used the AR and VR experience are more likely to refer a friend to visit the museum.*

Hypothesis 8 (H8): *The Virtual Reality experience can be monetized by the museum.*

Hypothesis 9 (H9): *Using a museum store discount as an incentive (prize) in a gamified Augmented Reality experience increases the number of purchases at the museum store.*

Museum Environmental Sustainability

Hypothesis 10 (H10): *It is perceived by both internal and external stakeholders that Augmented and Virtual Reality contributes to the environmental sustainability of the museum.*

Museum Social Sustainability

Hypothesis 11 (H11): *The Augmented and Virtual Reality experiences are not viewed as a requirement for a modern museum.*

According to Eleanor Cranmer, et al. [15] [16], museum visitors' experience is affected by their educational, entertainment, esthetic, escapist, and social experiences at the museum. The Moundville AR and VR experience does not include any social elements, hence this research does not address the impact on visitors' social experience at the museum. It is well known that

VR headsets provide escapist experience, hence this research does not address the impact on visitors' escapist experience at the museum.

Additionally to educational, entertainment, and esthetic experiences, this research addresses the recharging experience of the visitors attend the Recharger visitor persona.

Hypothesis 12 (H12): *The Augmented and Virtual Reality experiences positively contribute to the visitors' educational experience at the museum.*

Hypothesis 13 (H13): *The Augmented and Virtual Reality experiences positively contribute to the visitors' entertainment experience at the museum.*

Hypothesis 14 (H14): *The Augmented and Virtual Reality experiences positively contribute to the visitors' esthetic experience at the museum.*

Hypothesis 15 (H15): *The Augmented and Virtual Reality experiences positively contribute to the visitors' recharging experience at the museum.*

Gamefied and AR experiences can promote learning.

Hypothesis 16 (H16): *The gamified Augmented Reality experience helped visitors to learn more about the Moundville and the Mississippian Native American culture.*

Hypothesis 17 (H17): *The visitors are more likely to complete the a gamified Augmented Reality experience if a museum store discount was used as an incentive (prize).*

Other Assessments

In addition, the set of statements about the museum sustainability were derived from the works of Eleanor Cranmer, et al. [15] [16]. The list of the statements can be found in the Table 4.3.

While the natural guess will be that Augmented and Virtual Reality mostly attracts kids and young adults, the works of Eleanor Cranmer, et al. [15] [16] also indicate interest towards the Augmented and Virtual Reality experiences from the older museum visitors. Although the current research does not focus in this particular issue, it assesses the target museum visitor

age group for Augmented and Virtual Reality as perceived by museum internal and external stakeholders.

During the development of the Augmented and Virtual Reality experiences at Moundville, repatriation of a number of artifacts displayed at the Moundville museum back to the tribes descending from the Mississippian Native Americans was initiated. Although we had not granted a permission to substitute the repatriated artifacts with AR 3D models at the Moundville museum, the current research also assesses the opinions towards substituting artifacts with AR 3D models as perceived by museum internal and external stakeholders.

Although the current research does not focus on museum experience gamification beyond the Moundville museum case study, the current research does assess opinions of internal and external stakeholders towards museum experience gamification.

Mandy Ding [23] specifically highlighted the high cost of implementing an AR/VR experience at a museum as one of the obstacles for adoption of AR/VR by museums. This research does not focus on the cost to implement an AR/VR experience at a museum, but it does assess opinions on how the development of a museum AR/VR experience can be funded.

4.5 Population

At the Moundville Archaeological Park, the adult visitors of age 18 and older and the teenage visitors of age 13-18 were considered as potential participants to evaluate the AR and VR applications.

At the Jule Collins Smith Museum, the adult visitors of age 18 and older were considered as potential participants to evaluate the head-tracking technology.

The internal stakeholders at the Moundville Archaeological Park and the Jule Collins Smith Museum were encouraged to voice their ideas and concerns about the experiment. No formal interviews or surveys were attempted.

A score of of museums and museum professional associations were contacted to participate in the museum stakeholder survey. No results were received.

The general user surveys were posted at Facebook and Reddit [89] groups with museum and AR/VR theme, as well as academic and non-academic survey exchange groups.

Table 4.3: Statements derived from the work of Eleanor Cranmer, et al. [15] [16].

Implementing Augmented and Virtual Reality at a museums can...
... create more memorable visitor experiences
... improve marketing presence and competitiveness
... can attract new target markets
... positively affect working experience
... improve job security
... add value to the visitors' experience
... increase visitors' intent to return
... increase visitor attention to the exhibitions
... add more content to the exhibition
... trigger visitors' interest in the exhibition
... trigger visitors' interest in the exhibition topic
... help visitors explore the exhibitions in a new light
... increase footfall numbers
... enhance visitor engagement
... enrich visitor memories
... bring the exhibition to life
... enhance visitors' emotional attachment
... enhance visitors' social interaction
... personalize the visitors' experience
... help visitors to memorize exhibition
... help visitors learning
... help reach the purposes of the museum
... preserve and retain museum exhibits
... positively affect the museum environment
... positively affect spending at museum stores and cafeterias
... positively affect spending at the local community
... improve the museum accessibility
... make the museum less accessible

4.5.1 The Moundville Archaeological Park Visitor Personas

The Moundville Archaeological Park visitors include students from the nearby schools and universities. The park also features several trails and camping grounds. Based on the existing research, and taking into account the specifics of the Moundville Archaeological Park visitor demography, we summarized a set of visitor personas for the Moundville Archaeological Park, presented in the Table 4.4. The relevance of these personas will be tested during the proposed research.

Visitor Personas
John, Teenager John visits the park with the class tours. He is not much interested in the museum exhibits, but still enjoys being outdoors. *Can also be a young adult or visiting with another facilitator*
Ann, Teenager Ann is interested in gaining knowledge in enjoys exploring ancient history. Although she has been to the park with previous school tours, she always tries to find something new here. *Can also be a young adult or visiting with another facilitator*
Catherine, Adult Catherine has taken students to the museum a lot of times. She has good knowledge of the museum exhibition and passes through it almost automatically, without actually paying attention. Can *also be an adult, can be another type of facilitator*
Joseph, Young Adult Joseph accompanies his kids on their first school museum tour. He is excited about spending time with his children and hopes that they all can have a fun time learning and exploring something new. *Can also be an adult, can be another type of facilitator*
Mia, Young Adult
Continued on next page

Mia enjoys visiting museums, art galleries, exhibitions, and historical and cultural attractions. She visits the Moundville Archaeological Park for a mix of education and entertainment. *Can also be of another age group*
Andrew, Adult Andrew likes studying the history of different nations. He visits the Moundville Archaeological Park to learn more about the culture and history of Native Americans. *Can also be of another age group*
Sam, Adult Sam likes to spend time with outdoor activities, and that is the main reason he visits the park. The museum and historical and cultural values are secondary for him. *Can also be of another age group*
Julia, Young Adult Julia and her friends were traveling when they decided to visit this roadside attraction. Their visit was not planned, they do not have exact activities or expectations in mind. *Can also be of another age group*
Long Claw, Long Claw belongs to one of the modern Native American tribes that descend from the Mississippian culture. He is always happy to visit his heritage and is thrilled to help others explore it. *Can also be of another age group*

Table 4.4: The Moundville Archaeological Park Visitor Personas.

4.5.2 The Jule Collins Smith Museum of Fine Art Visitor Personas

The Jule Collins Smith Museum of Fine Art visitors largely include the students, faculty, and staff from the Auburn University. We summarized a set of visitor personas for the Jule Collins

Smith Museum of Fine Art, presented in the Table 4.5. The relevance of these personas will be tested during the proposed research.

Visitor Personas
Ana, Adult Ana is specifically interested in certain exhibits in the museum. She is not going to view rest of the exhibitions. *Can also be of another age group. Can be a student, faculty member, or not affiliated with the university.*
John, Adult John is a parent visiting with his family during the weekends. They plan to both view the exhibitions and spend some nice time at the museum. *Can also be of another age group Can be a student, faculty member, or not affiliated with the university.*
Mia, Young Adult Mia is a student. She visits the museum with her friends during the weekend to both view the exhibitions and spend some nice time at the museum. *Can also be of another age group Can be a student, faculty member, or not affiliated with the university.*
Andrew, Adult Andrew is a faculty member at the Auburn University, and he has an exhibition presented at the museum. Andrew is visiting with a couple of friends to show his exhibition.
Julia, Young Adult Julia is visiting the museum because one of her professors has an exhibition presented here. She is specifically visiting for that exhibition, but she will view the rest of the exhibits as well. *Can also be of another age group*
Joseph, Young Adult
Continued on next page

Joseph is a student visiting with his parents during the weekends. They plan to both view the exhibitions and spend some nice time at the museum. *Can also be of another age group*

Table 4.5: The Jule Collins Smith Museum of Fine Art Visitor Personas.

4.6 Experiment Design

4.6.1 Visitor Head-Tracking in Museums

18 individual exhibits and exhibit installations were selected to be included in the experiment. The list of these exhibits can be found in Table 4.2.

Two headsets were employed during the experiment. The first headset, an AR smart glasses Epson Moverio Bt-350, produced by the Epson Moverio, has the camera placement in the right endpiece. This kind of positioning can be found in all of the smartglasses available in the market. Epson Moverio Bt-350 has a constantly present virtual user interface. The second headset, a modified non-brand camera eyeglass, had a camera placed in the glasses' bridge. Such cameras are available in high-end MR headsets such as Hololens 1&2 and Magic Leap One.

Visitors were approached at the museum entrance and offered to participate in the research. The participants were asked to wear the headset during the whole duration of their visit. Upon exit, the participants were asked to complete a survey consisting of two sections.

An exit survey consisting of two sections was created to gather the visitors' reflections on their museum visit.

The first section assessed the participant demographic and the experience with the headset during the current visit. This section included questions about visitors' age, education level, and if they had previously visited the museum.

To address Hypothesis 3, this section included the following question: ”Did the head-mounted camera affect your behavior during visit?”, and the following scale: ”Strongly disagree (0) - Somewhat disagree (1) - Neither agree not disagree (2) - Somewhat agree (3) - Somewhat disagree (4)”.

To address Hypothesis 4, this section included the following question: ”Was the head-mounted camera obstructing?”, and the following scale: ”Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)”.

To address Hypothesis 5, this section included the following questions: ”Augmented Reality devices rely heavily on cameras. Are you concerned with violating other people’s privacy while wearing a device with a camera?”; ”Are you concerned with people wearing a device with a camera violating your privacy?”, and the following scale: ”Not concerned (0) - Somewhat concerned (1) - Strongly concerned (2)”.

The second section asked the participants to evaluate the attention paid to the exhibits. The schematic floor map of the museum with the participating and non-participating exhibits can be found in Figure 4.2. The exhibits were selected to cover the multitude of different types of exhibits usually found in museum exhibitions.

To address Hypothesis 1, this section included the following question: ”How much attention did you pay to this exhibit?”, and the following scale: ”None at all (0) - A little (1) - A moderate amount (2) - A lot (3) - A great deal (4)” for each exhibit.

To address the Hypothesis 2 the participants were also asked to select which exhibit in an installation they paid the most attention to.

For the AR-enabled exhibit A10, the visitors were asked about their experience with the AR portion of the exhibit.

The full survey for the evaluation of head-tracking technology at Jule Collins Smith Museum of Fine Art can be fount in Appendix A.

Similar to [88], the length of focus shot in seconds (focus length) was measured. Unlike [88], the measurement of focus length was performed manually. For exhibits within an installation, both the focus length for individual exhibits and the focus length for the installation were measured.

4.6.2 Applications of AR/VR for Museum Sustainability

To assess the perception of applications of Augmented and Virtual Reality at a museum, a survey was distributed among museum internal stakeholders, and another survey was published for the general public.

A case study was conducted at the Moundville Archaeological Park. The visitors of the Moundville Archaeological Park were divided into two groups: the Control Group and the the Case Group. The Control group visited the park as usual, while the Case Group used Moundville Augmented and Virtual Reality experiences during the visit.

Perception of the AR/VR at Museums by the general public

A survey was distributed among the general public via thematic Reddit groups, Facebook groups, and survey exchange platforms. This survey assessed public opinion on applications of AR/VR in museums. This survey contained the following sections:

1. *Personal Data*

   This section collected the participant's age, education level, country of residence, familiarity with AR/VR technologies, and perception of the museum's role in society.

2. *AR/VR in Museums*

   This section assessed the participant's perception of using an AR/VR application in a museum.

   To address the Hypothesis 11, the following questions were included in this section:

   (a) *"AR and VR experiences are a requirement for a modern museum experience."* question with the scale "Strongly disagree (0) - Somewhat disagree (1) - Undecided (2) - Somewhat agree (3) - Strongly agree (4)".

   (b) *"AR and VR experiences are a nice addition to a modern museum experience."* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

(c) *"Imagine the following situation. There are two museums, equally interesting for you, but due to your schedule, you can visit only one of them. One of the museums has an AR/VR experience. Would you choose that one?"* question with the scale "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)".

To address the Hypothesis 8, "In your opinion, must visitors be charged additionally for the AR/VR experience?" question was included in this section with the following scale: "No additional charges - 0-10% of the original museum admission - 10-25% of the original museum admission - 25-50% of the original museum admission - More than 50% of the original museum admission".

This section addressed the funding for the development of an AR/VR experience. In particular, the attitude of the participants towards donating to a museum for the development of an AR/VR experience was assessed with the following questions:

(a) *Would you donate to a museum to build an AR or VR experience?* question with the scale "Definitely not (0) - Probably not (1) - Might or might not (3) - Probably yes (4) - Definitely yes (5)".

(b) *How often do you donate to museums?* question with the scale "Never - Once a year - A couple of times per year - A current museum patron / donor / member / sponsor".

This section assessed the participant's agreement with the statements in the Table 4.3 in the context of applying Augmented and Virtual Reality in a museum.

3. *Gamification*

This section explored the types of games that a museum gamification must include as perceived by the participant.

This section also assessed the participant's agreement with the statements in the Table 4.3 in the context of museum gamification.

To assess the importance of museum gamification as perceived by the participant, the *"Imagine the following situation. There are two museums, equally interesting for you, but due to your schedule, you can visit only one of them. One of the museums has a gamified experience. Would you choose that one?"* question was included in this section with the following scale: "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)".

4. *Visitor Categories*

   To address the perceived target audience of Augmented and Virtual Reality museum experiences and gamified museum experiences, the following two questions were included in this section:

   (a) *Which visitor categories you think an AR/VR experience may attract the most? Choose two.* question with the scale "Kids (5-12) - Teenagers (13-17) - Young Adults (18-35) - Middle Age (36-55) - Older Adults (56+)".

   (b) *Which visitor categories you think a gamified experience may attract the most? Choose two.* question with the scale "Kids (5-12) - Teenagers (13-17) - Young Adults (18-35) - Middle Age (36-55) - Older Adults (56+)".

5. *Substituting Artifacts*

   This section explored the participant's perception towards substituting museum exhibits with virtual models.

   This section also assessed the quality of the 3D models created for the Moundville AR and VR experiences. It asked the participants to express their satisfaction level for each of the exhibits via the *You now will be asked to compare original exhibits from Moundville Archaeological Park (on the right) and their 3D replicas (on the left). Please, indicate how satisfied you will be with such a 3D replica in an AR experience.* question with the following scale: "Extremely dissatisfied (0) - Somewhat dissatisfied (1) - Neither satisfied nor dissatisfied (2) - Somewhat satisfied (3) - Extremely satisfied (4)".

Perception of the AR/VR at Museums by museum internal stakeholders

A survey was distributed among US museum workers via personalized email requests. This survey assessed museum worker opinion on applications of AR/VR in museums. This survey contained the following sections:

1. *Personal and Museum Data*

   This section collected the participant's age, education level, familiarity with AR/VR technologies, and perception of museum's role in society.

   This section collected data about the participant's museum such as size, location, type, number of visitors, and implemented interactive experiences.

2. *Implemented Augmented Reality*

   To explore the participant's experience with Augmented and Virtual Reality and other interactive museum experiences in case they were implemented at the participant's museum, the following set of questions were included:

   (a) *Are these experiences a permanent part of your exhibition?* question, with the options "Yes - No".

   (b) *Can you please describe this experience in one or two sentences?* question, open-ended.

   (c) *Can you please describe how this experience affected the museum and the visitors in one or two sentences?* question, open-ended.

   (d) *Do you charge additionally for this experience?* question, with the options "Yes - No".

   (e) *Can you please describe the nature of this additional charge in one or two sentences?* question, open-ended.

3. *AR/VR in Museums*

   This section assessed the participant's perception of using an AR/VR application in a museum.

To address the Hypothesis 11, the following questions were included in this section:

(a) *"AR and VR experiences are a requirement for a modern museum experience."* question with the scale "Strongly disagree (0) - Somewhat disagree (1) - Undecided (2) - Somewhat agree (3) - Strongly agree (4)".

(b) *"AR and VR experiences are a nice addition to a modern museum experience."* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

To address the Hypothesis 8, "In your opinion, must visitors be charged additionally for the AR/VR experience?" question was included in this section with the following scale: "No additional charges - 0-10% of the original museum admission - 10-25% of the original museum admission - 25-50% of the original museum admission - More than 50% of the original museum admission".

To address the funding for the development of an AR/VR experience the *In your opinion, how may the implementation of the AR/VR experience be funded? Please, select all the applicable funding sources.* question was included in this section with the following options: "I do not know - Internal museum funds - Museum stakeholders - Governmental grants - Grant from sponsors/donors - Crowdfunded by local community - Crowdfunded by visitors - Crowdfunded using online platforms - Other (Please, specify)".

This section assessed the participant's agreement with the statements in the Table 4.3 in the context of applying Augmented and Virtual Reality in a museum.

To explore possible new statements and ideas regarding applications of Augmented and Virtual Reality at museums, the following open-ended questions were included:

(a) *Please, describe in a couple of sentences what is your vision of a museum AR experience.*

(b) *Please, describe in a couple of sentences what is your vision of a museum VR experience.*

(c) *Are there any other potential benefits that you can think of with AR/VR experience at a museum? Please, describe with a couple of sentences.*

(d) *Are there any other potential challenges that you can think of with AR/VR experience at a museum? Please, describe with a couple of sentences.*

4. *Gamification*

This section explored the types of games that a museum gamification must include as perceived by the participant.

This section also assessed the participant's agreement with the statements in the Table 4.3 in the context of museum gamification.

5. *Visitor Categories*

To address the perceived target audience of Augmented and Virtual Reality museum experiences and gamified museum experiences, the following two questions were included in this section:

(a) *Which visitor categories you think an AR/VR experience may attract the most? Choose two.* question with the scale "Kids (5-12) - Teenagers (13-17) - Young Adults (18-35) - Middle Age (36-55) - Older Adults (56+)".

(b) *Which visitor categories you think a gamified experience may attract the most? Choose two.* question with the scale "Kids (5-12) - Teenagers (13-17) - Young Adults (18-35) - Middle Age (36-55) - Older Adults (56+)".

6. *Substituting Artifacts*

This section explored the participant's perception towards substituting museum exhibits with virtual models.

This section also assessed the quality of the 3D models created for the Moundville AR and VR experiences. It asked the participants to express their satisfaction level for each of the exhibits via the *You now will be asked to compare original exhibits from Moundville Archaeological Park (on the right) and their 3D replicas (on the left). Please, indicate*

how satisfied you will be with such a 3D replica in an AR experience. question with the following scale: ”Extremely dissatisfied (0) - Somewhat dissatisfied (1) - Neither satisfied nor dissatisfied (2) - Somewhat satisfied (3) - Extremely satisfied (4)”.

Moundville Archaeological Park Control Group

The Control Group consisted of Moundville museum visitors who visited the museum as usual without using the AR and VR experiences. The visitors in the Control Group were asked to complete a survey assessing their experience at the museum at the end of their visit. The exit survey for the Control Group consisted of 6 sections:

1. *Demographics*.

   This section collected the visitor’s age, education level, and whether they had visited Moundville Archaeological Park before

2. *Questions about your visit today*.

   This section explored the visitor’s experience during their visit. It assessed the visitor’s persona, chances for a revisit and a referral, the perceived significance for society, the environmental impact, and the three dimensions of social sustainability.

   To address the Hypothesis 6, ”Will you revisit Moundville?” question was included in this section with the following scale: ”Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)”. The results of this question were then compared with the results of the Case Group.

   To address the Hypothesis 7, ”Will you recommend Moundville to a friend?” question was included in this section with the following scale: ”Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)”. The results of this question were then compared with the results of the Case Group.

   To address the Hypothesis 10, ”Do you think Moundville helps to sustain the local environment?” question was included in this section with the following scale: ”Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)”. The results of this question were then compared with the results of the Case Group.

To address the Hypothesis 12, ”My visit to Moundville was educational, I learnt something new” question was included in this section with the following scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. The results of this question were then compared with the results of the Case Group.

To address the Hypothesis 13, ”My visit to Moundville was fun, I was entertained” question was included in this section with the following scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. The results of this question were then compared with the results of the Case Group.

To address the Hypothesis 15, ”My visit to Moundville was relaxing and recharging” question was included in this section with the following scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. The results of this question were then compared with the results of the Case Group.

3. *Questions about museum food store*.

   This section assessed the visitor's buying habits at museum food stores, asked if the visitor had made a purchase at the Moundville museum food store, and if the visitor would have made a purchase at the museum food store if a 25% discount was provided.

   To address the Hypothesis 9, the following questions were included in this section:

   (a) *”Did you purchase anything from the Moundville Museum food store?”* question with the ”No (0) - Yes (1)” scale kept track of the number of visitors who made a purchase at the museum food store for the comparison with the Case Group.

   (b) *”Would you purchase anything from the Moundville Museum food store, if 25% discount was given?”* question with the ”Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)” scale gathered insight into the visitor's attitude towards the discount that was used as an incentive in the Moundville AR experience.

4. *Questions about museum souvenir store*.

This section assessed the visitor's buying habits at museum souvenir stores, asked if the visitor had made a purchase at the Moundville museum souvenir store, and if the visitor would have made a purchase at the museum souvenir store if a 10-25% discount was provided. Although the museum souvenir store discount was not included as an incentive, this section assisted with addressing the Hypothesis 9.

5. *Questions about Augmented and Virtual Reality*.

   This section assessed the visitor's opinion on the necessity of AR and VR experiences at Moundville museum, and if the visitor would agree to pay an additional fee for such experiences. Before starting this section, the visitor was asked to watch two short videos showcasing the usage of Augmented and Virtual Reality in museums.

   To address the Hypothesis 11, the following questions were included in this section:

   (a) *"Do you think it WILL BE GREAT for Moundville to have an Augmented Reality experience?"* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

   (b) *"Do you think it is REQUIRED for Moundville to have an Augmented Reality experience?"* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

   (c) *"Do you think it WILL BE GREAT for Moundville to have an Virtual Reality experience?"* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

   (d) *"Do you think it is REQUIRED for Moundville to have an Virtual Reality experience?"* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

   To address the Hypothesis 8, "Would you pay an additional fee for these experiences?" question was included in this section with the following scale: "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

6. *A small quiz about the Moundville*. A knowledge quiz containing 9 questions covered most of the educational materials presented in the Moundville museum. This section addressed the Hypothesis 16 and will be compared with the results from the Case Group.

The full survey can be found in the Appendix B.

Moundville Archaeological Park Case Group

6 individual exhibits at the Moundville Archaeological Park were selected to be included in the experiment. The list of these exhibits can be found in Table 4.1.

The Control Group consisted of Moundville museum visitors who visited the museum and used the AR and VR experiences. The visitors in the Case Group were asked to use the AR application during their visit to the museum.

The steps of the Control Group visit were the following:

1. During the museum visit, the visitor was asked to use the Moundville AR experience. They were informed that the completion of the Moundville AR experience (finding all of the participating exhibits and completing the in-app quiz) would achieve them a prize.

2. After the visit to the museum, the visitor was asked to put on the Oculus Quest 2 headset and use the Moundville VR experience. The visitor was not provided any time limit to use the VR.

3. After using the VR experience, the visitor was asked to complete the exit survey assessing their experience.

The exit survey for the Moundville Archaeological Park Case Group consisted of 5 sections:

1. *Demographics*.

   This section collected the visitor's age, education level, and whether they had visited Moundville Archaeological Park before

2. *Questions about your visit today*.

   This section explored the visitor's experience during their visit. It assessed the visitor's persona, chances for a revisit and a referral, the perceived significance for society, the environmental impact, and the three dimensions of social sustainability.

   To address the Hypothesis 6, the following questions were included in this section:

   (a) *"Will you revisit Moundville?"* question with the scale "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)". The results of this question were then compared with the results of the Case Group.

   (b) *"Did the AR/VR experience influence your decision?"* question with the "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)" provided additional insight into the results.

   To address the Hypothesis 7, the following questions were included in this section:

   (a) *"Will you recommend Moundville to a friend?"* question with the scale "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)". The results of this question were then compared with the results of the Case Group.

   (b) *"Did the AR/VR experience influence your decision?"* question with the "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)" provided additional insight into the results.

   To address the Hypothesis 10, "Do you think Moundville helps to sustain the local environment?" question was included in this section with the following scale: "Definitely not (0) - Probably not (1) - Might or might not (2) - Probably yes (3) - Definitely yes (4)". The results of this question were then compared with the results of the Control Group.

   To address the Hypothesis 12, "My visit to Moundville was educational, I learnt something new" question was included in this section with the following scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely

agree (4)". The results of this question were then compared with the results of the Control Group.

To address the Hypothesis 13, "My visit to Moundville was fun, I was entertained" question was included in this section with the following scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". The results of this question were then compared with the results of the Control Group.

To address the Hypothesis 15, "My visit to Moundville was relaxing and recharging" question was included in this section with the following scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". The results of this question were then compared with the results of the Control Group.

3. *Questions about Moundville Virtual Reality Experience (headset).*

   This section assessed the visitor's experience with the Moundville VR experience.

   To address the Hypothesis 10, "The Virtual Reality app helps Moundville to sustain the local environment" question was included in this section with the following scale: "Definitely disagree (0) - Somewhat disagree (1) - Might or might not (2) - Somewhat agree (3) - Definitely agree (4)".

   To address the Hypothesis 12, the following questions were included:

   (a) *"The Moundville VR experience made my visit more educational"* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

   (b) *"The Moundville VR experience provided knowledge beyond what was presented in the museum"* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

   (c) *"I feel like I know more about Moundville and Native Americans after playing the VR app"* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

(d) *"The app was educational"* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". This question was taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

To address the Hypothesis 13, the following questions were included in this section:

(a) *"The Moundville VR experience made my visit more entertaining"* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

(b) *The app was fun* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

(c) *The app was amusing* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

(d) *The app was entertaining* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

(e) *The app was captivating* question with the scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

To address the Hypothesis 14, the following questions were included in this section:

(a) *"The Moundville VR experience made my visit more relaxing and recharging"* question with the scale "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

(b) *"The app was pleasant"* question with the scale "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

(c) *"The app was attractive"* question with the scale "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)". This question was taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

To address the Hypothesis 15, "The Moundville VR experience made my visit more relaxing and recharging" question was included in this section with the following scale: "Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)".

To address the Hypothesis 8, the following questions were included in this section:

(a) *"Would you pay an additional fee for these experiences?"* question with the scale "No pay (0) - Less than $5 (1) - $5-$10 (2) - More than $10 (4)".

(b) *"If you had a VR headset, would you download the Moundville VR experience (headset) to play it at home?"* question with the scale "Strongly disagree (0) - Disagree (1) - Undecided (2) - Agree (3) - Strongly agree (4)".

(c) *"Would you pay to download the Moundville VR experience (headset) to play it at home, knowing that his money will go to support the museum?"* question with the scale "No pay (0) - Less than $5 (1) - $5-$10 (2) - More than $10 (4)".

A set of questions was asked to assess the ease of use and the quality of the content.

4. *Questions about Moundville Augmented Reality Experience (smartphone).*

This section assessed the visitor's experience with the Moundville AR experience.

To address the Hypothesis 10, ”The Augmented Reality app helps Moundville to sustain the local environment” question was included in this section with the following scale: ”Definitely disagree (0) - Somewhat disagree (1) - Might or might not (2) - Somewhat agree (3) - Definitely agree (4)”.

To address the Hypothesis 12, the following questions were included:

(a) *”The Moundville AR experience made my visit more educational”* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

(b) *”The Moundville AR experience provided knowledge beyond what was presented in the museum”* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

(c) *”I feel like I know more about Moundville and Native Americans after playing the AR app”* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

(d) *”The app was educational”* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

To address the Hypothesis 13, the following questions were included in this section:

(a) *”The Moundville AR experience made my visit more entertaining”* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

(b) *The app was fun* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

(c) *The app was amusing* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

(d) *The app was entertaining* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

(e) *The app was captivating* question with the scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”. This question was directly taken from the survey by Eleanor Cranmer, et al. [15] assessing AR/VR experience at a museum.

To address the Hypothesis 14, the following questions were included in this section:

(a) *”The Moundville VR experience made my visit more relaxing and recharging”* question with the scale ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

(b) *”The app was pleasant”* question with the scale ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

(c) *”The app was attractive”* question with the scale ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

To address the Hypothesis 15, ”The Moundville AR experience made my visit more relaxing and recharging” question was included in this section with the following scale: ”Definitely disagree (0) - Somewhat disagree (1) - Not sure (2) - Somewhat agree (3) - Definitely agree (4)”.

To address the Hypothesis 9, the following questions were included in this section:

(a) *”Did you collect the prize?”* question with the scale ”Didn’t achieve it (0) - No (1) - Yes (2)”.

(b) *"Would you make the purchase, even if you hadn't had the prize?"* question with the scale "Definitely disagree (0) - Somewhat disagree (1) - Undecided (2) - Somewhat agree (3) - Definitely agree (4)".

(c) *"Were you satisfied with the prize?"* question with the scale "Definitely disagree (0) - Somewhat disagree (1) - Undecided (2) - Somewhat agree (3) - Definitely agree (4)".

To address the Hyphothesis 17, the "Would you complete the quiz, even if there was no prize?" question was included in this section with the following scale: "Definitely disagree (0) - Somewhat disagree (1) - Undecided (2) - Somewhat agree (3) - Definitely agree (4)".

5. *A small quiz about the Moundville*. A knowledge quiz containing 9 questions covered most of the educational materials presented in the Moundville museum. This section addressed the Hypothesis 16 and will be compared with the results from the Control Group.

   A set of questions was asked to assess the ease of use, the quality of the content, and the precision of the object recognition.

The full survey can be found in the Appendix C.

4.7 Limitations

Following limitations are currently known for the proposed research.

4.7.1 Visitor Head-Tracking in Museums

- Due to lack of eye-tracking headset, no direct comparison was performed with the eye-tracking technology.
- No automated analysis of the footage was attempted. Hence, this research strictly falls into technology discussion (the second known to the research authors).
- The visitor head-tracking was not paired with a museum Augmented Reality experience.

- The insight provided by the visitor head-tracking was not introduced into the Jule Collins Museum of Fine Art exhibition, and no second analysis was performed to verify that the insight provided by the visitor head-tracking did help the museum to improve it's exhibition.

4.7.2 Applications of AR/VR for Museum Sustainability

- The research is currently limited to the area of Moundville Archaeological Park. Although the park features a wide range of exhibits, remnants of a Native American city, and other data and landmarks, as described in detail in 4.2, we consider that applying the research only to the park museum is a limitation of this research. It must be highlighted, that similar research was also subject to limitation of discussing only a single museum case study.

- Due to resource limitations, no advanced Mixed Reality headsets such as Hololens, Hololens 2 and Magic Leap, are currently considered for the proposed research. Scenarios that require such devices are currently omitted, hence we cannot say that all of the available Augmented and Virtual Reality instrumentation was discussed in this research.

- Due to time and resource limitations, the features of the Moundville Archaeological Park were not fully exploited, hence we cannot say that the proposed research looked into all of the possibilities of applying Augmented and Virtual Reality technologies to an archaeological park and a museum.

- Due to time and resource limitations, the current research does not measure the long-term individual and multiplicative effect of the Moundville AR and VR experiences, although it provides necessary ground for future observations. In particular, only the short term effect on visitors' learning is measured via knowledge quiz in the exit interview.

- Due to time and resource limitations, no alterations to the Moundville Archaeological Museum exhibition and setup was performed to assist the Moundville AR and VR experiences.

- The Moundville Archaeological Park visitors are enrolled as participants. This means that we do not have a complete control of the participant demographics.

Chapter 5

System Design

5.1 Design of the Moundville AR experience

The Moundville AR experience is a platform-independent mobile application that allows the user to scan the participating exhibits in the Moundville Archaeological Park museum to view the 3D models of these exhibits and the associated educational materials. The Moundville AR experience also allows the user to access the gamification features - exhibit exploration, knowledge quiz, and prize.

The Moundville AR experience features the following screens:

- *Explore Screen.* The Explore Screen allows the user to scan an exhibit. If the exhibit is recognized as one of the participating exhibits, the 3D model and the associated educational materials for that exhibit will be shown, and the exhibit will be marked as unlocked. The exhibit 3D model can be zoomed in and out and rotated in the 3-dimensional space by scrolling and pinching the smartphone screen,

- *Exhibits Screen.* The Exhibits Screen contains the list of the participating exhibits. If an exhibit is unlocked, the visitor can view the 3D model and the associated educational materials for that exhibit,

- *Prize Screen.* The Prize Screen contains the description of the prize and directions to receive it. If the quiz is not completed, the Prize Screen informs the user that the quiz must first be completed. When prize is being received, the Moundville museum store cashier is asked to click the ”Received” button. If the prize is received, the Prize Screen informs the user that the prize was already received,

- *Quiz Screen.* The Quiz Screen contains the quiz questions. If not all of the exhibits are unlocked, the Quiz Screen informs the visitor that the quiz will be available once all of the exhibits are unlocked. Only one question is showed to the user at a time. Each time the user opens the Quiz Screen, a question is picked randomly from the unanswered questions. If all questions are answered, the Quiz Screen informs the user that the quiz is complete, and that the prize can be accessed,

- *Help Screen.* The Help Screen contains the directions about how to use the Moundville AR experience and the credits. The Help Screen is shown the first time the user opens the Moundville AR experience.

The state flow diagram of the Moundville AR experience can be found in the Figure 5.1.

The UI/UX design of the Moundville AR experience can be found in the Appendix F.

The description texts presented in the Moundville AR experience can be found in the Appendix H.

The quiz questions from the Moundville AR experience can be found in the Appendix J.

5.2 Design of the Moundville VR experience

The Moundville VR experience is a VR application running on an Oculus Quest 2 headset [75] that allows the user to explore inside of a virtual recreation of a traditional Mississippian house and to explore the three sisters garden outside of the house.

Only the bases of the Native American houses were preserved in the Moundville Archaeological Park. Based on the archaeological evidence and the traditions of the Native American descendants of the Mississippian people, it is possible to closely recreate the houses of the Native Americans at Moundville.

A 360-degree image taken on the top of the Moundville Mound B was used as the skybox for the VR experience. Skybox is the 360-degree background of the experience. Usage of an actual image taken at the Moundville allowed for a more realistic sky image.

The Mississippian house features the central hearth (bonfire) with fish cooking on top if it, a deer hide, and beds with exhibit models. During the excavations at Moundville, an

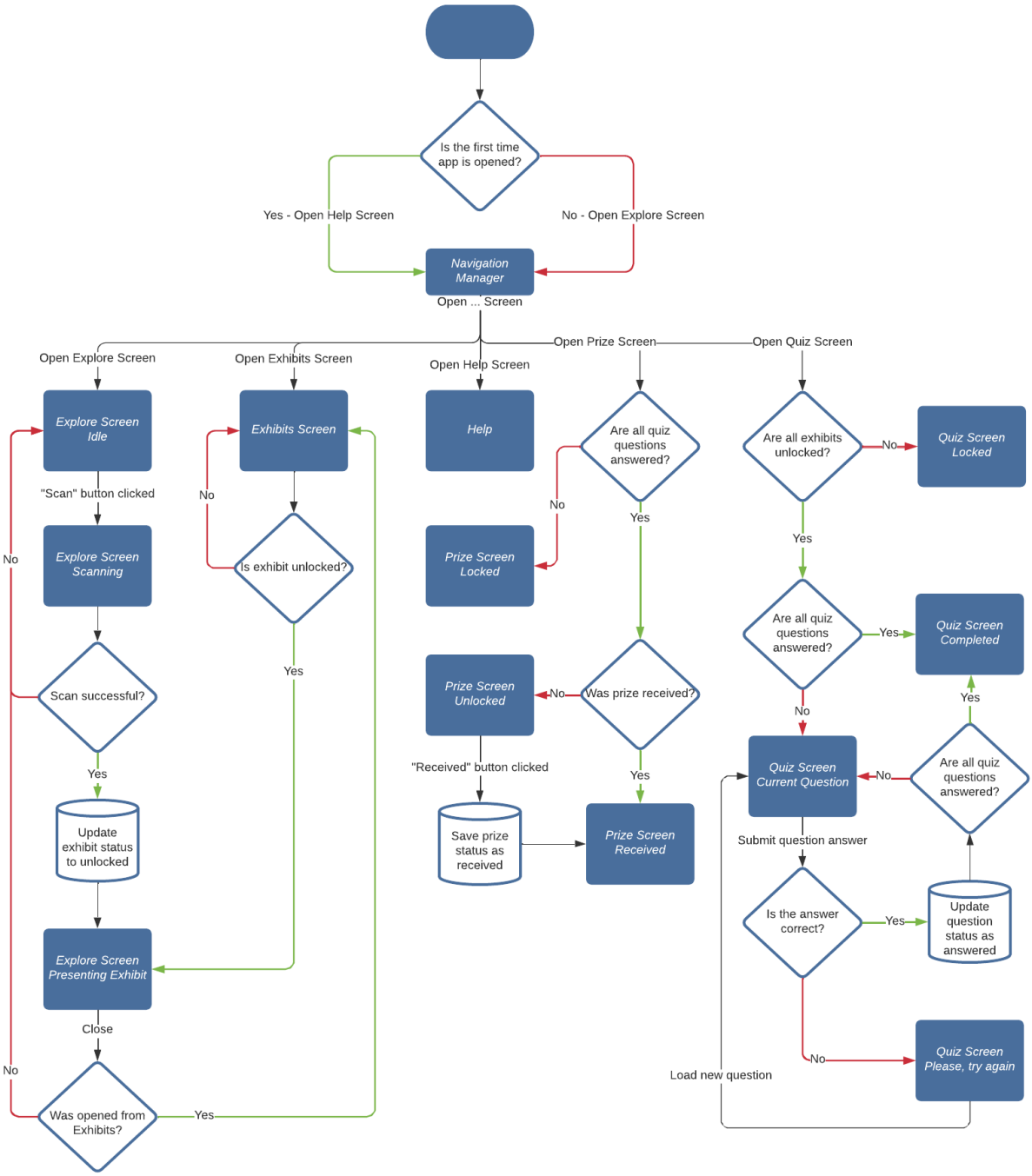


Figure 5.1: The state flow diagram of the Moundville AR experience.

earthlodge was discovered that served as a spiritual center and as a chiefly council house. The Mississippian house model includes various spiritual elements from the earthlodge, such as a model of four acorns and a rope that were buried under one of the earthlodge poles during a spiritual ritual. Although putting this symbols inside a regular Mississippian house may not be historically accurate, the decision was made to provide the visitors with more visual information about the earthlodge and Moundville Native Americans' beliefs.

The three sisters garden features corn plants, with bean plants twining around the corn plants, and squash plants covering the ground. The three sisters garden is encircled with a wooden palisade in the Moundville VR experience. Although this is not historically accurate, the decision was made to provide natural boundaries in VR, to hide the rest of the skybox, and to serve as an example of a palisade.

An evening with light rain was implemented as an environment of the Moundville VR experience. This allowed to use smoother light sources in the three sisters garden, covering some of the rendering imperfections.

The sound design included the bonfire cracking, rain, and distant thunder sounds, as well as randomly appearing sounds of birds, frogs, and village dogs.

The Moundville VR experience showcased educational materials associated with the models and concepts presented in the experience. The user could switch the texts on and off by pressing the "B" button on the VR controls.

A complete set of screenshots of the virtual environment of the Moundville VR experience can be found in the Appendix G.

The educational materials presented in the Moundville VR experience can be found in the Appendix I.

5.3 Hardware Stack

5.3.1 Head-tracking

The following hardware was utilized for head-tracking:

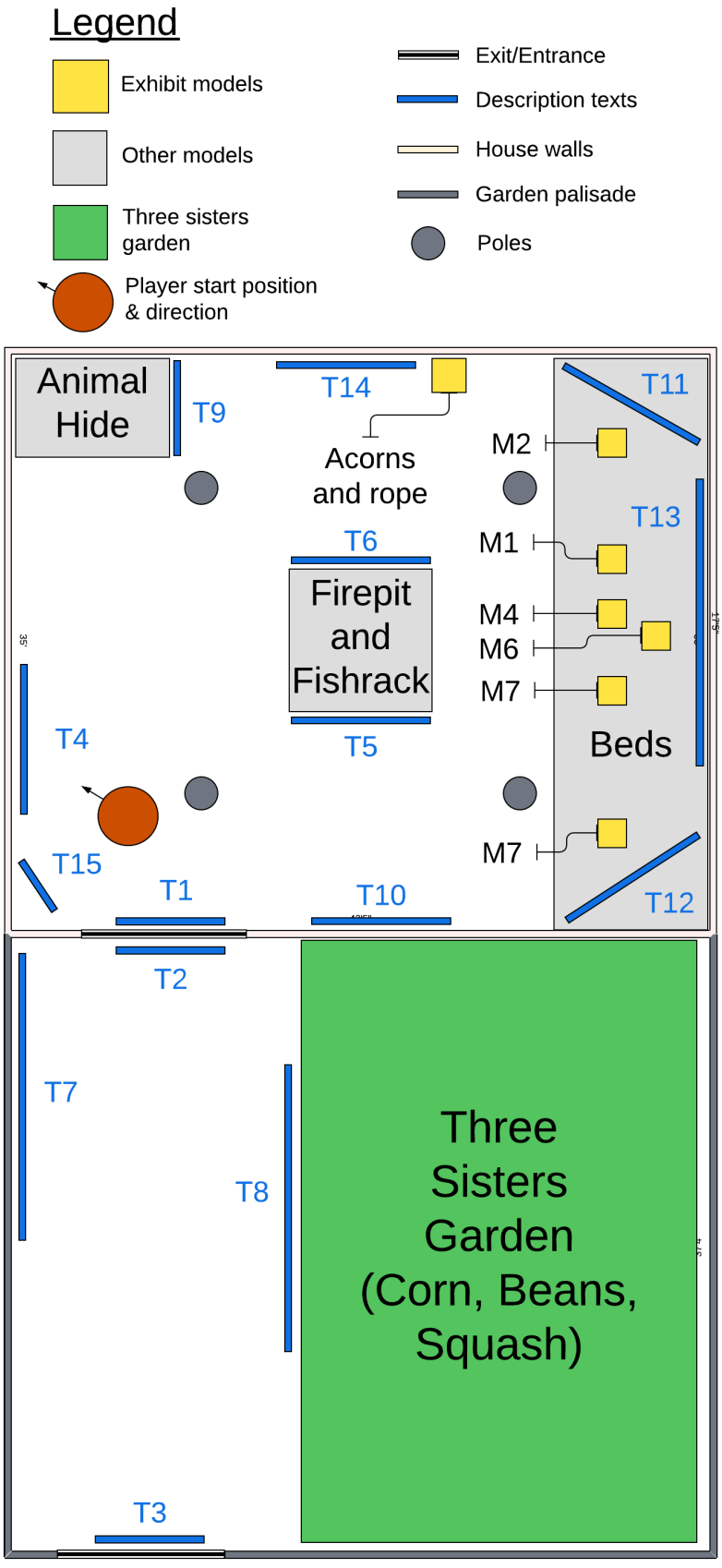


Figure 5.2: The schematic representation of the Mississippian house and garden in the Moundville VR experience.

- Epson Moverio BT-350 [67] smart glasses. The camera is located on the right endpiece of the glasses. These smart glasses are twice as cheap as the most affordable eye-tracking glasses, and there are no paid tools required to extract and analyze recorded footage. The Epson Moverio BT-350 has a constantly present virtual interface in the center of user's field of view. The brightness of this interface was reduced to the minimum during the experiment to reduce its effect on the visitor experience.

- Non-name camera glasses. The camera is located on the bridge of the glasses. These video glasses are approximately 40 times cheaper than the most affordable eye-tracking glasses.

There is no special software required to process and analyze the recorded video samples. Adobe Premier Pro was utilized for that purposes.

Due to time and financial constraints, no specialized eye-tracking headset or eye-tracking enabled headset was acquired. An eligible candidate would be the Hololens 2 high-end MR headset [63].

5.3.2 Moundville VR experience

Oculus Quest 2 [75] Virtual Reality headset was chosen for the Moundville VR experience. It is a relatively affordable, high-end Virtual Reality headset. Unlike HTC Vive [110], Oculus Quest 2 is standalone and does not require an active connection with computer or the installation of external tracking beacons. Besides controller devices, Oculus Quest 2 also has a built-in hand gesture support.

5.4 Software Stack

5.4.1 Head-Tracking

The Adobe Premier Pro [83] by Adobe, a proprietary professional video-editing software, was used to analyze the footage from AR headset cameras and flag the focus shots.

5.4.2 Moundville AR and VR Experience

The Moundville AR experience targets Apple iPhones running iOS 12 or later, and Android smartphones running Android 7.0 or later. The selection is based on the current operating version distribution for iOS [8] and Android [5] and the minimal requirement of Unity AR Foundation [1].

The Moundville VR experience targets Oculus Quest 2 VR headset.

The following software tools were used for the development of the Moundville AR and VR experiences:

- Unity [106] - a popular game development engine, featuring native and 3rd party support for Augmented Reality development. Unity is selected as a developer platform for the Moundville AR guide because it supports both Android and iOS smartphones and enables developers to attach native developed components if required.

- Vistual Studio [39] - an Integrated Development Environment (IDE) that supports developing for Unity with C#.

- PyCharm [85] - an IDE for Python development. PyCharm was used to train a convolutional neural network with Tensorflow.

- DB Browser for SQLite [18] - an open source tool to view, create, and edit SQLite databases. DB Browser for SQlite was used to design the SQLite database for the Moundville AR experience.

- Blender [11] - an open-source 3D modeling software. Blender was used to create 3D models for both the Moundville AR and VR experiences.

- GIMP [34] - an open-source image editing software. GIMP was used to create textures for the 3D models as well as to preprocess image databases for Tensorflow.

- Adobe PhotoShop [77] - a proprietary image editing software by Adobe. PhotoShop was used to create textures for the 3D models.

- Adobe Premier Pro [83] - a proprietary video editing software by Adobe. Premier Pro was used to transform exhibit video into an image sequence that served as the image dataset for image Tensorflow.

- Audacity [17] - an open source sound editor. Audacity was used to create the Moundville VR experience sound design.

The following software technologies were used:

- Tensorflow [100] Tensorflow was used to train a convolutional neural network to recognize the exhibits.

- Unity AR Foundation package [1] was used to position virtual objects within the real environment in the Moundville AR guide.

- Unity OpenCV package [79] was used to run camera frames through the generated neural network model.

- Unity Oculus package [31] was used to develop the Moundville VR game.

- Unity SQLite Database package [95] was used to store permanent app data.

5.5 Exhibit Recognition for the Moundville AR experience

The exhibits serve as the triggers for the Moundville AR experience. The first approach was to use NFT datasets to recognize the exhibits. The following libraries were attempted:

- ARToolkitX [7] - an open source computer vision libraries and tools. ARToolkitX can be compiled for both iOS and Android devices and can be added to a Unity project. Unlike many other Augmented Reality frameworks and toolkits relying on marker-based Augmented Reality, ARToolkitX is capable of natural feature tracking (NFT). ARToolkitX also provides tools to train and extract an NFT dataset for future runtime use in an application, allowing markerless Augmented Reality.

- Unity AR Foundation package [1] - this package supports native NFT recognition features for ARCore (Android) [14] and ARKit (iOS) [40].

- Vuforia [32] - Vuforia is a proprietary platform for developing AR applications. Vuforia provides a Unity library capable of recognizing NFTs free of charge.

For each exhibit, photos of that exhibit from different angles served as the NFT database. None of the libraries were able to provide a consistent recognition of the museum exhibits. The NFT recognition was not sufficient for a 3-dimensional object in a complex environment. The inconsistency of NFT recognition was also the point of failure for Blanco-Pons Silvia, et al. [10].

An image classifier can be trained using convolutional neural netowrks. Tensorflow [100] provides a toolset to train a custom image classifier.

The exhibits at Moundville Archaeological Park cannot be taken outside of their lockers without a specific permission. Even if taken out, the exhibits must be handled with care. The exhibits can be photographed only in a limited number of environments inside the museum building. With these limitations, it is impossible to naturally create an image dataset that is large and diverse enough to train an image classifier.

The transfer learning technique was used to overcome this issue. During transfer learning the top layers of a pre-trained (base) image classifier model are being unfrozen and retrained with the new dataset. This allows taking advantage of an image classifier model that was trained on a large dataset and tuning it to classify the custom dataset. Tensorflow allows for performing transfer learning out of the box [103]. The MobilenetV2 [92] was used as the base model.

To generate the custom dataset for the exhibits, the following steps were performed:

1. A high-definition (4K) video of the exhibit was taken in the museum.
2. The video was exported into a sequence of high-definition images.
3. The image sequence was cleaned of corrupted images:
    - Images where the exhibit is distorted due to camera moving abruptly
    - Images where the exhibit is distorted by the glare of the museum lights
    - Images where the exhibit is distorted by the elements of the exhibit lockbox

4. The remaining image sequence was broken into the following categories:

    - Training dataset: 50% of the images
    - Validation dataset: 25% of the images
    - Testing dataset: 25% of the images

The classifier was trained for 10 epochs. The training and validation accuracy, and the training and validation loss for the 10 epochs of image classifier training can be seen in the Figure 5.4. We will name our image classifier model MoundvilleClassifier.

Unity can accept only fully frozen models. The transfer learning unfreezes the top layers of the model. After the transfer learning, the newly created model must be frozen again before it can be imported into Unity.

Despite 100% training accuracy and 95% validation accuracy reported during the training, the real-life accuracy of the MoundvilleClassifier was lower. The accuracy of the MoundvilleClassifier over 30 scans is presented in the Table 5.1. As can be seen, the MoundvilleClassifier performed poorly for the Lipped Ceramic Vessel. This potentially happened due to close resemblance with the Caddoan Ceramic Bottle and Bat Effigy Bowl.

The MoundvilleClassifier was prone to produce false positives. The exhibits presented in the Figure 5.3 were mistakenly recognized as the Lipped Ceramic Vessel due to close resemblance. Several replicas of the museum exhibits included in the Moundville AR experience could be found in the museum installations depicting life in the Moundville. These replicas are also treated as false positives. A usual black cup was recognized as the Lipped Ceramic Vessel or the Caddoan Style Ceramic Bottle with more than 80% confidence.

To overcome these issues, the following two approaches were used in the Moundville AR experience:

- The threshold to consider the matching class recognized by the MoundvilleClassifier as a valid guess is 70% confidence.
- Using on-demand classification instead of ongoing classification. Instead of constantly classifying the frames received from the phone camera, the application asked the user

Table 5.1: Average accuracy of MoundvilleClassifier over 30 exhibit scans.

	Bat Effigy Bowl	Caddoan Ceramic Bottle	Human Effigy Bowl	Lipped Ceramic Vessel	Stepped Square Vessel	Stone Pendant
Accuracy	96%	100%	100%	67%	100%	100%

Figure 5.3: Example of artifacts at the Moundville Archaeological Park that were mistakenly recognized as the Lipped Ceramic Vessel.

to turn on the classifier (”to scan”) after the smartphone camera was pointed towards the exhibit. This significantly reduced the number of false positives because the users were scanning only the exhibits themselves. The scan time window was chosen to be 4 seconds.

- Asking for user’s assistance. To avoid mistakes between similar-looking exhibits, the users were asked to choose which exhibit was scanned from the top two matching classes if the difference in confidence between them was below 20%.

The flow diagram of the exhibit recognition can be found in the Figure 5.5

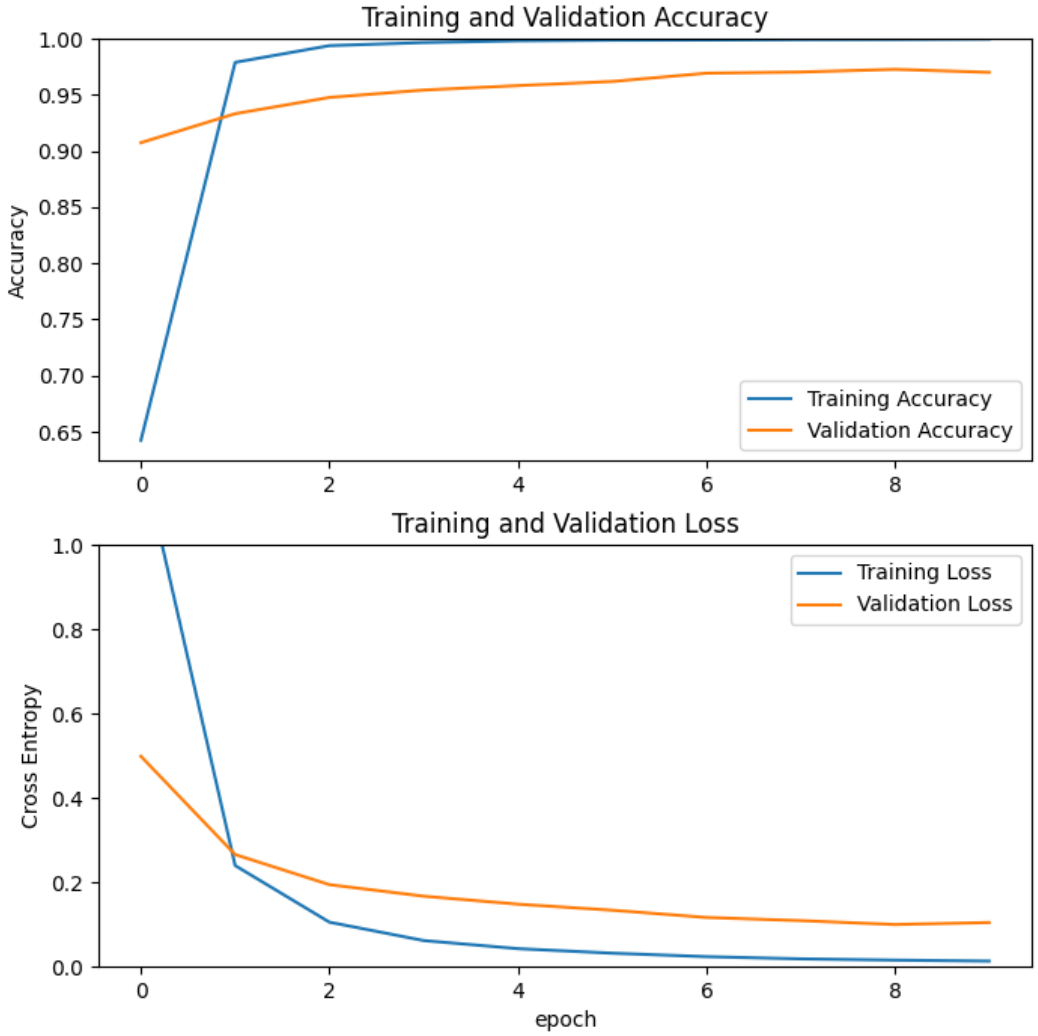


Figure 5.4: The training and validation accuracy, and the training and validation loss for the 10 epochs of transfer learning.

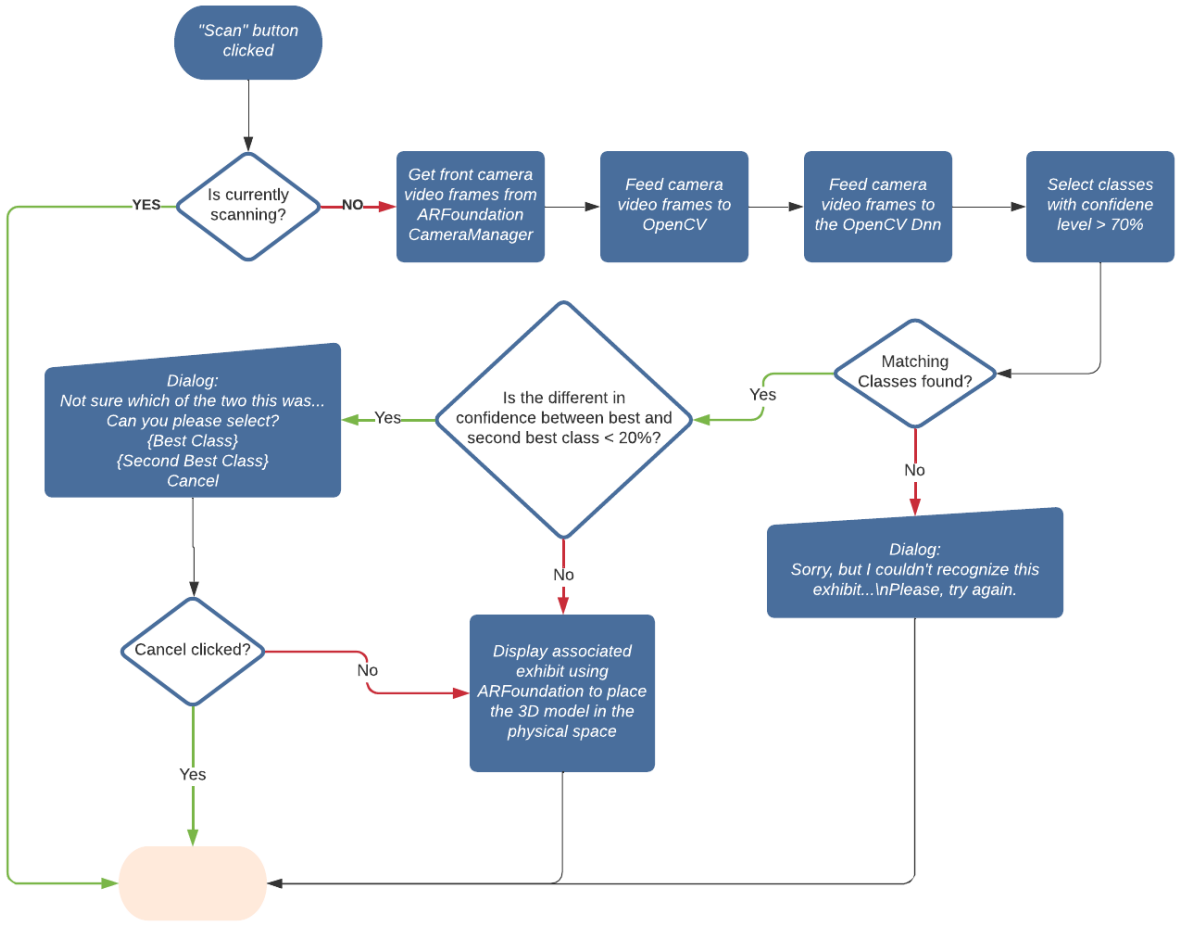


Figure 5.5: The flow diagram explaining the exhibit scan process in the Moundville AR experience.

Chapter 6

Results and Discussions

6.1 Visitor Head-Tracking in Museums

In total, 26 museum visitors agreed to participate in the research. The list of all participant demographics can be found in Table 6.1. There were 21 valid survey submissions and 14 valid camera footage records. More details about visitor and participant numbers can be found in Table 6.2.

The average visit length was 1785 seconds and the visit length standard deviation was 573 seconds. To normalize the focus length, the adjusted focus length was calculated for each exhibit for each visitor:

$$AdjustedFocusLength = \frac{FocusLength}{VisitLength} \tag{6.1}$$

The correlation coefficients between the adjusted focus length and the visitors' self-report of attention paid to the exhibits can be found in Table 6.6.

Exhibit A1 (painting) was dropped from the research. As seen in Figure 4.2, this exhibit is located right next to the participant check-in location. Although exhibit A1 did not appear in any footage, only 6 participants indicated not paying any attention to it at all. This may be due to participants attending exhibit A1 before or after wearing the headset.

As seen in Figure 4.2, exhibits A11 (installation) and A24 (wall of text) occupy large portions of the wall and are impossible to bypass during the visit. Hence, these exhibits can

Table 6.1: The list of all participants (total of 26).

Participant Code	Device	Notes	Visit Duration (mm:ss)	Visitor Persona	Exploration Style	Returning Visitor	Age
C1	Camera glasses	Corrupt Data	-	Experience Seeker; Recharger	Ant	Yes	60+
E1	Epson Moverio Bt-350	Corrupt Data	-	-	-	-	-
C2	Camera glasses	Corrupt Data	-	Explorer; Recharger	Ant Butterfly	Yes	21-29
E2	Epson Moverio Bt-350	No Survey Taken	20:19	-	-	-	-
C3	Camera glasses	Corrupt Data	-	Experience Seeker Professional/Hobbyist	Butterfly	No	40-49
C4	Camera glasses	-	28:18	Experience Seeker; Explorer	Ant	No	30-39
E3	Epson Moverio Bt-350	Distracting	-	-	-	-	-
C5	Camera glasses	-	40:34	Experience Seeker; Explorer	Ant	Yes	50-59
E4	Epson Moverio Bt-350	-	34:16	Explorer; Recharger	Ant Butterfly	No	20-29
E5	Epson Moverio Bt-350	Taking off the headset during the visit	22:51	Experience Seeker; Recharger	Fish Butterfly	Yes	21-29
C6	Camera glasses	-	10:26	Explorer; Professional/Hobbyist	Ant	Yes	21-29
C7	Camera glasses	-	29:11	Experience Seeker; Explorer	Fish	No	18-20
E6	Epson Moverio Bt-350	-	36:22	Explorer; Recharger	Ant	Yes	60+
E7	Epson Moverio Bt-350	-	26:11	Explorer; Professional/Hobbyist	Fish Butterfly	No	50-59
C8	Camera glasses	-	35:59	Experience Seeker; Explorer	Ant Butterfly	No	40-49
E8	Epson Moverio Bt-350	Distracting	-	-	-	-	-
E9	Epson Moverio Bt-350	Corrupt Data	-	Experience Seeker; Recharger	Ant Butterfly	Yes	21-29
E10	Epson Moverio Bt-350	Corrupt Data	-	Explorer; Professional/Hobbyist	Ant	Yes	21-29
C9	Camera glasses	-	46:00	Experience Seeker; Explorer	Fish Butterfly	Yes	21-29
E12	Epson Moverio Bt-350	Corrupt Data	-	Explorer; Recharger	Butterfly	Yes	21-29
C10	Camera glasses	-	25:38	Explorer; Recharger	Fish Butterfly	No	21-29
E11	Epson Moverio Bt-350	Out of Power	-	-	-	-	-
C11	Camera glasses	-	15:28	Experience Seeker; Explorer	Fish	No	21-29
C12	Camera glasses	Optical glasses worn over camera glasses	94:04	Explorer; Professional/Hobbyist	Ant Butterfly	Yes	60+
C13	Camera glasses	-	29:45	Explorer; Recharger	Butterfly	Yes	18-20
E13	Epson Moverio Bt-350	-	28:40	Experience Seeker; Explorer	Butterfly	No	21-29

Table 6.2: Visitors and participants.

	Number
Total visitors approached	43
Total visitors declining to participate	17
Visitors declining to participate due to videotaping-related privacy concerns	1
Visitors declining to participate due to previous unsatisfying experience with AR in museums	2
Total participants	26
Valid footage extracted from the headset camera	13
Valid survey completed on exit	21

Table 6.3: Results of survey questions on privacy concerns associated with AR headset camera.

Question	Not concerned (0)	Somewhat concerned (1)	Somewhat concerned (2)
Augmented Reality devices rely heavily on cameras. Are you concerned with violating other people's privacy while wearing a device with a camera?	66.6% (14)	33.3% (7)	0% (0)
Are you concerned with people wearing a device with a camera violating your privacy?	76.2% (16)	23.8% (5)	0% (0)

Table 6.4: Results of survey question on if wearing the AR camera affects their behavior.

Question	Strongly disagree (0)	Somewhat disagree (1)	Neither agree nor disagree (2)	Somewhat agree (3)	Strongly agree (4)
Did the head-mounted camera affect your behavior during visit?	28.6% (6)	4.8% (1)	14.3% (3)	33.3% (7)	9.5% (2)

Table 6.5: Results of survey question on if wearing the AR camera obstructed their experience.

Question	Definitely not (0)	Probably not (1)	Might or might not (2)	Probably yes (3)	Definitely yes (4)
Was the head-mounted camera obstructing?	23.8% (5)	19.0% (4)	9.5% (2)	28.6% (6)	0% (0)

Table 6.6: Correlation between adjusted focus length and the visitors' estimation of attention paid to the exhibit in the survey. Green - strong correlation, White - moderate correlation, Yellow - Moderate correlation, but statistically insignificant, Orange - No correlation.

#	Exhibit Code	Correlation to survey reports	Statistical Significance
1	A1	N/A	N/A
2	A60	$R = 0.62$ Moderate Positive	$p = 0.018$ Significant
3	A2	$R = 0.67$ Moderate Positive	$p = 0.008$ Significant
4	A24	$R = 0.51$ Moderate Positive	$p = 0.062$ Not Significant
5	A59	$R = 0.73$ Moderate Positive	$p = 0.003$ Significant
6	A20	$R = 0.80$ Strongly Positive	$p = 0.0005$ Significant
7	A4	$R = 0.3$ No Correlation	$p = 0.29$ Not Significant
8	A32	$R = 0.61$ Moderate Positive	$p = 0.02$ Significant
9	A49	$R = 0.40$ No Correlation	$p = 0.15$ Not Significant
10	A16	$R = 0.24$ No Correlation	$p = 0.41$ Not Significant
11	A55	$R = 0.79$ Strongly Positive	$p = 0.0007$ Significant
12	A27	$R = 0.61$ Moderate Positive	$p = 0.02$ Significant
13	A23	$R = 0.23$ No Correlation	$p = 0.042$ Significant
14	A31	$R = 0.63$ Moderate Positive	$p = 0.015$ Significant
15	A51	$R = 0.37$ No Correlation	$p = 0.19$ Not Significant
16	A58	$R = 0.51$ Moderate Positive	$p = 0.006$ Not Significant
17	A10	$R = 0.32$ No Correlation	$p = 0.26$ Not Significant
17	A11	$R = 0.26$ No Correlation	$p = 0.2$ Not Significant

be centered in the footage frames without the participants paying attention. Additionally, participants may observe them with their side eyesight, which is impossible to capture with a head-mounted camera alone.

The AR-enabled exhibit A10 illustrated another issue. With A10, the participants spent a significant amount of time reading the exhibit description compared to viewing the exhibit itself. A similar behavior can be observed for exhibits A31 (installation of two paintings), A32 (painting), and A38 (blanket with paintings).

The exhibits A49 (sculpture), A16 (clothing exhibits on a manikin), and A4 (sculpture) closely resemble some of the other exhibits in the museum. This can explain the lack of correlation between the captured footage and the survey results. More analysis of the footage is required to draw a conclusion. Additionally, due to their location, all three exhibits can be observed without being centered in the footage frame.

In Figure 4.2 it can be seen that exhibit A51 appears as the first exhibit when a visitor enters the exhibition hall. This had potentially distorted the visitor behavior regarding exhibit A51, hence the lack of correlation.

Exhibit A58 also appears in the center of the exhibition hall. So visitors could potentially view it from a distance or with side eyesight, hence the lack of correlation.

As can be seen in Figure 4.2, due to its location, a visitor viewing exhibit A55 is not distracted by other exhibits. Similarly, exhibit A20, being installed on a table, requires the visitor to look down at the table to view the exhibit. In both cases, the visitor behavior is simple, with the head direction being explicitly connected with attention. Hence, the a strong correlation of results.

It can be concluded that Hypothesis 1 holds for some of the exhibits.

The Hypothesis 1 not holding for some of the exhibits illustrates the pitfalls of the simplistic approach towards measuring the focus length. Individual exhibits and installations require a system of weights applied to the focus length based on the position of the exhibit within a frame, its size within a frame, and the speed of the head movement. Further research is required to develop a framework addressing this issue.

Table 6.7: The percentage of correctly guessed exhibits within an installation that the visitor payed most attention to, and the T-test against the desired guess value of 80%.

Exhibit Code	Guessed %	T-test
A55	46.15%	$t(13) = -2.35$ $p < 0.05$
A27	50%	$t(13) = -1.98$ $p < 0.05$
A31	23.07%	$t(13) = -4.68$ $p < 0.05$
A58	76.92%	$\mathbf{t(13) = -0.25}$ $\mathbf{p = 0.4}$

Table 6.8: The results of T-tests of the results of the survey question "Did the head-mounted camera affect your behavior during visit?" against the positive scale values "Strongly agree (4)" and "Somewhat agree (3)"

Population	Average Score	T-test against "Somewhat agree (3)"	T-test against "Strongly agree (4)"
All participants (21)	1.74	$t(21) = -3.87$ $p < .05$	$t(13) = -6.88$ $p < .05$
Participants with camera glasses (13)	1.23	$t(13) = -4.15$ $p < .05$	$t(13) = -6.5$ $p < .05$
Participants with Epson Moverio Bt-350 smart glasses (8)	2.5	$\mathbf{t(8) = -1.18}$ $\mathbf{p = .27}$	$t(8) = -3.54$ $p < .05$

For each exhibit in the installation, the one with the longest adjusted focus length was selected. These selections were matched against the visitors' self-report of the exhibit within an installation to which they directed most attention, as seen in Table 6.7.

The Hypothesis 2 not holding for installations A55 and A31 illustrates the issue that using an AR headset camera between closely located exhibits as an AR headset camera cannot capture the eye movements between these exhibits.

The Hypothesis 2 not holding for installation A27 should be investigated further to understand the visitor behavior towards this particular exhibit and tune the focus length measurement approach.

The installation A58 illustrates an ideal scenario for an AR headset camera. The exhibits within the installation are located relatively far away. Visitors clearly favored exhibit A58-A over the A58-B. So there was no eye movement between the two exhibits.

It can be concluded that Hypothesis 2 holds for certain scenarios.

Table 6.9: The results of T-tests of the results of the survey question "Was the head-mounted camera obstructing?" against the positive scale values "Definitely yes (4)" and "Probably yes (3)"

Population	Average Score	T-test against "Probably yes (3)"	T-test against "Definitely yes (4)"
All participants (21)	1.61	$t(21) = -5.25$ $p < .05$	$t(13) = -9.06$ $p < .05$
Participants with camera glasses (13)	1	$t(13) = -7.21$ $p < .05$	$t(13) = -10.81$ $p < .05$
Participants with Epson Moverio Bt-350 smart glasses (8)	2.62	$\mathbf{t(8) = -1.42}$ $\mathbf{p = 0.2}$	$t(8) = -5.22$ $p < .05$

Table 6.10: The results of T-tests of the results of the survey question "Augmented Reality devices rely heavily on cameras. Are you concerned with violating other people's privacy while wearing a device with a camera?" against the value "Not concerned (0)"

Population	Average Score	T-test against "Not concerned (3)"
All participants (21)	0.3	$t(21) = -3.16$ $p < .05$
Young and middle-aged adults (15)	0.35	$t(15) = 3.05$ $p < .05$
Older adults (6)	0.16	$\mathbf{t(6) = 1}$ $\mathbf{p = 0.36}$

Table 6.11: The results of T-tests of the results of the survey question "Are you concerned with people wearing a device with a camera violating your privacy?" against the value "Not concerned (0)"

Population	Average Score	T-test against "Not concerned (3)"
All participants (21)	0.2	$t(21) = 2.5$ $p < .05$
Young and middle-aged adults (15)	0.21	$t(15) = 2.25$ $p < .05$
Older adults (6)	0.16	$\mathbf{t(6) = 1}$ $\mathbf{p = .036}$

The results of the survey question ”Did the head-mounted camera affect your behavior during the visit?” can be seen in Table 6.4. The results of can be seen in Table 6.8. The Hypothesis 3 holds for Epson Moverio Bt-350 users against ”Somewhat agree (3)”. This is supported by the complaints from some of the participants that they constantly expect an AR experience to launch, albeit told that only the camera of the AR headset is enabled. Unlike the camera glasses, the Epson Moverio also had an idle virtual user interface displayed during the experiment. The Hypothesis 3 holds for the case of using Epson Moverio Bt-350 AR headset with the virtual interface.

The results of the survey question ”Was the head-mounted camera obstructing?” can be seen in Table 6.4. The results can be seen in Table 6.9. The Hypothesis 4 holds for Epson Moverio Bt-350 users against ”Probably yes (3)”. This is supported by two participants pausing the participation complaining the AR headset distracts their experience, and two visitors rejecting to participate under the pretext that their previous AR experience at the museum was distracting. Unlike the camera glasses, the Epson Moverio Bt-350 also had an idle virtual user interface displayed during the experiment. The Hypothesis 4 holds for the case of using Epson Moverio Bt-350 Bt-350 AR headset with the virtual interface.

The results of the survey questions ”Augmented Reality devices rely heavily on cameras. Are you concerned with violating other people’s privacy while wearing a device with a camera?” and ”Are you concerned with people wearing a device with a camera violating your privacy?” can be seen in Table 6.3. The results of T-tests against the value ”Not concerned (0)” can be seen in Table 6.10 and in Table 6.11. The Hypothesis 5 did hold.

The questions by the museum curators were answered as follows based on the footage analysis:

1. *There museum exhibition halls are interconnected creating a loop. No signage of which direction to start from is provided to the visitors. Is there a preference in the start direction among the visitors?* No preferences were indicated, participants split evenly.

2. *Do visitors engage with the AR experience of exhibit A10?* No, the visitors did not.

3. *Do visitors pay attention to exhibit A24?* The visitors spend 10 seconds at exhibit A24 on average. Given that the text in exhibit A24 takes 80 seconds to read, it can be safely assumed that the visitors didn't attend exhibit A24.

4. *Do visitors pay attention to the installation A27?* Yes, the visitors spend 2 minutes at the installation A27 on average.

5. *What part of the installation A27 is the most popular among the visitors?* Based solely on the footage, 61% of visitors attended exhibit C, 23% of visitors attended exhibit B, and 23% of visitors attended exhibit A.

6. *Do visitors have a preference between the two paintings in the installation A31?* Based solely on the footage, both paintings were equally attended by the visitors.

7. *The exhibits A32 and A38 are next to each other and share a similar color pattern. Exhibit A38 is the first to view when a visitor enters the exhibition hall. Is exhibit A32 neglected?* Contrary to the museum curator expectations, visitors spent 3 seconds longer attending exhibit A32 on average.

8. *Do visitors pay attention to exhibit A59?* It was assumed by the curators that exhibit A59 is neglected. 50% of the visitors paid attention to exhibit A59. On average, the visitors viewed it for 7.2 seconds. It can be assumed that the visitors do pay attention to exhibit A59.

9. *Do visitors pay attention to exhibit A60?* It was assumed by the curators that exhibit A60 is neglected. 50% of the visitors paid attention to exhibit A60. On average, the visitors viewed it for 9.3 seconds. It can be assumed that the visitors do pay attention to exhibit A60.

6.2 Applications of AR/VR for Museum Sustainability

49 participants completed the public survey. The demographics of these participants can be found in the Table 6.12. The participants do present a diverse group by age, education, exhibition preferences and perception of a museum's role.

Personalised emails were sent to 30 museums asking for participation in the survey. A request was sent to the Southeastern Museum Conference asking to distribute the survey among the member museums. 4 museums responded with an interest to participate in the research. No survey results were received.

At the Moundville Archaeological Park, 32 visitors were recruited over 2 weekends to participate in the Control Group. 22 visitors were recruited over 4 weekends to participate in the Case Group. The reason for slower enrollment for the Case Group was not the lack of willingness of the participants, but that only a single participant was accommodated at a time. The demographics of these participants can be found in the Table 6.13 and Table 6.14. The participants do present a diverse group by age, education, museum visitor persona and exhibition exploration style. The low number of participants under age of 18 can be considered a limitation of this research as middle schoolers and high schoolers are considered as one of the target population of the Moundville Archaeological Park.

Museum Economic Sustainability

As it can be seen from the Table 6.15 and Table 6.16, the presence of an AR and VR experience did not result in a higher chance of a revisit or a referral. Although the visitors from the Case Group indicated that AR and VR experiences did positively affect their intention to revisit the Moundville Archaeological Park or to recommend it to a friend, it can be safely concluded that both Hypothesis 6 and Hypothesis 7 did not hold. It must be mentioned, that the location of Moundville Archaeological Park may affect these results. The Moundville Archaeological Park is located in a rural/suburban area and requires a significant travel to visit.

The Table 6.17 and Table 6.18 present the experience of the Control and Case Groups with museum store purchases. Although from the first glance it can be inferred that the Moundville AR experience did successfully increase the percentage of the visitors performing a purchase, these visitors would have performing the purchase anyway. Hence, it can be concluded that the Hypothesis 9 did not hold. It should be mentioned that at the time of the experiment the items at the Moundville museum food store/cafeteria included only a small choice of ice cream, drinks, jerky, and coffee, and the main customers were kids and families with kids. Out of 10 Case

Table 6.12: Public Survey Participant Demographics.

	18-20	21-30	31-40	41-50	Above 50
Age	20.41% (10)	34.69% (17)	22.45% (11)	16.33% (8)	6.12% (3)

	Middle School	High School	College	Undergraduate	Graduate
Education Level	0% (0)	14.29% (7)	4.08% (2)	46.94% (23)	38.78% (19)

	Extremely bad	Somewhat bad	Somewhat good	Extremely good
How would you rate your computer skills and knowledge?	0% (0)	4.08% (2)	74.47% (36)	22.45% (11)

	Not familiar at all	Somewhat familiar	Extremely familiar
How familiar are you with AR?	16.33% (8)	57.14% (28)	6.12% (3)
How familiar are you with VR?	6.12% (3)	67.35% (33)	12.24% (6)

	Definitely no	Probably no	Might or might not	Probably yes	Definitely yes
Did the videos in the beginning of the survey help you better understand what AR and VR is?	0% (0)	0% (0)	20.41% (10)	53.06% (26)	26.53% (13)
Did the videos in the beginning of the survey help you better understand how AR and VR can be used at a museum?	0% (0)	0% (0)	14.29% (7)	48.98% (24)	34.69% (17)

	Once in few years	Once a year	More than once a year
How often do you visit museums?	28.57% (14)	38.78% (19)	32.65% (16)

	Art – paintings	Art – installations	Art – pots and sculptures	Natural History	Human History	Technological	Science	Kids – Educational	Thematic company/ product exhibition	Interactive Exhibitions
What type of exhibitions do you prefer to visit?	67.35% (33)	46.94% (23)	32.65% (16)	53.06% (26)	44.9% (22)	36.73% (18)	65.31% (32)	0% (0)	18.37% (9)	51.02% (25)

	Preserve	Present / Showcase	Informal Education	Entertainment	Recreation
What you think is the main purpose of a museum?	73.47% (36)	71.43% (35)	85.71% (42)	63.27% (31)	34.69% (17)

Table 6.13: Moundville Control Group Participant Demographics.

	Under 18	18-20	21-30	31-40	41-50	Above 50
Age	12.5% (4)	18.75% (6)	15.63% (5)	18.75% (6)	12.5% (4)	21.88% (7)

	Middle School	High School	College	Undergraduate	Graduate
Education Level	6.25% (2)	15.63% (5)	28.12% (9)	26% (8)	25% (8)

	Yes	No
Have you been to Moundville before?	37.5% (12)	62.5% (20)

	Ant	Fish	Grasshopper	Butterfly
Please, select the two exploration style descriptions that fit most to your current visit	53.2% (17)	50% (16)	6.25% (2)	3.12% (1)

	Explorer	Recharger	Experience Seeker	Facilitator	Professional
Please, select the two visitor descriptions that fit most to your current visit	87.5% (28)	37.5% (12)	12.5% (4)	9.37% (3)	6.25% (2)

	Yes	No
Where you at Moundville today for a specific event?	21.8% (7)	78.2% (25)

Table 6.14: Moundville Case Group Participant Demographics.

	Under 18	18-20	21-30	31-40	41-50	Above 50
Age	12% (3)	8% (2)	24% (6)	12% (3)	20% (5)	20% (5)

	Middle School	High School	College	Undergraduate	Graduate
Education Level	8% (2)	8% (2)	20% (5)	24% (6)	32% (8)

	Yes	No
Have you been to Moundville before?	20% (5)	80% (20)

	Ant	Fish	Grasshopper	Butterfly
Please, select the two exploration style descriptions that fit most to your current visit	56% (14)	12% (4)	16% (3)	56% (14)

	Explorer	Recharger	Experience Seeker	Facilitator	Professional
Please, select the two visitor descriptions that fit most to your current visit	96% (24)	8% (2)	24% (6)	4% (1)	36% (9)

	Yes	No
Where you at Moundville today for a specific event?	4% (1)	96% (24)

Table 6.15: Moundville Control Group, chances for revisits and referrals.

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score
Will you revisit Moundville?	0% (0)	12.5% (4)	0% (0)	31.25% (10)	56.25% (18)	3.24
Will you recommend Moundville to a friend?	0% (0)	0% (0)	0% (0)	15.63% (5)	84.38% (27)	3.92

Table 6.16: Moundville Case Group, chances for revisits and referrals. * *The 7 participants who indicated that they are not going to revisit the Moundville Archaeological Park have also indicated that AR/VR experience did not influence their decision. Hence, they were removed from the average score calculations for this particular case.*

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score
Will you revisit Moundville?	0% (0)	28% (7)	0% (0)	40% (10)	32% (8)	2.76
Did the AR/VR experience influence this decision?	28% (7)	12% (3)	12% (3)	12% (3)	36% (9)	3*
Will you recommend Moundville to a friend?	0% (0)	0% (0)	0% (0)	48% (12)	52% (13)	3.52
Did the AR/VR experience influence this decision?	0% (0)	12% (3)	4% (1)	48% (12)	36% (9)	3.08

Table 6.17: Moundville Control Group experience with the Moundville food and souvenir store.

	Yes	No
Did you purchase anything from the Moundville Museum food store?	28.12% (9)	71.87% (23)
Did you purchase anything from the Moundville Museum souvenir store?	28.12% (9)	71.87% (23)

	Always	Often	Sometimes	Seldom	Never
When visiting a museum, do you make purchases at museum food stores or cafeterias?	9.37% (3)	15.62% (5)	46.87% (15)	28.12% (9)	0% (0)
When visiting a museum, do you make purchases at museum souvenir stores or cafeterias?	15.62% (5)	21.87% (7)	31.25% (10)	31.25% (10)	0% (0)

	Strongly Disagree (0)	Somewhat Disagree (1)	Undecided (2)	Somewhat Agree (3)	Strongly Agree (4)	Average Score
Would you purchase anything from the Moundville Museum food store, if 25% discount was given?	0% (0)	6.25% (2)	34.37% (11)	34.37% (11)	21.87% (7)	2.65
Would you purchase anything from the Moundville Museum souvenir store, if 10%-25% discount was given?	0% (0)	0% (0)	34.37% (11)	40.62% (13)	21.87% (7)	2.78

Table 6.18: Moundville Case Group experience with the Moundville food and souvenir store. The second table is given only for the participants who did achieve the prize. The third table presents the results only for the participants who did use the prize.

	Yes	No	Didn't achieve it
Did you use the prize?	40% (10)	36% (9)	24% (6)

	Strongly Disagree (0)	Somewhat Disagree (1)	Undecided (2)	Somewhat Agree (3)	Strongly Agree (4)	Average Score	p-test (against score 3 and 4)
Were you satisfied with the prize?	0% (0)	0% (0)	0% (0)	24% (6)	48% (12)	3.67	$p < 0.05$
Would you make the purchase, even if you hadn't had the prize?	4% (1)	12% (3)	8% (2)	36% (9)	12% (3)	2.56	$p < 0.05$

	Strongly Disagree (0)	Somewhat Disagree (1)	Undecided (2)	Somewhat Agree (3)	Strongly Agree (4)	Average Score	p-test (against score 3 and 4)
Were you satisfied with the prize?	0% (0)	0% (0)	0% (0)	20% (2)	80% (8)	3.8	$p < 0.05$
Would you make the purchase, even if you hadn't had the prize?	0% (0)	0% (0)	10% (1)	70% (7)	30% (3)	3.5	$p < 0.05$

Table 6.19: Case group opinions on if the Moundville VR experience should be monetized.

	No fee	Less than $5	$5-$10	More than $10			
How much would you pay for the Moundville VR experience in additional to the admission fee?	28% (7)	20% (5)	48% (12)	4% (1)			
	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score	p-test (against score 3 and 4)
If you had a VR headset, would you download the Moundville VR experience to play at home?	8% (2)	4% (1)	24% (6)	32% (8)	32% (8)	2.76	$p < 0.0$
	No fee	Less than $5	$5-$10	More than $10			
Value of the Moundville VR (fee or purchase)	16% (4)	24% (6)	56% (14)	4% (1)			

Table 6.20: Control group opinions on if museum AR/VR experiences should be monetized.

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score	p-test (against score 3 and 4)
Would you pay an additional admission fee for these experiences?	3.12% (1)	6.25% (2)	34.37% (11)	28.12% (9)	28.12% (9)	2.7	$p < 0.05$

Table 6.21: Public survey opinions on if museum AR/VR experiences should be monetized.

	No additional charges	0-10% of original museum fee	10-25% of original museum fee	25-50% of original museum fee
In your opinion, must visitors be charged additionally for the AR/VR experience?	46.94% (23)	36.73% (18)	14.29% (7)	2.04% (1)

Group participants who did use the price 8 were kids or families with kids, and only 2 were individual adults.

The opinions on monetising the Moundville VR experience by the Case Group, the Control Group, and the public survey participants can be found in the Table 6.19, the Table 6.20 and the Table 6.21 respectfully. From the Table 6.20 and Table 6.21 it can be concluded that the monetising the Moundville VR experience is not favorable. However, the Table 6.19 clearly indicates that the Case Group did see monetary value in the Moundville VR experience. One of the issues may be the wording of the questions for the public survey and the Control Group that united the monetising Augmented and Virtual Reality into a single question. It can be safely concluded that the Hypothesis 8 does hold.

It can be concluded that the Hypothesis 9 did not hold.

Museum Environmental Sustainability

The perception of the effect of Moundville AR and VR experiences on sustaining the local environment by the Case Group can be seen in Table 6.23. The perception of the Control Group and Case Group on Moundville's efforts to sustain the local environment can be fond in the Table 6.22 and Table 6.23 respectively.

It can be safely assumed that the Augmented and Virtual reality were perceived to help the Moundville Archaeological Park to contribute to the sustainability of the local environment. However, the perception of Moundville's contribution towards sustaining the local environment was unchanged between the Control and Case groups. It can be concluded, that Hypothesis 10 holds.

Museum Social Sustainability

The perceived opinion of the level of necessity of Augmented and Virtual Reality at Moundville by participants of the public survey and the Control Group are presented in the Table 6.24 and Table 6.25 accordingly. It can be concluded that the 11 holds. The Augmented and Virtual Reality experiences are not seen as a requirement, but as a nice addition to the museum experience.

Table 6.22: The perception of the effect of Augmented and Virtual Reality on environmental sustainability by the Moundville Control Group.

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Definitely Agree (3)	Somewhat Agree (4)	Average Score
Do you think Moundville helps to sustain the local environment?	0% (0)	0% (0)	3.12% (1)	59.27% (19)	37.5% (12)	3.34

Table 6.23: The perception of the effect of Augmented and Virtual Reality on environmental sustainability by the Moundville Case Group.

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Definitely Agree (3)	Somewhat Agree (4)	Average Score
Do you think Moundville helps to sustain the local environment?	(0)	(0)	28% (7)	36% (9)	36% (9)	3.08
The Virtual Reality app helps Moundville to sustain the local environment	(0)	(0)	32% (8)	36% (9)	32% (8)	3
The Augmented Reality app helps Moundville to sustain the local environment	(0)	(0)	36% (9)	20% (5)	44% (11)	3.08

Table 6.24: The perceived opinion of the level of necessity of Augmented and Virtual Reality in a museum by participants of the public survey.

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score	p-test (against score 3 and 4)
AR and VR experiences are a nice addition to a modern museum experience.	0% (0)	4.08% (2)	4.08% (2)	38.78% (19)	53.06% (26)	3.4	$p < 0.05$
AR and VR experiences are a requirement for a modern museum experience.	0% (0)	0% (0)	0% (0)	15.63% (5)	84.38% (27)	2.2	$p < 0.05$
Imagine the following situation. There are two museums, equally interesting to you, but due to your schedule, you can visit only one. One of them has an AR/VR experience. Would you choose it?	2.04% (1)	6.12% (3)	6.12% (3)	55.1% (27)	30.61% (15)	3.06	$p < 0.05$
Imagine the following situation. There are two museums, equally interesting to you, but due to your schedule, you can visit only one. One of them has a gamified experience. Would you choose it?	0% (0)	0% (0)	18.37% (9)	44.9% (22)	30.61% (15)	2.93	$p < 0.05$

Table 6.25: The perceived opinion of the level of necessity of Augmented and Virtual Reality at Moundville by participants of the Control Group.

	Strongly Disagree (0)	Disagree (1)	Undecided (2)	Agree (3)	Strongly Agree (4)	Average Score	p-test (against score 3 and 4)
Do you think it WILL BE GREAT for Moundville to have an Augmented Reality experience?	0% (0)	0% (0)	6.25% (2)	28.12% (9)	65.62% (21)	3.59	$p < 0.05$
Do you think it IS REQUIRED for Moundville to have an Augmented Reality experience?	0% (0)	7% (21.87)	10% (31.25)	37.5% (12)	9.37% (3)	2.34	$p < 0.05$
Do you think it WILL BE GREAT for Moundville to have an Virtual Reality experience?	0% (0)	0% (0)	15.62% (5)	28.12% (9)	56.25% (18)	3.40	$p < 0.05$
Do you think it IS REQUIRED for Moundville to have an Virtual Reality experience?	3.12% (1)	25% (8)	25% (8)	31.25% (10)	15.62% (5)	2.31	$p < 0.05$

Table 6.26: Moundville Control Group, evaluation of the current visit.

	None of them	Some of them	Most of them	All of them			
Did you view all exhibits at Moundville Museum?	0% (0)	12.5% (4)	21.87% (7)	65.62% (21)			
Did you view all exhibit descriptions at Moundville Museum?	3.12% (1)	28.12% (9)	40.62% (13)	28.12% (9)			
	Not valuable at a all (0)	Somewhat valuable (1)	Very valuable (2)			Average Score	p-test (against score 2)
How valuable do you think Moundville is for the society?	0% (0)	15.62% (5)	84.37 (27)			1.84	$p < 0.05$
	Very Poor (0)	Poor (1)	Acceptable (2)	Good (3)	Very Good (4)	Average Score	p-test (against score 3 and 4))
Please, rate your overall experience at Moundville	0% (0)	0% (0)	0% (0)	21.87% (7)	78.12 (25)	3.78	$p < 0.05$
	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score	p-test (against score 3 and 4)
My visit to Moundville was educational, I learnt something new	0% (0)	0% (0)	6.25% (2)	28.12% (9)	65.62% (21)	3.59	$p < 0.05$
My visit to Moundville was fun, I was entertained	0% (0)	0% (0)	3.12% (1)	12.5% (4)	84.37% (27)	3.81	$p < 0.05$
My visit to Moundville was relaxing and recharging	0% (0)	0% (0)	0% (0)	46.87% (15)	53.12% (17)	3.53	$p < 0.05$

Table 6.27: Moundville Case Group, evaluation of the current visit.

	None of them	Some of them	Most of them	All of them			
Did you view all exhibits at Moundville Museum?	0% (0)	12% (3)	28% (7)	60% (15)			
Did you view all exhibit descriptions at Moundville Museum?	8% (2)	24% (6)	48% (12)	20% (5)			
	Not valuable at a all (0)	Somewhat valuable (1)	Very valuable (2)			Average Score	p-test (against score 2)
How valuable do you think Moundville is for the society?	0% (0)	24% (6)	76% (19)			1.76	$p < 0.05$
	Very Poor (0)	Poor (1)	Acceptable (2)	Good (3)	Very Good (4)	Average Score	p-test (against score 3 and 4))
Please, rate your overall experience at Moundville	0% (0)	0% (0)	0% (0)	24% (6)	76% (19)	3.76	$p < 0.05$
	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Somewhat Agree (3)	Definitely Agree (4)	Average Score	p-test (against score 3 and 4)
My visit to Moundville was educational, I learnt something new	0% (0)	0% (0)	8% (2)	12% (3)	80% (20)	3.72	$p < 0.05$
The Moundville VR experience made my visit more educational	0% (0)	0% (0)	8% (2)	36% (9)	56% (14)	3.48	$p < 0.05$
The Moundville AR experience made my visit more educational	0% (0)	0% (0)	0% (0)	44% (11)	56% (14)	3.56	$p < 0.05$
My visit to Moundville was fun, I was entertained	0% (0)	0% (0)	0% (0)	16% (4)	84% (21)	3.84	$p < 0.05$
The Moundville VR experience made my visit more entertaining	0% (0)	0% (0)	4% (1)	8% (2)	88% (22)	3.84	$p < 0.05$
The Moundville AR experience made my visit more entertaining	0% (0)	4% (1)	0% (0)	36% (9)	60% (15)	3.52	$p < 0.05$
My visit to Moundville was relaxing and recharging	0% (0)	0% (0)	0% (0)	24% (6)	76% (19)	3.76	$p < 0.05$
The Moundville VR experience made my visit more relaxing and recharging	0% (0)	4% (1)	8% (2)	36% (9)	44% (11)	3.36	$p < 0.05$
The Moundville AR experience made my visit more relaxing and recharging	0% (0)	0% (0)	12% (3)	44% (11)	44% (11)	3.32	$p < 0.05$

Table 6.28: The Case Group visitors' assessment of the Moundville VR experience

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Definitely Agree (3)	Somewhat Agree (4)	Average Score	p-test (against score 3 and 4)
Educational Experience						**3.54**	
The Moundville VR experience provided knowledge beyond what was presented in the museum	0% (0)	0% (0)	12% (3)	32% (8)	56% (14)	3.44	$p < 0.05$
The app was educational	0% (0)	0% (0)	4% (1)	28% (7)	68% (17)	3.64	$p < 0.05$
I feel like I know more about Moundville and Native Americans after playing the VR app	0% (0)	4% (1)	8% (2)	36% (9)	52% (13)	3.6	$p < 0.05$
Esthetic Experience						**3.68**	
The app was pleasant	0% (0)	0% (0)	0% (0)	20% (5)	80% (20)	3.8	$p < 0.05$
The app was attractive	0% (0)	4% (1)	4% (1)	24% (6)	68% (17)	3.56	$p < 0.05$
Entertainment Experience						**3.43**	
The app was fun	0% (0)	0% (0)	4% (1)	24% (6)	72% (18)	3.68	$p < 0.05$
The app was amusing	0% (0)	0% (0)	8% (2)	24% (7)	64% (16)	3.56	$p < 0.05$
The app was entertaining	0% (0)	0% (0)	4% (1)	48% (12)	48% (12)	3.44	$p < 0.05$
The app was captivating	0% (0)	4% (1)	36% (8)	20% (5)	44% (11)	3.04	$p < 0.05$
Application						**3.25**	
The app was easy to use	0% (0)	4% (1)	0% (0)	40% (10)	56% (14)	3.48	$p < 0.05$
The Virtual Reality world felt realistic	8% (2)	16% (4)	4% (1)	32% (8)	40% (10)	2.8	$p < 0.05$
I felt like I visited ancient Moundville	0% (0)	4% (2)	4% (2)	60% (15)	24% (6)	3.0	$p < 0.05$
I felt like I visited an ancient Native American house	0% (0)	8% (2)	16% (4)	36% (9)	40% (10)	3.08	$p < 0.05$
I will tell my friends and family about this experience	0% (0)	0% (0)	12% (3)	12% (3)	76% (19)	3.64	$p < 0.05$
Would you recommend other Moundville visitors to use this app?	4% (1)	0% (0)	8% (2)	20% (5)	68% (17)	3.48	$p < 0.05$
	None of them	Some of them	Most of them	All of them			
Did you read all educational materials in the app?	20% (5)	28% (7)	36% (9)	12% (3)			
Did you pick up and view the exhibits in the app?	8% (2)	36% (9)	28% (7)	24% (6)			

Table 6.29: The Case Group visitors' assessment of the Moundville AR experience

	Definitely Disagree (0)	Somewhat Disagree (1)	Not Sure (2)	Definitely Agree (3)	Somewhat Agree (4)	Average Score	p-test (against score 3 and 4)
Educational Experience						**3.42**	
The Moundville AR experience provided knowledge beyond what was presented in the museum	0% (0)	4% (1)	12% (3)	28% (7)	56% (14)	3.36	$p < 0.05$
The app was educational	0% (0)	0% (0)	0% (0)	36% (9)	64% (16)	3.64	$p < 0.05$
I feel like I know more about Moundville and Native Americans after playing the AR app	0% (0)	8% (2)	0% (0)	32% (8)	56% (14)	3.28	$p < 0.05$
Esthetic Experience						**3.6**	
The app was pleasant	0% (0)	0% (0)	12% (3)	12% (3)	76% (19)	3.64	$p < 0.05$
The app was attractive	0% (0)	4% (1)	8% (2)	16% (4)	72% (18)	3.56	$p < 0.05$
Entertainment Experience						**3.43**	
The app was fun	0% (0)	4% (1)	4% (1)	16% (4)	76% (19)	3.64	$p < 0.05$
The app was amusing	0% (0)	4% (1)	8% (2)	20% (5)	68% (17)	3.52	$p < 0.05$
The app was entertaining	0% (0)	4% (1)	4% (1)	32% (8)	60% (15)	3.48	$p < 0.05$
The app was captivating	0% (0)	4% (1)	16% (4)	24% (6)	56% (14)	3.32	$p < 0.05$
Application						**3.25**	
The app was easy to use	4% (1)	0% (0)	0% (0)	44% (11)	52% (13)	3.4	$p < 0.05$
The exhibit scanning worked perfectly	0% (0)	12% (3)	12% (3)	44% (11)	28% (7)	2.8	$p < 0.05$
The app design represents the Moundville Heritage well	0% (0)	0% (0)	16% (4)	20% (5)	60% (15)	3.32	$p < 0.05$
I will tell my friends and family about this experience	0% (0)	0% (0)	4% (1)	20% (5)	76% (19)	3.72	$p < 0.05$
Would you recommend other Moundville visitors to use this app?	0% (0)	0% (0)	8% (2)	12% (3)	80% (20)	3.72	$p < 0.05$
	None	One	Two	Three	Four	Five	Six
Did you scan all the participating exhibits?	0% (0)	4% (1)	8% (2)	0% (0)	8% (2)	4% (1)	76% (19)
Did you answer all the quiz questions?	24% (6)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	76% (19)

Table 6.30: Quiz scores for Case and Control Groups.

Question #	Median Score Case / Control	% of Correct Answers Case / Control	Max Score Case / Control	Min Score Case / Control
1	1 / 1	100% / 62%	1 / 1	1 / 0
2	1 / 1	100% / 72%	1 / 1	1 / 0
3	1 / 0	53% / 24%	1 / 1	0 / 0
4	1 / 1	76% / 75%	1 / 1	0 / 0
5	1 / 0	65% / 27%	1 / 1	0 / 0
6	1 / 0	65% / 44%	1 / 1	0 / 0
7	1 / 1	61% / 48%	1 / 1	0 / 0
8	1 / 0	80% / 41%	1 / 1	0 / 0
9	1 / 0	57% / 37%	1 / 1	0 / 0
	Total Median Score Case / Control	Total Mean Score Case / Control	Total Max Score Case / Control	Total Min Score Case / Control
Total	7 / 5	6.8 / 4.16	8 / 7	4 / 0
	Total % Median Score Case / Control	Total % of Correct Answers Case / Control	Total % Max Score Case / Control	Total % Min Score Case / Control
Total	78% / 56%	76% / 51%	89% / 1	44% / 0

The evaluation of the visit by the Control Group and Case Group visitors is presented in the Table 6.26 and Table 6.27, respectively. The evaluation of the Moundville VR and Moundville AR experiences by the Case Group visitors is presented in the Table 6.28 and the Table 6.29, respectively. The comparison of the quiz results between Case and Control groups is presented in the Table 6.30.

Despite the average score for the Moundville educational, entertainment, and recreational experience is not improved within the Case Group, the Case Group visitors indicated the the Moundville AR and VR experiences positively affect the Moundville educational, entertainment, esthetic, and recreational experience. It can be safely concluded, that the Hypothesis 12, Hypothesis 13, Hypothesis 14, and Hypothesis 15 hold partially.

The visitors indicated issues with the Moundville AR object recognition.

The visitors were more eager to explore the Moundville VR experience with the virtual educational materials being hidden.

19 participants found all six exhibits in the Moundville AR experience. All 19 visitors completed the quiz.

The visitors were attempting to grab fish, squash, corn, and beans in the Moundville VR experience, while only the artifacts were grabbable. More items should be grabbable in the next version of the Moundville VR experience.

It was observed that the Moundville AR experience positively affects the visitors' exploration in the museum. The visitors usually overlook the exhibits located on the column and ceiling shelves. The Human Effigy Bowl, included in the Moundville AR experience, is located in one of these shelves, prompting the visitors to search though all of these shelves while exploring the artifacts exhibited there. This hints that museum Augmented Reality experiences can alter the visitors' behavior.

Despite being told that only 6 exhibits are part of the Moundville AR experience, the visitors did attempt to scan other exhibits and museum installations.

As illustrated in the Table 6.30, the Case Group visitors performed significantly better on the exit quiz when compared with the Control Group visitors. The Hypothesis 16 holds.

Table 6.31: The likelihood of the Case Group visitor to complete the Moundville AR experience quiz if no incentive was provided.

Would you complete the quiz, even if there was no prize?	Percent (Count)
Definitely Agree	52% (13)
Somewhat Agree	32% (3)
Not Sure	4% (1)
Somewhat Disagree	12% (3)
Definitely Disagree	0% (0)
Average Score	3.24
p-test (against 0 and 1)	$p < 0.05$

The likelihood of the Case Group visitor to complete the Moundville AR experience quiz if no incentive was provided is provided in the Table 6.31. The Case Group visitors expressed agreement that they would complete the Moundville AR experience quiz even if no incentive was provided. It can be concluded that the Hypothesis 17 did not hold.

Apart of the surveyed visitors, 7 archaeologists and historians, 1 Native American tribal member, 7 kids below age of 13, and 6 adults one of whom was over 80 years old visiting the Moundville Archaeological Part expressed interest in trying the Moundville AR and VR experiences. They highly praised the developed experiences and indicated that they were fun and educational.

Other Assessments

Statements About AR/VR and Gamification in Museums. The public assessment of the statements derived from the work of Eleanor Cranmer, et al. [15] [16] in context AR/VR and gamification at museums can be found in the Table 6.32. Notably:

- The participants of the public survey disagreed that implementing an AR/VR experience at a museum can improve job security. Eleanor Cranmer, et al. where concluding this from the standpoint that introduction of Augmented and Virtual Reality into museums can help to the museums to stay relevant hence retaining the job security of the museum staff. The public survey participants may have had a point of view that introduction of Augmented and Virtual Reality may make some of the museum staff positions, such as museum guides, less essential for the museum operations. A long-term case study

Table 6.32: Public opinions on the statements derived from the work of Eleanor Cranmer, et al. [15] [16]. Definitely disagree (0) - Somewhat disagree (1) - Neither agree nor disagree (2) - Somewhat agree (3) - Definitely agree (4). Yellow - the average score is below 3 (Somewhat agree). Red - the average score is below 2 (Neither agree nor disagree).

	Statement	Average Score In the context of AR/VR at a museum	Average Score In the context of Gamification at a museum
1	... create more memorable visitor experiences	3.2	3.51
2	... improve marketing presence and competitiveness	3.28	3.22
3	... can attract new target markets	3.26	-
4	... positively affect working experience	2.67	-
5	... improve job security	1.75	-
6	... add value to the visitors' experience	3.36	3.34
7	... increase visitors' intent to return	3.04	3.06
8	... increase visitor attention to the exhibitions)	3.26	3.26
9	... add more content to the exhibition	3.38	3.20
10	... trigger visitors' interest in the exhibition	3.28	3.28
11	... trigger visitors' interest in the exhibition topic)	3.2	3.1
12	... help visitors explore the exhibitions in a new light	3.42	3.32
13	... increase footfall numbers	2.69	2.57
14	... enhance visitor engagement	3.36	3.30
15	... enrich visitor memories	3.22	3.24
16	... bring the exhibition to life	3.53	3.34
17	... enhance visitors' emotional attachment	2.75	2.83
18	... enhance visitors' social interaction	2.57	2.77
19	... personalize the visitors' experience	2.95	2.97
20	... help visitors to memorize exhibition	2.95	2.95
21	... help visitors learning	3.06	3.2
22	... help reach the purposes of the museum	2.71	2.61
23	... preserve and retain museum exhibits	2.14	-
24	... positively affect the museum environment	2.63	-
25	... positively affect spending at museum stores and cafeterias	2.22	1.95
26	... positively affect spending at the local community	1.91	-
27	... improve the museum accessibility	2.22	
28	... make the museum less accessible	1.32	1.42

Table 6.33: The public perception of the visitor age categories that museum AR/VR and gamification experiences can attract.

Age Group	Which visitor categories you think an AR/VR experience may attract the most?	Which visitor categories you think a gamified experience may attract the most?
Kids (5-12)	40.82% (20)	79.56% (39)
Teenagers (13-17)	83.67% (41)	91.84% (45)
Young Adults (18-35)	59.18% (29)	24.49% (12)
Middle Age (36-55)	12.24% (6)	2.04 (1)
Older Adults (56+)	4.08% (2)	2.04 (1)

research is required to assess this statement. There was also no agreement that it can positively affect working experience.

- The participants of the public survey did not express agreement that introducing Augmented and Virtual Reality into museum, or introducing gamification into museums, will lead to a positive economic impact on the museum stores and cafeterias and the local community.

- According to the average score for the statements 27 and 28, the participants disagreed that museum accessibility will be negatively affected. There was also no agreement that it will be positively affected.

- There was no agreement that the footfall number will increase.

- There was no agreement that a set of social sustainability aspects of the museum will be improved (Statements 17-20, Statements 22-24).

The Target Age Group of AR/VR and Gamification in Museums. The public perception of the visitor age categories that museum AR/VR and gamification experiences can attract is presented in the table Table 6.33. Despite both studies by Eleanor Cranmer, et al. [15] [16] and the Moundville Archaeological Park case study indicate that adults are attracted by these experiences and engage easily, the public perception is that these experiences should be targeted mostly towards teenagers and kids. This may be due to the public perception of games

Table 6.34: The public perception of the gamified experiences that should be included in a museum. The scale: Definitely disagree (0) - Somewhat disagree (1) - Neither agree nor disagree (2) - Somewhat agree (3) - Definitely agree (4). Yellow - the average score is below 3 (Somewhat agree). Red - the average score is below 2 (Neither agree nor disagree).

Gamifying a museum experience must include following types of experiences:	Average Score
Text Quiz	1.79
Interactive Quiz (13-17)	2.79
Quest	3.18
Combat/Fight Simulator	1.81
Explorative	3.42
Building	2.79
Storytelling	3.24
Visual Novel	2.97
Treasure Hunt	3.04

in general and AR/VR experiences in particular are regarded as something fitting teenagers and kids, while in reality it appeals to all age groups.

The Preferred Types of Games in Museums. The public perception of the gamified experiences that should be included in a museum is presented in the Table 6.34. The Moundville AR and VR experiences include Text Quiz, Treasure Hunt, and Explorative elements. During the case study at Moundville, the Case Group participants did indicate on a several occasions that a plain text quiz may not appeal to a general public. It must be highlighted that these results align with findings by Ioannis Paliokas and Stella Sylaiou [80] who also indicate that ”Destroy” and ”Shoot” (Combat/Fight Simulator) patterns are rarely used in the museums.

Substituting Missing Exhibits with AR 3D Models. The perception of participants of the public survey on a set of issues associated with substituting missing exhibits with AR 3D models can be found in the Table 6.35, Table 6.36, Table 6.37, and Table 6.38. It can be inferred that:

- The missing exhibits do cause visitor frustration.
- The AR 3D models are not perceived to be more satisfactory than a video of the missing exhibit.

Table 6.35: The public perception of the frustration level when encountering missing exhibits. Scale: Extremely frustrated (2) - Somewhat frustrated (1) - Not frustrated (0).

How frustrated will you be if an exhibit is missing that is...	Average
of high significance for you	1.47
of average significance for you	0.77
of little significance for you	0.30

Table 6.36: The public perception of the satisfaction level when a missing exhibit is substituted. Scale: Extremely dissatisfied (0) - Somewhat dissatisfied (1) - Neither satisfied nor dissatisfied (2) - Somewhat satisfied (3) - Extremely satisfied (4).

	Average
An exhibit of high significance for you is substituted by...	
Image/Video	1.73
Physical replica	2.67
Virtual AR replica model	2.49
Virtual AR 3D scan model	2.76
An exhibit of high significance for you is substituted by...	
Image/Video	1.77
Physical replica	2.61
Virtual AR replica model	2.55
Virtual AR 3D scan model	2.65
An exhibit of high significance for you is substituted by...	
Image/Video	2.16
Physical replica	2.59
Virtual AR replica model	2.57
Virtual AR 3D scan model	2.61

Table 6.37: The public perception of the role of 3D replicas of museum exhibits.

	Recreating the exhibits as preserved	Recreating the original look of exhibits
What aspect of virtual AR 3D replicas do you think is more important?	34.69% (17)	65.31% (32)

Table 6.38: The public perception of issues associated with substituting missing exhibits with AR 3D models. The participants of the public survey were asked to rate each issue from 1 to 5, 1 being most and 5 least most important.

Please, rank the following issues of using virtual AR replica models	Mean Rating	Median Rating
The 3D model does not have accurate shape	3.14	3
The 3D model does not have accurate colors	3.91	4
The 3D model is not detailed	3	3
The AR app is not user friendly	2.66	2
The AR experience requires a special device (e.g. AR headset)	2.27	1

Table 6.39: Donations to a museum to develop an AR/VR experience, as perceived by the public survey participants.

Would you donate to a museum to build an AR or VR experience?	
Average	1.69
How often do you donate to museums?	
Never	73.47% (36)
Once a year	18.37% (9)
A couple of times per year	4.08% (2)
A current museum patron / donor / member / sponsor	4.08% (2)

- The main challenges of substituting the missing experiment by an AR 3D model are (1) the requirement of a special device, (2) the AR app being not user friendly, and (3) the 3D model being not detailed.

Funding Development of an AR/VR Experience at a Museum. The attitude towards the public survey participants towards donating to a museum to develop an AR/VR experience is illustrated in the Table 6.39. It can be derived that visitor donations are not a reliable source to fund a development of an AR/VR experience at a museum.

Public Survey Participants' Grade of the Moundville AR/VR Experience 3D Models. Before the Moundville AR and VR experiences were launched, the opinions about the created exhibit 3D models were gathered via the public survey. The Table 6.41 contains the public survey participant scores of the Moundville AR/VR experience 3D models. After receiving initial feedback, improvements were made to the models and the render quality was improved. As it can be seen, the scores are not high, despite the praise received later during the case study at the Moundville. Most likely this is due to a 2D render being unable to illustrate all of the detail of the 3D model.

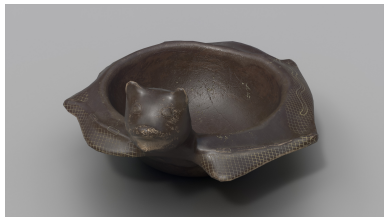
The Table 6.40 contains the public survey participant opinions on two versions of the Human Bowl 3D models. The first is the restored version with no cracks. The second is "as-is"

Table 6.40: The public survey participant score of the ”as-is” and ”restored” 3D models of the Human Effigy Bowl.

Version	3D Model	Average Score
”Restored”		1.88
”As-Is”		1.96

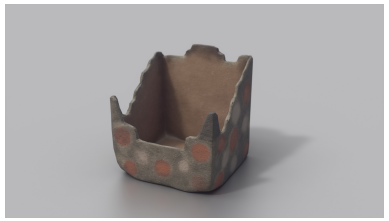
with the cracks that can be seen on the preserved Human Effigy Bowl. We cannot clearly say that the preference was given to any of the two versions.

Table 6.41: The public survey participant scores of the Moundville AR/VR experience 3D models.

Exhibit Code	Name	Exhibit Photo	Exhibit Model Render First Iteration	Exhibit Model Render Second Iteration	Average Score (23 opinions)	Average Score (26 opinions)
M1	Bat Effigy Bowl				1.73	1.84
M2	Caddoan Style Ceramic Bottle				1.73	2.46

Continued on next page

M4	Human Effigy Bowl				1.78	1.88
M6	Lipped Ceramic Vessel				2.39	2.73
Continued on next page						

M7	Stepped Square Vessel				2.56	2.76
M8	Stone Pendant				2.56	2.43

6.3 A Discussion of Development of Augmented and Virtual Reality Experiences at a Museum

Based on our experience at the Jule Collins Museum of Fine Art and the Moundville Archaeological Museum, the following workflow is suggested for development of an Augmented and Virtual Reality experiences at a museum. Many of these are intuitive, but we find that it is beneficial to have this discussion provided.

6.3.1 Development

One of the following approaches may be taken to create exhibit 3D models based on the rules and regulations applied to the exhibit in question, the physical properties of the exhibit, and the technology availability:

1. The 3D models can be manually created.
2. The artifacts can be 3D-scanned using enterprise and professional 3D scanners.
3. The artifacts can be scanned using consumer grade 3D scanners, including camera- and smartphone-based 3D scanner applications.

We can identify the following steps to develop a museum Virtual Reality experience:

1. The hardware for the experience must be identified.
    - If the hardware suggests the visitor physically moving in the real space (e.g. an Oculus Quest headset with room-scale boundaries), a safe physical space fitting the virtual space must be negotiated.
    - One may choose to alter the layout of the virtual space to match the available physical space.
2. Content (3D models, educational texts) for the VR experience must be developed.
    - A compromise between historical and cultural accuracy and the quality and environment boundaries of the VR experience and the applicable VR UI/UX practices must be negotiated with the museum stakeholders.

  - There is no scientific evidence that individual gardens in Moundville were protected by a palisade.
  - The Moundville VR experience includes a palisade to provide intuitive boundaries to the user and to lay out ground for educational materials about palisades.
  - The Moundville VR experience specifically includes signs warning the visitor that the Three Sisters Garden is a replica created for educational purposes and not an exact recreation of Three Sisters Garden.
- Educational texts, slides, imagery, and videos should be adjusted to fit the virtual environment.
- A compromise between the desired educational content and the applicable VR UI/UX practices must be negotiated with the museum stakeholders.
  - The educational materials presented in the Moundville Archaeological Park were shortened and rewritten to fit the available virtual space without overwhelming the user.

We can identify the following steps to develop a museum Augmented Reality experience:

1. The hardware for the experience must be identified.
   - If the museum visitors are supposed to download the application on their devices, one must be prepared that the process of publishing the AR experience to appropriate application may include providing evidence of authorized use of included artifacts and educational materials.
2. The AR technology must be identified.
   - Markerless AR. Markerless AR can provide on-demand AR experiences and educational materials.
   - QR Codes and NFT images.
     - QR Codes and NFT images must be considered if it is not possible to train a classifier for object recognition and other AR technologies (markerless, location-based) do not fit the designed experience.

        * Look-alike exhibits.
        * Poor illumination.
        * Other conditions that may make training the classifier or scanning the exhibit itself challenging.
    - If QR Codes and NFTs are to be installed, a compromise between the aesthetics of the QR Codes and NFTs and their function must be negotiated with the museum stakeholders.
- Object recognition.
    - Data source
        * Frames extracted from a video footage.
        * Frames extracted from the 3D scanner or rendered using 3D scanner result model.
    - Training the classifier
        * Transfer learning should be used to train a classifier for the exhibits.
        * Major machine learning tools (Tensorflow, PyTorch, DarkNet/Yolo, etc.) support transfer learning.
- Location-based AR.
    - NFC and Bluetooth beacons for indoors and outdoors.
    - GPS based for outdoors.
    - Classifier capable of recognizing visitor's location via camera feedback.

3. Content (3D models, educational texts) for the VR experience must be developed.
    - A compromise between historical and cultural accuracy and the quality and detail of the models used in the AR experience must be negotiated with the museum stakeholders.
    - A compromise between the desired educational content and the applicable UI/UX practices must be negotiated with the museum stakeholders.

6.3.2 Visitor Testing

The testing phase of any software product does include the end customer using the product and providing feedback. During our experience at the Jule Collins Museum of Fine Art and the Moundville Archaeological Park we were advised by the museum staff to make the exit surveys as short as possible so the visitors are not discouraged from participating.

This suggests the following approach for organizing exit surveys. If exit surveys are longer than tolerated by the museum visitors, one can break the exit surveys into multiple, logically coherent parts. The participants than will be divided into several groups, each taking a particular part of the exit survey. This approach makes the testing process longer but also less disturbing.

6.3.3 Support

Upon completion of the development of the AR and VR experiences, the museum staff should be left with detailed instructions on how to operate the software products. These instructions should include:

1. *Installation instructions.* Even if the software product is supposed to be downloaded by the visitors and used from the visitors' own devices, the museum staff should be provided with detailed installation instructions to assist the visitors with the installation if required.

2. *Operation instructions.* Even if the software product is supposed to be used from the visitors' own devices, the museums staff should be provided with detailed operation instructions as the visitors will be appealing to the museum staff if any questions rise.

3. *Maintenance instructions.* The museum staff should be instructed on maintenance of any hardware, signs, stickers, area, etc. required for the Augmented and Virtual Reality experiences.

4. *Potential issues and their troubleshooting.* If the museum visitors encounter an error or incorrect behavior of the AR/VR experiences, they will be appealing to the museum staff

for assistance. Hence, the museum staff should be provided with a list of known and potential issues, their troubleshooting, and potential fixes.

When creating instructions, one should take into account that the museum staff are not a software product support specialists so the directions included should be composed in layman's terms and suitable for a person with little technical background.

Chapter 7

Conclusion

The Table 7.1 contains a summary for the hypotheses addressed in this research.

We have successfully demonstrated that using head-tracking to analyze visitor experience is applicable in the museums by successfully applying it in a diverse museum environment. Although our research does not perform an automated analysis of museum visitors' experience using footage of an AR device camera, we outline a set of approaches that we believe are key elements of creation of such a system. We have also successfully demonstrated that head-tracking can answer museum staff's immediate questions about the visitors' experience.

We have voiced the issue of privacy with using Augmented Reality applications in museums and provided initial evidence of lack of museum visitors' privacy concerns regarding Augmented Reality.

We have underlined that an Augmented Reality wearable and even an Augmented Reality smartphone application alter the visitors' behavior in the museum. The benefits and issues of this altered behavior should be explored in more detail in future researches.

We claim to be the first research who performed and discussed a use case of Augmented and Virtual Reality experiences targeting all three dimensions of museum sustainability. We have successfully demonstrated that Augmented and Virtual Reality technologies can positively affect all three dimensions of museum sustainability. In particular, we demonstrated: the museum economic sustainability can benefit from monetizing VR experience; the museum AR and VR experiences are perceived to assist the museum in contributing to sustainability of the local environment; the museum social sustainability is benefiting from improved educational, entertainment, esthetic, and recreational visitor experience.

We have outlined a set of potential issues and challenges when implementing Augmented and Virtual Reality experiences. We have provided pathways to organize exhibit scanning inside the museum Augmented Reality experience that are fit for different scenarios and environments. Use cases that describe the development of each of the presented pathways in detail are subject of future research and technical reports.

We have hinted on potential applications of gamification in museum environments (computer-assisted gamification in particular) to improve museum sustainability. As of our knowledge, we are the first research to do that, although previous works exist that present gamified museum experiences.

Alas, we were unable to receive any response from the museum internal stakeholders. Despite our public surveys and our use cases provide valuable information on statements in Table 4.3, we cannot make a final conclusion on them without a broader survey with museum internal and external stakeholders.

We can firmly state that we have successfully applied means of computer science to solve another sustainability issue.

Table 7.1: Hypothesis results. Green - holds, yellow - holds with condition, red - did not hold.

Section	#	Hypothesis	Conclusion
Visitor	1	There is a correlation between the time spent at an exhibit derived from the headset camera footage and the visitor's self-assessment of the attention paid to the exhibit.	**Holds** Improvements required
	2	The AR camera can detect the AOI within an exhibit that a visitor paid the most attention to.	**Holds** For sparsely located AOI
	3	Wearing AR headset affects the visitor behavior.	**Holds** For AR device with active interface
	4	The AR headset does obstruct the visitor experience.	**Holds** For AR device with active interface
	5	The museum visitors do not have privacy concerns associated with AR headset camera.	**Holds**
Museum	6	Museum visitors who used the AR and VR experience are more likely to revisit the museum.	**Did not hold**
	7	Museum visitors who used the AR and VR experience are more likely to refer a friend to visit the museum.	**Did not hold**
	8	The Virtual Reality experience can be monetized by the museum.	**Holds**
	9	Using a museum store discount as an incentive (prize) in a gamified Augmented Reality experience increases the number of purchases at the museum store.	**Did not hold**
Museum Environmental Sustainability	10	It is perceived by both internal and external stakeholders that Augmented and Virtual Reality contributes to the environmental sustainability of the museum.	**Holds**
	11	The Augmented and Virtual Reality experiences are not viewed as a requirement for a modern museum.	**Holds**
	12	The Augmented and Virtual Reality experiences positively contribute to the visitors' educational experience at the museum.	**Holds** Contributes but doesn't affect overall perspective
	13	The Augmented and Virtual Reality experiences positively contribute to the visitors' entertainment experience at the museum.	**Holds** Contributes but doesn't affect overall perspective
	14	The Augmented and Virtual Reality experiences positively contribute to the visitors' esthetic experience at the museum.	**Holds** Contributes but doesn't affect overall perspective
	15	The Augmented and Virtual Reality experiences positively contribute to the visitors' recharging experience at the museum.	**Holds** Contributes but doesn't affect overall perspective
	16	The gamified Augmented Reality experience helped visitors to learn more about the Moundville and the Mississippian Native American culture.	**Holds**
	17	The visitors are more likely to complete the a gamified Augmented Reality experience if a museum store discount was used as an incentive (prize).	**Did not hold**

Chapter 8

Post-Research And Future Work

The research team is planning to deliver 2-3 publications based on the results of the research.

New features and fixes should be added to the Moundville VR experience:

- Grabbalbe squash, corn, beans
- Grabbalbe fish
- Interactive doors

The Moundville Archaeological park is interested in having the Moundville AR and VR experiences as a permanent part of the Moundville Archaeological Park visitor experience:

- The Moundville AR experience must be made public in Android and iOS app stores for the visitors to download.
- An Oculus Quest 2 headset will be available at the Moundville Archaeological Park to run the Moundville VR experience.
- Moundville staff must be provided with detailed installation, maintenance, operation, and troubleshooting instructions.

Optionally, the Moundville VR experience may be made public at the Oculus Quest 2 official app store.

We position our research as an invitation for future researches and use cases exploring applications of Augmented and Virtual Reality for museum sustainability in different types of museums, environments, and conditions.

References

[1] “About Ar Foundation: Ar Foundation: 4.2.2.” AR Foundation — 4.2.2, https://docs.unity3d.com/Packages/com.unity.xr.arfoundation@4.2/manual/index.html.

[2] Al-Baddai, Saad, Barbara Ströhl, Elmar W. Lang, and Bernd Ludwig. ”Do Museum Visitors See what Educators Want Them to See?.” Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization. 2017.

[3] Almeshari, Moneerah, John Dowell, and Julianne Nyhan. ”Personalisation of digital museum guides through implicit recognition of visitor personas.” Proceedings of the 2nd Workshop on Mobile Access to Cultural Heritage co-located with 20th International Conference on Human-Computer Interaction with Mobile Devices and Services (Mobile HCI 2018). CEUR, 2018.

[4] Almeshari, Moneerah, John Dowell, and Julianne Nyhan. ”Using Personas to Model Museum Visitors.” Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization. 2019.

[5] “Android Distribution Dashboard : Android Developers.” Android Developers, developer.android.com/about/dashboards.

[6] Amber Garage. “HoloKit.” HoloKit, holokit.io/.

[7] “ArtoolkitX.” ArtoolkitX, www.artoolkitx.org/.

[8] Apple Inc. “App Store.” App Store - Support - Apple Developer, developer.apple.com/support/app-store/.

[9] Barz, Michael, et al. ”Automatic recognition and augmentation of attended objects in real-time using eye tracking and a head-mounted display.” ACM Symposium on Eye Tracking Research and Applications. 2021.

[10] Blanco-Pons, Silvia, et al. ”Design and implementation of an augmented reality application for rock art visualization in Cova dels Cavalls (Spain).” Journal of Cultural Heritage 39 (2019): 177-185.

[11] Blender Foundation. “Home of the Blender Project - Free and Open 3D Creation Software.” Blender.org, www.blender.org/.

[12] Bojko, Aga. Eye tracking the user experience: A practical guide to research. Rosenfeld Media, 2013.

[13] Brigham, Tara J. ”An introduction to gamification: adding game elements for engagement.” Medical reference services quarterly 34.4 (2015): 471-480.

[14] “Build New Augmented Reality Experiences That Seamlessly Blend the Digital and Physical Worlds — Arcore — Google Developers.” Google, Google, https://developers.google.com/ar.

[15] Cranmer, Eleanor, Timothy Jung, and A. Miller. ”Implementing Augmented Reality to Increase Tourist Attraction Sustainability.” (2016).

[16] Cranmer, Eleanor, and Timothy Jung. ”The Value of Augmented Reality from a Business Model Perspective.” e-Review of Tourism Research 8 (2017).

[17] Crook, James. “Home.” Audacity ®, 7 Mar. 2022, https://www.audacityteam.org/.

[18] “DB Browser for Sqlite.” DB Browser for SQLite, 25 July 2021, https://sqlitebrowser.org/.

[19] Desai, Nilam. ”Recreation of history using augmented reality.” ACCENTS Transactions on Image Processing and Computer Vision 4.10 (2018): 1-5.

[20] Deterding, Sebastian, et al. ”Gamification: Toward a definition.” CHI 2011 gamification workshop proceedings. Vol. 12. Vancouver BC, Canada, 2011.

[21] tom Dieck, M. Claudia, and Timothy Hyungsoo Jung. ”Value of augmented reality at cultural heritage sites: A stakeholder approach.” Journal of Destination Marketing & Management 6.2 (2017): 110-117.

[22] Diegmann, Phil, et al. ”Benefits of augmented reality in educational environments-a systematic literature review.” Benefits 3.6 (2015): 1542-1556.

[23] Ding, Mandy. ”Augmented reality in museums.” Arts Management & Technology Laboratory, Heinz College (2017): 3-8.

[24] Djaouti, Damien, Julian Alvarez, and Jean-Pierre Jessel. ”Classifying serious games: the G/P/S model.” Handbook of research on improving learning and motivation through educational games: Multidisciplinary approaches. IGI Global, 2011. 118-136.

[25] Einhäuser, Wolfgang, et al. ”Human eye-head co-ordination in natural exploration.” Network: Computation in Neural Systems 18.3 (2007): 267-297.

[26] Eghbal-Azar, Kira, and Thomas Widlok. ”Potentials and limitations of mobile eye tracking in visitor studies: Evidence from field research at two museum exhibitions in Germany.” Social science computer review 31.1 (2013): 103-118.

[27] Falk, John H. Identity and the museum visitor experience. Routledge, 2016.

[28] Farnsworth, Bryn. “Eye Tracker Prices - An Overview of 20 Eye Trackers.” Imotions, 18 July 2019, imotions.com/blog/eye-tracker-prices/

[29] Fuchs, Henry, and Gary Bishop. ”Research directions in virtual environments.” (1992).

[30] Gehle, Raphaela, Antje Amrhein, Maximilian Krug, and Karola Pitsch. ”Towards Using Eyetracking Data as Basis for Conversation Analysis on Real-World Museum Interaction.” SAGA-International Workshop on Solutions for Automatic Gaze Data Analysis: Proceedings. 2015.

[31] “Get Started with Oculus in Unity.” Oculus for Developers, https://developer.oculus.com/documentation/unity/unity-gs-overview/.

[32] “Getting Started with VUFORIA Engine in Unity.” Getting Started with Vuforia Engine in Unity — VuforiaLibrary, https://library.vuforia.com/articles/Training/getting-started-with-vuforia-in-unity.html.

[33] Ghouaiel, Nehla, et al. ”Mobile Augmented Reality in Museums: Towards Enhancing Visitor’s Learning Experience.” International Journal of Virtual Reality 17.1 (2017): 21-31.

[34] GIMP, https://www.gimp.org/.

[35] “Google Glass.” Google, www.google.com/glass/start/.

[36] “Google Cardboard.” Google Cardboard – Google VR, Google, arvr.google.com/cardboard/.

[37] Goossens, Hieronymus HLM, and A. John Van Opstal. ”Human eye-head coordination in two dimensions under different sensorimotor conditions.” Experimental Brain Research 114.3 (1997): 542-560.

[38] Graham, Peter. “Mixed Reality Lynx R-1 Gets Huge Price Drop, Launching September Kickstarter.” VRFocus, 9 July 2021, https://www.vrfocus.com/2021/07/mixed-reality-lynx-r-1-gets-huge-price-drop-launching-september-kickstarter/.

[39] “IDE and Code Editor for Software Developers and Teams.” Visual Studio, 9 Mar. 2022, https://visualstudio.microsoft.com/.

[40] Inc., Apple. “Augmented Reality.” Apple Developer, https://developer.apple.com/augmented-reality/.

[41] Hammady, Ramy, Minhua Ma, and Nicholas Temple. ”Augmented reality and gamification in heritage museums.” Joint International Conference on Serious Games. Springer, Cham, 2016.

[42] Hammady, Ramy, Minhua Ma, and Anna Powell. ”User Experience of Markerless Augmented Reality Applications in Cultural Heritage Museums:‘MuseumEye’as a Case Study.” International Conference on Augmented Reality, Virtual Reality and Computer Graphics. Springer, Cham, 2018.

[43] Hammady, Ramy, et al. ”Design and development of a spatial mixed reality touring guide to the Egyptian museum.” Multimedia Tools and Applications 79.5 (2020): 3465-3494.

[44] Hein, George E. Learning in the Museum. routledge, 2002.

[45] Jung, Timothy, et al. ”Effects of virtual reality and augmented reality on visitor experiences in museum.” Information and communication technologies in tourism 2016. Springer, Cham, 2016. 621-635.

[46] Kapp, Sebastian, et al. ”ARETT: Augmented Reality Eye Tracking Toolkit for Head Mounted Displays.” Sensors 21.6 (2021): 2234.

[47] Keil, Jens, et al. ”A digital look at physical museum exhibits: Designing personalized stories with handheld Augmented Reality in museums.” 2013 Digital Heritage International Congress (DigitalHeritage). Vol. 2. IEEE, 2013.

[48] Klopfer, Eric. Augmented learning: Research and design of mobile educational games. MIT press, 2008.

[49] Klopfer, Eric, and Kurt Squire. ”Environmental Detectives—the development of an augmented reality platform for environmental simulations.” Educational technology research and development 56.2 (2008): 203-228.

[50] Klopfer, Eric, and Josh Sheldon. ”Augmenting your own reality: Student authoring of science-based augmented reality games.” New directions for youth development 2010.128 (2010): 85-94.

[51] Krafka, Kyle, et al. ”Eye tracking for everyone.” Proceedings of the IEEE conference on computer vision and pattern recognition. 2016.

[52] Kyriakou, Panayiotis, and Sorin Hermon. ”Can I touch this? Using natural interaction in a museum augmented reality system.” Digital Applications in Archaeology and Cultural Heritage 12 (2019): e00088.

[53] Lanier, Jaron. ”Virtual reality: The promise of the future.” Interactive Learning International 8.4 (1992): 275-79.

[54] Lee, Hyunae, et al. ”Experiencing immersive virtual reality in museums.” Information & Management (2019): 103229.

[55] Lindqvist, Katja. ”Museum finances: challenges beyond economic crises.” Museum Management and Curatorship 27.1 (2012): 1-15.

[56] “The Future of Mixed Reality, Now.” Lynx, https://lynx-r.com/.

[57] Macchiarella, Nickolas D., and Dennis A. Vincenzi. ”Augmented reality in a learning paradigm for flight aerospace maintenance training.” The 23rd Digital Avionics Systems Conference (IEEE Cat. No. 04CH37576). Vol. 1. IEEE, 2004.

[58] “Magic Leap: Reality Is Just Beginning.” Spatial Computing for Enterprise — Magic Leap, www.magicleap.com/en-us.

[59] Marius’t Hart, Bernard, et al. ”Gaze allocation in natural stimuli: Comparing free exploration to head-fixed viewing conditions.” Visual Cognition 17.6-7 (2009): 1132-1158.

[60] Mastandrea, Stefano, Gabriella Bartoli, and Giuseppe Bove. ”Preferences for ancient and modern art museums: Visitor experiences and personality characteristics.” Psychology of Aesthetics, Creativity, and the Arts 3.3 (2009): 164.

[61] Merge VR. “Hands-on AR/VR Play and Learning: AR/VR Learning & Creation.” Merge, mergeedu.com/headset.

[62] Merriman, Nick. ”Museum collections and sustainability.” Cultural trends 17.1 (2008): 3-21.

[63] “Microsoft HoloLens: Mixed Reality Technology for Business.” Microsoft HoloLens ; Mixed Reality Technology for Business, www.microsoft.com/en-us/hololens?icid=SSM_AS_Promo_Devices_HoloLens2.

[64] Miyashita, Tsutomu, et al. ”An augmented reality museum guide.” 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality. IEEE, 2008.

[65] Mokatren, Moayad, Tsvi Kuflik, and I. Shimshoni. ”Exploring the Potential Contribution of Mobile Eye-tracking Technology in Enhancing the Museum Visit Experience.” AVI* CH. 2016.

[66] “MOVERIO Augmented Reality Smart Glasses.” Augmented Reality and Mixed Reality — by MOVERIO — Epson.com — Epson US, epson.com/moverio-augmented-reality.

[67] “Moverio BT-350 Smart Glasses.” Moverio BT-350 Smart Glasses ; Smart Glasses ; Wearables ; For Work ; Epson US, epson.com/For-Work/Wearables/Smart-Glasses/Moverio-BT-350-Smart-Glasses/p/V11H837020#.

[68] Naspetti, Simona, et al. ”Automatic analysis of eye-tracking data for augmented reality applications: A prospective outlook.” International Conference on Augmented Reality, Virtual Reality and Computer Graphics. Springer, Cham, 2016.

[69] Nayyar, Anand, et al. ”Virtual Reality (VR) & Augmented Reality (AR) technologies for tourism and hospitality industry.” International Journal of Engineering & Technology 7.2.21 (2018): 156-160.

[70] Nelson, Mark J. ”Soviet and American precursors to the gamification of work.” Proceeding of the 16th international academic MindTrek conference. 2012.

[71] Niantic. “Catch Pokémon in the Real World with Pokémon GO!” Homepage — Pokémon Go, www.pokemongo.com/en-us/.

[72] Noreikis, Marius, et al. ”Effects of Gamified Augmented Reality in Public Spaces.” IEEE Access 7 (2019): 148108-148118.

[73] North. “Explore Focals.” North, www.bynorth.com/focals.

[74] “Oculus Go: Standalone VR Headset.” Oculus, www.oculus.com/go/.

[75] “Oculus Quest 2: Our Most Advanced New All-in-One VR Headset.” Oculus, https://www.oculus.com/quest-2/.

[76] “Oculus Rift.” Oculus, www.oculus.com/rift/.

[77] Official Adobe Photoshop — Photo and Design Software. https://www.adobe.com/products/photoshop.html.

[78] “OpenCV.” OpenCV, 4 Mar. 2020, opencv.org/.

[79] “OpenCV for Unity: Integration.” Unity Asset Store, https://assetstore.unity.com/packages/tools/integration/opencv-for-unity-21088.

[80] Paliokas, Ioannis, and Stella Sylaiou. ”The use of serious games in museum visits and exhibitions: A systematic mapping study.” 2016 8th International conference on games and virtual worlds for serious applications (VS-GAMES). IEEE, 2016.

[81] Pine, B. Joseph, and James H. Gilmore. ”Welcome to the experience economy.” Harvard business review 76 (1998): 97-105.

[82] Pop, Izabela Luiza, and Anca Borza. ”Factors influencing museum sustainability and indicators for museum sustainability measurement.” Sustainability 8.1 (2016): 101.

[83] Professional Video Editing Software — Adobe Premiere Pro. https://www.adobe.com/products/premiere.html.

[84] Pupil Dev Team. “Pupil Core Eye Tracking Headset.” Pupil Labs, pupil-labs.com/products/core/.

[85] “PyCharm: The Python IDE for Professional Developers by Jetbrains.” JetBrains, https://www.jetbrains.com/pycharm/.

[86] Quek, Francis, Roger Ehrich, and Thurmon Lockhart. ”As go the feet... on the estimation of attentional focus from stance.” Proceedings of the 10th international conference on Multimodal interfaces. 2008.

[87] Rae, Juno, and Lizzie Edwards. ”Virtual reality at the British Museum: What is the value of virtual reality environments for learning by children and young people, schools, and families.” Proceedings of the Annual Conference of Museums and the Web, Los Angeles, CA, USA. 2016.

[88] Razavian, Ali S., et al. ”Estimating attention in exhibitions using wearable cameras.” 2014 22nd International Conference on Pattern Recognition. IEEE, 2014.

[89] “Reddit.” Reddit, www.reddit.com/.

[90] Roussou, Maria, et al. ”A life of their own: museum visitor personas penetrating the design lifecycle of a mobile experience.” CHI’13 Extended Abstracts on Human Factors in Computing Systems. 2013. 547-552.

[91] “Samsung Gear VR with Controller.” The Official Samsung Galaxy Site, www.samsung.com/global/galaxy/gear-vr/.

[92] Sandler, Mark, et al. ”Mobilenetv2: Inverted residuals and linear bottlenecks.” Proceedings of the IEEE conference on computer vision and pattern recognition. 2018.

[93] Schmitow, Clara, et al. ”Using a head-mounted camera to infer attention direction.” International Journal of Behavioral Development 37.5 (2013): 468-474.

[94] Serrell, Beverly. ”Paying attention: The duration and allocation of visitors’ time in museum exhibitions.” Curator: The museum journal 40.2 (1997): 108-125.

[95] “SimpleSQL: Integration.” Unity Asset Store, https://assetstore.unity.com/packages/tools/integration/simplesql-3845.

[96] Sommerauer, Peter, and Oliver Müller. "Augmented reality in informal learning environments: A field experiment in a mathematics exhibition." Computers & Education 79 (2014): 59-68.

[97] Sommerauer, Peter, and Oliver Müller. "Augmented Reality in Informal Learning Environments: Investigating Short-term and Long-term Effects." (2018).

[98] Sostel. "Eye Tracking - Mixed Reality." Eye Tracking - Mixed Reality ; Microsoft Docs, docs.microsoft.com/en-us/windows/mixed-reality/eye-tracking.

[99] Sutherland, Ivan E. "A head-mounted three dimensional display." Proceedings of the December 9-11, 1968, fall joint computer conference, part I. 1968.

[100] "Tensorflow." TensorFlow, https://www.tensorflow.org/.

[101] Thomas, P. C., and W. M. David. "Augmented reality: An application of heads-up display technology to manual manufacturing processes." Hawaii International Conference on System Sciences. 1992.

[102] Toyama, Takumi, et al. "Museum Guide 2.0–an eye-tracking based personal assistant for museums and exhibits." Proceedings of the international conference: Re-Thinking Technology in Museums. 2011.

[103] "Transfer Learning and Fine-Tuning: Tensorflow Core." TensorFlow, https://www.tensorflow.org/tutorials/images/transfer_learning.

[104] Tu, Shaorong. "Analysis on the Development Trend and Application Technology of Digital Museum." 1st International Symposium on Innovation and Education, Law and Social Sciences (IELSS 2019). Atlantis Press, 2019.

[105] Ultraleap. "Tracking: Leap Motion Controller." Ultraleap, www.ultraleap.com/product/leap-motion-controller/.

[106] Unity Technologies. "Unity." Unity, unity.com/.

[107] "Unreal Engine: The Most Powerful Real-Time 3D Creation Platform." What Is Unreal Engine 4, www.unrealengine.com/en-US/.

[108] Varinlioglu, Guzden, and Suheyla Muge Halici. "Gamification of Heritage through Augmented Reality." (2019).

[109] Véron, Eliséo, and Martine Levasseur. Ethnographie de l'exposition: l'espace, le corps et le sens. Centre Georges Pompidou, Bibliothèque publique d'information, 1989.

[110] Vive. "Find the Right High-End VR System for You: VIVE™." VIVE, www.vive.com/us/product/.

[111] Vuzix. "Vuzix Products." Vuzix, www.vuzix.com/products.

[112] "Welcome to Moundville Archaeological Park." Moundville Archaeological Park, moundville.museums.ua.edu/

[113] Wessel, Daniel, Eva Mayr, and Kristin Knipfer. "Re-viewing the museum visitor's view." Workshop Research Methods in Informal and Mobile Learning, Institute of Education, London, UK. 2007.

[114] Yuen, Steve Chi-Yin, Gallayanee Yaoyuneyong, and Erik Johnson. "Augmented reality: An overview and five directions for AR in education." Journal of Educational Technology Development and Exchange (JETDE) 4.1 (2011): 11.

Appendix A

Jule Collins Museum Visitor Survey

A.1 Demographics

1. Please, select your age:
   (a) Under 18
   (b) Under 18-20
   (c) Under 21-30
   (d) Under 31-40
   (e) Under 41-50
   (f) Above 50-59
   (g) Above 60
2. Please, select your educational level:
   (a) Middle School
   (b) High School
   (c) Undergraduate
   (d) Graduate (master or PhD)

A.2 Current visit

1. Which device did you use?
   (a) Epson Moverio
   (b) Head-mounted camera
2. Have you been to this museum before?
   (a) Yes
   (b) No
3. The head-mounted camera affected your behavior during your visit

(a) Strongly agree

(b) Somewhat agree

(c) Neither agree nor disagree

(d) Somewhat disagree

(e) Strongly disagree

4. Was the head-mounted camera obstructing?

   (a) Definitely not

   (b) Probably not

   (c) Might or might not

   (d) Probably yes

   (e) Definitely yes

5. Augmented Reality devices rely heavily on cameras. Are you concerned with violating other people's privacy while wearing a device with a camera?

   (a) Extremely concerned

   (b) Somewhat concerned

   (c) Not concerned

6. Are you concerned with people wearing a device with a camera violating your privacy?

   (a) Extremely concerned

   (b) Somewhat concerned

   (c) Not concerned

7. Please, select the two visitor descriptions that fit most to your current visit

   (a) Explorer - visit museums to satisfy their curiosity and generally have an interest in the field, seek knowledge.

   (b) Experience seekers - seek more pleasure than knowledge.

   (c) Facilitator - visit to support other people (e.g. parents and teachers taking children to a museum.)

   (d) Professional / hobbyist - visit museums for a specific interest.

   (e) Recharger - hoping to relax and recharge their energy.

8. Please, select the two exploration style descriptions that fit most to your current visit

   (a) Ant - closely view almost all exhibits and follow the defined path.

   (b) Fish - view most of the exhibits but does that from a distance without getting into detail.

   (c) Butterfly - view most of the exhibits but do that with no order and frequently changing direction.

   (d) Grasshopper - closely view only specific exhibits and ignore most of the others.

A.3 Exhibits

For Exhibits A1, A2, A4, A9, A10, A11, A13, A16, A20, A24, A27, A31, A32, A33, A38, A43-53, A49, A51, A55, A58, A59, A60

1. Exhibit photo provided - How much attention did you pay to this exhibit?
    (a) None at all
    (b) A little
    (c) A moderate amount
    (d) A lot
    (e) A great deal

For Exhibit A10:

1. Did you try the AR experience for this exhibit?
    (a) Yes
    (b) No
    (c) I didn't know it's an AR experience
    (d) I couldn't make it work

For Installation A9:

1. Which exhibit did you pay more attention to?
    (a) A
    (b) B
    (c) C
    (d) Equal

For Installation A13:

1. Which exhibit did you pay more attention to?
    (a) A, B, C, D, E, F
    (b) G
    (c) Equal

For Installation A27:

1. Which exhibit did you pay more attention to?
    (a) A
    (b) B
    (c) C

(d) Equal

For Installation A31:

1. Which exhibit did you pay more attention to?

   (a) A
   (b) B
   (c) Equal

For Installation A43-53:

1. Which exhibit did you pay more attention to?

   (a) A
   (b) B
   (c) Equal

For Installation A55:

1. Which exhibit did you pay more attention to?

   (a) A
   (b) B
   (c) C
   (d) Equal

For Installation A58:

1. Which exhibit did you pay more attention to?

   (a) A
   (b) B
   (c) Equal

Appendix B

Moundville Visitors, Control Group: Regular Visitor Survey

B.1 Demographics

1. Please, select your age:
   (a) Under 18
   (b) Under 18-20
   (c) Under 21-30
   (d) Under 31-40
   (e) Under 41-50
   (f) Above 50-59
   (g) Above 60
2. Please, select your educational level:
   (a) Middle School
   (b) High School
   (c) Undergraduate
   (d) Graduate (master or PhD)
3. Have you been to Moundville before?
   (a) Yes
   (b) No

B.2 Questions about your visit today

1. Did you view all exhibits at Moundville Museum?
   (a) None of them
   (b) Some of them
   (c) Most of them

(d) All of them

2. Did you view all exhibit descriptions at Moundville Museum?

   (a) None of them
   (b) Some of them
   (c) Most of them
   (d) All of them

3. Please, select the two visitor descriptions that fit your current visit the most

   (a) Explorer - visit museums to satisfy their curiosity and generally have an interest in the field, seek knowledge.
   (b) Experience seekers - seek more pleasure than knowledge.
   (c) Facilitator - visit to support other people (e.g. parents and teachers taking children to a museum.)
   (d) Professional / hobbyist - visit museums for a specific interest.
   (e) Recharger - hoping to relax and recharge their energy.

4. Please, select the two exploration style descriptions that fit your current visit the most

   (a) Ant - closely view almost all exhibits and follow the defined path.
   (b) Fish - view most of the exhibits but does that from a distance without getting into detail.
   (c) Butterfly - view most of the exhibits but do that with no order and frequently changing direction.
   (d) Grasshopper - closely view only specific exhibits and ignore most of the others.

5. Where you at Moundville today for a specific event?

   (a) Yes
   (b) No

6. Will you revisit Moundville?

   (a) Definitely Yes
   (b) Probably Yes
   (c) Probably No
   (d) Definitely no

7. Will you recommend Moundville to a friend?

   (a) Definitely Yes
   (b) Probably Yes
   (c) Probably No
   (d) Definitely No

8. How valuable do you think Moundville is for society?
    (a) Very Valuable
    (b) Somewhat valuable
    (c) Not valuable at all
9. How valuable do you think Moundville is for the local community?
    (a) Very Valuable
    (b) Somewhat valuable
    (c) Not valuable at all
10. Do you think Moundville helps to sustain the local environment?
    (a) Definitely Yes
    (b) Somewhat Yes
    (c) Not Sure
    (d) Somewhat No
    (e) Definitely No
11. Please, rate your overall experience at Moundville
    (a) Very Good
    (b) Good
    (c) Acceptable
    (d) Poor
    (e) Very Poor
12. My visit to Moundville was educational, I learnt something new
    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree
13. My visit to Moundville was fun, I was entertained
    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree
14. My visit to Moundville was relaxing and recharging

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

B.3 Questions about museum food store

1. When visiting a museum, do you regularly make purchases at museum food stores or cafeterias?

   (a) Always

   (b) Often

   (c) Sometimes

   (d) Seldom

   (e) Never

2. Did you purchase anything from the Moundville Museum food store?

   (a) Yes

   (b) No

3. Would you purchase anything from the Moundville Museum food store, if 25% discount was given?

   (a) Strongly Agree

   (b) Agree

   (c) Undecided

   (d) Disagree

   (e) Strongly Disagree

B.4 Questions about museum souvenir store

1. When visiting a museum, do you regularly make purchases at museum souvenir stores?

   (a) Always

   (b) Often

   (c) Sometimes

   (d) Seldom

   (e) Never

2. Did you purchase anything from the Moundville Museum souvenir store?

   (a) Yes

(b) No

3. Would you purchase anything from the Moundville Museum souvenir store, if 10-25% discount was given?

   (a) Strongly Agree
   (b) Agree
   (c) Undecided
   (d) Disagree
   (e) Strongly Disagree

B.5 Questions about Augmented and Virtual Reality

Ask the Researcher to show you videos about Augmented and Virtual Reality at museums.

1. Do you think it WILL BE GREAT for Moundville to have an Augmented Reality experience?

   (a) Strongly Agree
   (b) Agree
   (c) Undecided
   (d) Disagree
   (e) Strongly Disagree

2. Do you think it is REQUIRED for Moundville to have an Augmented Reality experience?

   (a) Strongly Agree
   (b) Agree
   (c) Undecided
   (d) Disagree
   (e) Strongly Disagree

3. Do you think it WILL BE GREAT for Moundville to have a Virtual Reality experience?

   (a) Strongly Agree
   (b) Agree
   (c) Undecided
   (d) Disagree
   (e) Strongly Disagree

4. Do you think it is REQUIRED for Moundville to have a Virtual Reality experience?

   (a) Strongly Agree
   (b) Agree
   (c) Undecided

(d) Disagree

(e) Strongly Disagree

5. Would you pay an additional fee for these experiences?

   (a) Strongly Agree

   (b) Agree

   (c) Undecided

   (d) Disagree

   (e) Strongly Disagree

B.6 A small quiz about the Moundville

1. What are the "Three Sisters"?

   (a) The three main goddesses of Moundville

   (b) The three goddesses of the Realm of the Death in Moundville

   (c) Corn, beans, and squash: three crops grown together by Native Americans

   (d) Corn, potatoes, and tomatoes: three crops grown together by Native Americans

2. What is the "Trail of Tears"?

   (a) The path a soul takes to the afterlife, as per Moundville beliefs

   (b) The name of the burial ceremony practiced at Moundville

   (c) The forced relocation of Native Americans from Mississippi, Alabama, and Florida into reservations by US government

   (d) The forced relocation of Native Americans into Alabama by US government

3. Select the one FALSE statement about Earthlodge

   (a) It was destroyed by fire

   (b) Its solid room represented the dome of the sky

   (c) It was used for ceremonies and as a chiefly council house

   (d) The three center posts represented the three parts of the human soul

4. Select the one TRUE statement about Moundville that we know about from excavations:

   (a) Moundville was an isolated community

   (b) Moundville only connected to nearby villages and chiefdoms

   (c) Moundville was part of a trade network spanning across the modern southeastern US

   (d) Moundville was part of a trade network reaching Aztec lands in Mexico

5. Select the one FALSE statement about Moundville beliefs

   (a) The world consisted of three parts: Celestial Realm, Earthly Plain, and Underworld

(b) Path of the Souls, known to us as Milky Way, was the starry path a human soul took after death

(c) Moundville was considered a place with a gateway to the Realm of the Death

(d) The Hand with an Eye symbol represents the Scorpio constellation, and the Winged Serpent represents the Orion constellation

6. Select the one FALSE statement about Moundville regalia

(a) A gorget was worn around the neck by the Moundville ruling class

(b) The foreign items were not worn by Moundville rulers because they were considered a part of the Realm of the Death

(c) The males of the ruling family carry wooden-handled, copper -bladed axes as symbols of their political authority

(d) The regalia showed the worldly and otherworldly attributes of the ruling elite

7. Select one FALSE statement about how Moundville was explored

(a) The museum building was built by Civilian Conservation corps in 1938-1940

(b) The first European, a Spaniard Hernando de Soto, visited Moundville in 17th century

(c) More than 500 artifacts were found in Moundville

(d) The past of Moundville is restored using methods of Archaeology, Art History, Ethnography, and Folklore

8. Select one TRUE statement about Moundville people

(a) No descendants of Mississippian people have survived

(b) The Mississippians were part of Mezoamerican culture

(c) The descendants of Mississippian people are Choctaw, Chickasaw, Cherokee, Muskogee/Creek, Natchez, Yuchi, Seminole, and Miccosukee

(d) There are just a few thousands of descendants of Mississippian people today

9. Select the FALSE statement. The City of Moundville was...

(a) The largest ever Native American city north of Mexico

(b) Abandoned by the year 1600

(c) A part of the Mississippian culture

(d) A walled city, protected by wooden palisade

Appendix C

Moundville Visitors, Case Group: Survey of Visitors After Using AR/VR Experiences

C.1 Demographics

1. Please, select your age:
   (a) Under 18
   (b) 18-20
   (c) 21-30
   (d) 1-40
   (e) 41-50
   (f) 50-59
   (g) Above 60
2. Please, select your educational level:
   (a) Middle School
   (b) High School
   (c) Undergraduate
   (d) Graduate (master or PhD)
3. Have you been to Moundville before?
   (a) Yes
   (b) No

C.2 Questions about your visit today

1. Did you view all exhibits at Moundville Museum?
   (a) None of them
   (b) Some of them
   (c) Most of them

(d) All of them

2. Did you view all exhibit descriptions at Moundville Museum?

   (a) None of them
   (b) Some of them
   (c) Most of them
   (d) All of them

3. Please, select the two visitor descriptions that fit your current visit the most

   (a) Explorer - visit museums to satisfy their curiosity and generally have an interest in the field, seek knowledge.
   (b) Experience seekers - seek more pleasure than knowledge.
   (c) Facilitator - visit to support other people (e.g. parents and teachers taking children to a museum.)
   (d) Professional / hobbyist - visit museums for a specific interest.
   (e) Recharger - hoping to relax and recharge their energy.

4. Please, select the two exploration style descriptions that fit your current visit the most

   (a) Ant - closely view almost all exhibits and follow the defined path.
   (b) Fish - view most of the exhibits but does that from a distance without getting into detail.
   (c) Butterfly - view most of the exhibits but do that with no order and frequently changing direction.
   (d) Grasshopper - closely view only specific exhibits and ignore most of the others.

5. Where you at Moundville today for a specific event?

   (a) Yes
   (b) No

6. Will you revisit Moundville?

   (a) Definitely Yes
   (b) Probably Yes
   (c) Probably No
   (d) Definitely no

7. Did the AR/VR experience influence your decision?

   (a) Definitely Yes
   (b) Probably Yes
   (c) Not Sure
   (d) Probably No

(e) Definitely no

8. Will you recommend Moundville to a friend?

   (a) Definitely Yes
   (b) Probably Yes
   (c) Probably No
   (d) Definitely No

9. Did the AR/VR experience influence your decision?

   (a) Definitely Yes
   (b) Probably Yes
   (c) Not Sure
   (d) Probably No
   (e) Definitely No

10. How valuable do you think Moundville is for society?

    (a) Very Valuable
    (b) Somewhat valuable
    (c) Not valuable at all

11. How valuable do you think Moundville is for the local community?

    (a) Very Valuable
    (b) Somewhat valuable
    (c) Not valuable at all

12. Do you think Moundville helps to sustain the local environment?

    (a) Definitely Yes
    (b) Probably Yes
    (c) Not Sure
    (d) Probably No
    (e) Definitely No

13. Please, rate your overall experience at Moundville

    (a) Very Good
    (b) Good
    (c) Acceptable
    (d) Poor
    (e) Very Poor

14. My visit to Moundville was educational, I learnt something new

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

15. My visit to Moundville was fun, I was entertained

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

16. My visit to Moundville was relaxing and recharging

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

C.3 Questions about Moundville Virtual Reality Experience (headset)

1. The Moundville VR experience made my visit more educational

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

2. The Moundville VR experience provided knowledge beyond what was presented in the museum

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

3. The Moundville VR experience made my visit more entertaining

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

4. The Moundville VR experience made my visit more relaxing and recharging

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

5. The Virtual Reality app helps Moundville to sustain the local environment

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

6. The app was easy to use

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

7. The app was fun

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

8. The app was amusing

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

9. The app was entertaining

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

10. The app was captivating

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

11. The app was pleasant

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

12. The app was attractive

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

13. The app was educational

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

14. The educational materials were informative

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

15. Did you read all educational materials in the app?

(a) None of them
(b) Some of them
(c) Most of them
(d) All of them

16. Did you pick up and view the exhibits in the app?

(a) None of them
(b) Some of them
(c) Most of them
(d) All of them

17. I feel like I know more about Moundville and Native Americans after playing the VR app

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

18. The Virtual Reality world felt realistic

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

19. You would recommend this app to other Moundville visitors

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

20. How much would you pay for the Moundville VR experience (headset) in addition to the admission fee?

    (a) No pay
    (b) Less than $5
    (c) $5-$10
    (d) More than $10

21. If you had a VR headset, would you download the Moundville VR experience (headset) to play it at home?

    (a) Definitely Yes
    (b) Probably Yes
    (c) Not Sure
    (d) Probably No
    (e) Definitely No

22. Would you pay to download the Moundville VR experience (headset) to play it at home, knowing that his money will go to support the museum?

    (a) No pay
    (b) Less than $5
    (c) $5-$10
    (d) More than $10

C.4 Questions about Moundville Augmented Reality Experience (smartphone)

1. The Moundville AR experience made my visit more educational

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

2. The Moundville AR experience provided knowledge beyond what was presented in the museum

    (a) Definitely Agree
    (b) Somewhat Agree
    (c) Not Sure
    (d) Somewhat Disagree
    (e) Definitely Disagree

3. The Moundville AR experience made my visit more entertaining

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

4. The Moundville AR experience made my visit more relaxing and recharging

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

5. The Augmented Reality app helps Moundville helps to sustain the local environment

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

6. The app was easy to use

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

7. The app was fun

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

8. The app was amusing

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

9. The app was entertaining

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

10. The app was captivating

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

11. The app was pleasant

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

12. The app was attractive

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

13. The app was educational

(a) Definitely Agree

(b) Somewhat Agree

(c) Not Sure

(d) Somewhat Disagree

(e) Definitely Disagree

14. The help section was informative

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

15. The app design represents the Moundville heritage well

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

16. The educational materials were informative

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

17. I feel like I know more about Moundville and Native Americans after playing the VR app

(a) Definitely Agree
(b) Somewhat Agree
(c) Not Sure
(d) Somewhat Disagree
(e) Definitely Disagree

18. The exhibit scanning worked perfectly

(a) None of them
(b) Some of them
(c) Most of them
(d) All of them

19. Did you scan all the participating exhibits?

(a) None
(b) One
(c) Two
(d) Three

(e) Four

(f) Five

(g) Six

20. Did you answer all the quiz questions?

    (a) None

    (b) One

    (c) Two

    (d) Three

    (e) Four

    (f) Five

    (g) Six

21. Did you collect the prize?

    (a) Yes

    (b) No

    (c) Didn't achieve it

22. Were you satisfied with the prize?

    (a) Definitely Agree

    (b) Somewhat Agree

    (c) Somewhat Disagree

    (d) Definitely Disagree

23. Would you complete the quiz, even if there was no prize?

    (a) Definitely Agree

    (b) Somewhat Agree

    (c) Somewhat Disagree

    (d) Definitely Disagree

24. Would you recommend this app to other Moundville visitors?

    (a) Definitely Agree

    (b) Somewhat Agree

    (c) Not Sure

    (d) Somewhat Disagree

    (e) Definitely Disagree

C.5 A small quiz about the Moundville

1. What are the “Three Sisters”?

   (a) The three main goddesses of Moundville

   (b) The three goddesses of the Realm of the Death in Moundville

   (c) Corn, beans, and squash: three crops grown together by Native Americans

   (d) Corn, potatoes, and tomatoes: three crops grown together by Native Americans

2. What is the “Trail of Tears”?

   (a) The path a soul takes to the afterlife, as per Moundville beliefs

   (b) The name of the burial ceremony practiced at Moundville

   (c) The forced relocation of Native Americans from Mississippi, Alabama, and Florida into reservations by US government

   (d) The forced relocation of Native Americans into Alabama by US government

3. Select the one FALSE statement about Earthlodge

   (a) It was destroyed by fire

   (b) Its solid room represented the dome of the sky

   (c) It was used for ceremonies and as a chiefly council house

   (d) The three center posts represented the three parts of the human soul

4. Select the one TRUE statement about Moundville that we know about from excavations:

   (a) Moundville was an isolated community

   (b) Moundville only connected to nearby villages and chiefdoms

   (c) Moundville was part of a trade network spanning across the modern southeastern US

   (d) Moundville was part of a trade network reaching Aztec lands in Mexico

5. Select the one FALSE statement about Moundville beliefs

   (a) The world consisted of three parts: Celestial Realm, Earthly Plain, and Underworld

   (b) Path of the Souls, known to us as Milky Way, was the starry path a human soul took after death

   (c) Moundville was considered a place with a gateway to the Realm of the Death

   (d) The Hand with an Eye symbol represents the Scorpio constellation, and the Winged Serpent represents the Orion constellation

6. Select the one FALSE statement about Moundville regalia

   (a) A gorget was worn around the neck by the Moundville ruling class

   (b) The foreign items were not worn by Moundville rulers because they were considered a part of the Realm of the Death

(c) The males of the ruling family carry wooden-handled, copper -bladed axes as symbols of their political authority

(d) The regalia showed the worldly and otherworldly attributes of the ruling elite

7. Select one FALSE statement about how Moundville was explored

(a) The museum building was built by Civilian Conservation corps in 1938-1940

(b) The first European, a Spaniard Hernando de Soto, visited Moundville in 17th century

(c) More than 500 artifacts were found in Moundville

(d) The past of Moundville is restored using methods of Archaeology, Art History, Ethnography, and Folklore

8. Select one TRUE statement about Moundville people

(a) No descendants of Mississippian people have survived

(b) The Mississippians were part of Mezoamerican culture

(c) The descendants of Mississippian people are Choctaw, Chickasaw, Cherokee, Muskogee/Creek, Natchez, Yuchi, Seminole, and Miccosukee

(d) There are just a few thousands of descendants of Mississippian people today

9. Select the FALSE statement. The City of Moundville was...

(a) The largest ever Native American city north of Mexico

(b) Abandoned by the year 1600

(c) A part of the Mississippian culture

(d) A walled city, protected by wooden palisade

Appendix D

General Audience: Survey on Perception of AR/VR in Museums

D.1 Intro

Before you proceed, please, view the following YouTube videos to familiarize yourself with Augmented and Virtual Reality technologies (about 5 minutes required):

General overview of AR and VR:
`https://www.youtube.com/watch?v=vz0UUVDt2ps`

Example of VR in a museum:
`https://www.youtube.com/watch?v=c1xbACZYb1Q`

Examples of AR in museums:
`https://www.youtube.com/watch?v=DrLjPpt_K5g`
`https://www.youtube.com/watch?v=hDRVLYsCgxA`

D.2 Personal Data

1. Please, select your age:
   (a) Under 18
   (b) Under 18-20
   (c) Under 21-30
   (d) Under 31-40
   (e) Under 41-50
   (f) Above 50-59
   (g) Above 60
2. What is your current country of residence?
   (a) Text Input
3. Please, select your educational level:
   (a) Middle School
   (b) High School
   (c) Undergraduate

(d) Graduate (master or PhD)

4. How would you rate your computer skills and knowledge?

   (a) Extremely bad
   (b) Somewhat bad
   (c) Somewhat good
   (d) Extremely good

5. How familiar are you with AR?

   (a) Extremely familiar
   (b) Somewhat familiar
   (c) Not familiar at all

6. How familiar are you with VR?

   (a) Extremely familiar
   (b) Somewhat familiar
   (c) Not familiar at all

7. Did the videos in the beginning of the survey help you better understand what AR and VR is?

   (a) Definitely not
   (b) Probably not
   (c) Might or might not
   (d) Probably yes
   (e) Definitely yes

8. If you are paying attention, please, select Somewhat Agree

   (a) Strongly disagree
   (b) Somewhat disagree
   (c) Neither agree nor disagree
   (d) Somewhat agree
   (e) Strongly agree

9. Did the videos in the beginning of the survey help you better understand how AR and VR can be used at a museum?

   (a) Definitely not
   (b) Probably not
   (c) Might or might not
   (d) Probably yes

(e) Definitely yes

10. How often do you visit museums?

    (a) Once in few years
    (b) Once a year
    (c) More than once a year

11. What type of exhibitions do you prefer to visit? Please, select all that apply.

    (a) Art – paintings
    (b) Art – installations
    (c) Art – pots and sculptures
    (d) Natural History
    (e) Human History
    (f) Technological
    (g) Science
    (h) Kids – Educational
    (i) Thematic company/product exhibition
    (j) Interactive Exhibitions
    (k) Other (Please, specify) - Text Input

12. What you think is the main purpose of a museum? Please, select all that apply.

    (a) Preserve
    (b) Present / Showcase
    (c) Informal Education
    (d) Entertainment
    (e) Recreation
    (f) Other (Please, specify) - Text Input

D.3 AR/VR in Museums

1. AR and VR experiences are a nice addition to a modern museum experience.

    (a) Strongly disagree
    (b) Somewhat disagree
    (c) Neither agree nor disagree
    (d) Somewhat agree
    (e) Strongly agree

2. AR and VR experiences are a requirement for a modern museum experience.

    (a) Strongly disagree

(b) Somewhat disagree

(c) Neither agree nor disagree

(d) Somewhat agree

(e) Strongly agree

3. If you are paying attention, please, select Somewhat Disagree

   (a) Strongly disagree

   (b) Somewhat disagree

   (c) Neither agree nor disagree

   (d) Somewhat agree

   (e) Strongly agree

4. Imagine the following situation. There are two museums, equally interesting for you, but due to your schedule, you can visit only one of them. One of the museums has an AR/VR experience. Would you choose that one?

   (a) Definitely not

   (b) Probably not

   (c) Might or might not

   (d) Probably yes

   (e) Definitely yes

5. 26. Please, rate how much do you agree or disagree with the following: implementing an AR/VR experience at the museum can...

   (a) For Each

      i. ...create more memorable visitor experiences
      ii. ...improve marketing presence and competitiveness
      iii. ...can attract new target markets
      iv. ...positively affect working experience
      v. ...improving job security
      vi. ...adding value to the visitors' experience
      vii. ...increase visitors' intent to return
      viii. ...increase visitors' attention to the exhibitions
      ix. ...add more content to the exhibition
      x. ...trigger visitors' interest in the exhibition
      xi. ...trigger visitors' interest in the exhibition topic
      xii. ...help visitors explore the exhibitions in a new light
      xiii. ...increase footfall numbers
      xiv. ...enhanced visitor engagement
      xv. ...enrich visitor memories
      xvi. ...bring the exhibition to life

xvii. ...enhance visitors' emotional attachment
xviii. ...enhance visitors' social interaction
xix. ...personalize the visitors' experience
xx. ...help visitors to memorize exhibition
xxi. ...help visitors learning
xxii. ...help reaching the purposes of the museum
xxiii. ...select strongly agree
xxiv. ...preserve and retain museum exhibits
xxv. ...positively affect the museum environment
xxvi. ...positively affect museum stores and cafeterias economy
xxvii. ...positively affect spending at the local community
xxviii. ...improve the museum accessibility
xxix. ...make museum less accessible

(b) Choices

i. Strongly disagree
ii. Somewhat disagree
iii. Neither agree nor disagree
iv. Somewhat agree
v. Strongly agree

6. In your opinion, must visitors be charged additionally for the AR/VR experience?

(a) No additional charges
(b) 0-10% of the original museum admission
(c) 10-25% of the original museum admission
(d) 25-50% of the original museum admission
(e) More than 50% of the original museum admission

7. Would you donate to a museum to build an AR or VR experience?

(a) Definitely not
(b) Probably not
(c) Might or might not
(d) Probably yes
(e) Definitely yes

8. How often do you donate to museums?

(a) Never
(b) Once a year
(c) A couple of times per year
(d) A current museum patron / donor / member / sponsor

D.4 Gamification

To gamify a museum experience, one may add an interactive educational game. For example, the Cairo museum experience was gamified by adding an interactive game AR game. Gamifying experience also means adding game-like features to it. For example, in the Yerevan Geological Museum, a visitor can receive points for each mineral they guessed during the tour and convert these points towards the museum merchandise.

1. Please, rate how much do you agree or disagree with the following: Gamifying a museum experience must include following types of experiences:
   (a) For Each
      i. Text Quiz
      ii. Interactive Quiz
      iii. Quest
      iv. Combat/Fight Simulator
      v. Explorative
      vi. Building
      vii. Storytelling
      viii. Visual Novel
      ix. Treasure Hunt
   (b) Choices
      i. Strongly disagree
      ii. Somewhat disagree
      iii. Neither agree nor disagree
      iv. Somewhat agree
      v. Strongly agree
2. Please, rate how much do you agree or disagree with the following: Gamifying at the museum experience can...
   (a) For Each
      i. ...create more memorable visitor experiences
      ii. ...improve marketing presence and competitiveness
      iii. ...add value to the visitors' experience
      iv. ...increase visitors' intent to return
      v. ...increase visitor attention to the exhibitions
      vi. ...add more content to the exhibition
      vii. ...trigger visitors' interest to the exhibition
      viii. ...trigger visitors' interest to the exhibition topic
      ix. ...help visitors explore the exhibitions in a new light
      x. ...increase footfall numbers
      xi. ...select strongly disagree
      xii. ...enhance visitor engagement

xiii. ...enrich visitor memories
xiv. ...bring the exhibition to life
xv. ...enhance visitors' emotional attachment
xvi. ...enhance visitors' social interaction
xvii. ...personalize the visitors' experience
xviii. ...help visitors to memorize the exhibition
xix. ...help visitors learn
xx. ...help reach the purposes of the museum
xxi. ...positively affect spending at museum stores and cafeterias
xxii. ...improve the museum accessibility
xxiii. ...make the museum less accessible

(b) Choices

i. Strongly disagree
ii. Somewhat disagree
iii. Neither agree nor disagree
iv. Somewhat agree
v. Strongly agree

3. Imagine the following situation. There are two museums, equally interesting for you, but due to your schedule, you can visit only one of them. One of the museums has a gamified experience. Would you choose that one?

(a) Definitely not
(b) Probably not
(c) Might or might not
(d) Probably yes
(e) Definitely yes

D.5 Visitor Categories

1. Which visitor categories you think an AR/VR experience may attract the most? Choose two.

(a) Kids (5-12)
(b) Teenagers (13-17)
(c) Young Adults (18-35)
(d) Middle Age (36-55)
(e) Older Adults (56+)

2. Which visitor categories you think a gamified experience may attract the most? Choose two.

(a) Kids (5-12)

(b) Teenagers (13-17)

(c) Young Adults (18-35)

(d) Middle Age (36-55)

(e) Older Adults (56+)

D.6 Substituting Artifacts

Modern exhibitions are rarely static. An exhibit can be loaned to be temporarily included into another exhibitions and collections, or an exhibit may be temporarily missing due to restorations or lack of space caused by ongoing thematic exhibitions. In the USA, Native American artifacts may also be removed by tribal demand. As a result, an exhibit may not be on display at the moment of your visit.

There are different methods to substitute an unavailable exhibit. Images or video of the exhibit can be put in its place. A physical replica can be made, or, with Augmented Reality (AR), one can also view a virtual 3D replica of the exhibit. The virtual 3D replica can be either created by hand, or be an exact 3D scan generated by an expensive scanner.

1. How frustrated will you be if an exhibit is missing that is...

   (a) For Each

      i. of high significance for you
      ii. of average significance for you
      iii. of little significance for you

   (b) Choices

      i. Extremely frustrated
      ii. Somewhat frustrated
      iii. Not frustrated

2. An exhibit of high significance for you is substituted by...

   (a) For Each

      i. Image/Video
      ii. Physical replica
      iii. Virtual AR replica model
      iv. Virtual AR 3D scan model

   (b) Choices

      i. Extremely dissatisfied
      ii. Somewhat dissatisfied
      iii. Neither satisfied nor dissatisfied
      iv. Somewhat satisfied
      v. Extremely satisfied

3. An exhibit of average significance for you is substituted by...

   (a) For Each

i. Image/Video
ii. Physical replica
iii. Virtual AR replica model
iv. Virtual AR 3D scan model

(b) Choices

i. Extremely dissatisfied
ii. Somewhat dissatisfied
iii. Neither satisfied nor dissatisfied
iv. Somewhat satisfied
v. Extremely satisfied

4. An exhibit of low significance for you is substituted by...

(a) For Each

i. Image/Video
ii. Physical replica
iii. Virtual AR replica model
iv. Virtual AR 3D scan model

(b) Choices

i. Extremely dissatisfied
ii. Somewhat dissatisfied
iii. Neither satisfied nor dissatisfied
iv. Somewhat satisfied
v. Extremely satisfied

5. What aspect of virtual AR 3D replicas do you think is more important?

(a) Recreating the original look of exhibits
(b) Recreating the exhibits as preserved

6. Please, select Very effective

(a) Not effective at all
(b) Slightly effective
(c) Moderately effective
(d) Very effective
(e) Extremely effective

7. Please, rank the following issues of using virtual AR replica models

(a) The 3D model does not have accurate shape
(b) The 3D model does not have accurate colors
(c) The 3D model is not detailed
(d) The AR app is not user friendly

(e) The AR experience requires a special device (e.g. AR headset)

8. You now will be asked to compare original exhibits from Moundville Archaeological Park (on the right) and their 3D replicas (on the left). Please, indicate how satisfied you will be with such a 3D replica in an AR experience.

   (a) For Each Approved Exhibit

   (b) Choices

      i. Extremely dissatisfied
      ii. Somewhat dissatisfied
      iii. Neither satisfied nor dissatisfied
      iv. Somewhat satisfied
      v. Extremely satisfied

Appendix E

Museum Workers: Survey on Perception of AR/VR in Museums

E.1 Intro

Before you proceed, please view the following YouTube videos to familiarize yourself with Augmented and Virtual Reality technologies (about 5 minutes required):

General overview of AR and VR:
https://www.youtube.com/watch?v=vz0UUVDt2ps

Example of VR in a museum:
https://www.youtube.com/watch?v=c1xbACZYb1Q

Examples of AR in museums:
https://www.youtube.com/watch?v=DrLjPpt_K5g
https://www.youtube.com/watch?v=hDRVLYsCgxA

E.2 Personal and Museum Data

1. Please, select your age:
   (a) Under 18
   (b) 18-20
   (c) 21-30
   (d) 31-40
   (e) 41-50
   (f) 51-59
   (g) Above 60
2. Please, select your educational level:
   (a) Middle School
   (b) High School
   (c) Undergraduate
   (d) Graduate (master or PhD)
3. How would you rate your computer skills and knowledge?

(a) Extremely bad

(b) Somewhat bad

(c) Somewhat good

(d) Extremely good

4. How familiar are you with AR?

   (a) Extremely familiar

   (b) Somewhat familiar

   (c) Not familiar at all

5. How familiar are you with VR?

   (a) Extremely familiar

   (b) Somewhat familiar

   (c) Not familiar at all

6. Did the videos in the beginning of the survey help you better understand what AR and VR is?

   (a) Definitely not

   (b) Probably not

   (c) Might or might not

   (d) Probably yes

   (e) Definitely yes

7. Did the videos in the beginning of the survey help you better understand how AR and VR can be used at a museum?

   (a) Definitely not

   (b) Probably not

   (c) Might or might not

   (d) Probably yes

   (e) Definitely yes

8. Please, describe your position in the museum. (e.g. volunteer, guide, director, etc.) (Text Input)

   (a) Text Input

9. Where is the museum located?

   (a) Urban

   (b) Suburban

   (c) Countryside

10. How would you describe the size of the museum?
    (a) Very small
    (b) Small
    (c) Medium
    (d) Large
    (e) Very large
11. Please, estimate number of yearly visitors
    (a) Not known
    (b) ¡ 30,000
    (c) 30,000 - 100,000
    (d) 100,000 - 1,000,000
    (e) 1,000,000+
12. What type of exhibitions can be found in the museum? Please, select all that apply.
    (a) Art – paintings
    (b) Art – installations
    (c) Art – pots and sculptures
    (d) Natural History
    (e) Human History
    (f) Technological
    (g) Science
    (h) Kids – Educational
    (i) Thematic company/product exhibition
    (j) Interactive Exhibitions
    (k) Other (Please, specify) - Text Input
13. What you think is the main purpose of a museum? Please, select all that apply.
    (a) Preservation
    (b) Presentation / Showcasing
    (c) Informal Education
    (d) Entertainment
    (e) Recreation
    (f) Other (Please, specify) - Text Input
14. How is the museum financed? Please, select all that apply.
    (a) Federal support
    (b) State support

(c) Local support

(d) Donations/Patrons

(e) Earned income (tickets, souvenirs, rentals, etc.)

(f) Investment income

(g) I don't know

(h) Other (Please, specify) - Text Input

15. Do you currently offer any of the following as part of the exhibition? Please, select all that apply.

    (a) Self-guided tours

    (b) Audio guided tours

    (c) Guided tours (individual or group)

    (d) Interactive informational systems

    (e) Interactive games, mechanisms, and automatons

    (f) Videos, slideshows

    (g) Holograms

    (h) Augmented Reality mobile app

    (i) Augmented or Mixed Reality headset experience

    (j) Virtual Reality headset experience

    (k) Cardboard VR headset experience

E.3 Implemented Augmented Reality

1. 19. Are these experiences a permanent part of your exhibition?

    (a) Yes

    (b) No

2. Can you please describe this experience in one or two sentences?

    (a) Text Input

3. Can you please describe how this experience affected the museum and the visitors in one or two sentences?

    (a) Text Input

4. Do you charge additionally for this experience?

    (a) Yes

    (b) No

5. Can you please describe the nature of this additional charge in one or two sentences?

    (a) Text Input

E.4 AR/VR in Museums

1. Please, describe in a couple of sentences what is your vision of a museum AR experience.
   (a) Text Input
2. Please, describe in a couple of sentences what is your vision of a museum VR experience.
   (a) Text Input
3. AR and VR experiences are a nice addition to a modern museum experience.
   (a) Strongly disagree
   (b) Somewhat disagree
   (c) Neither agree nor disagree
   (d) Somewhat agree
   (e) Strongly agree
4. AR and VR experiences are a requirement for a modern museum experience.
   (a) Strongly disagree
   (b) Somewhat disagree
   (c) Neither agree nor disagree
   (d) Somewhat agree
   (e) Strongly agree
5. 26. Please, rate how much you agree or disagree with the following: implementing an AR/VR experience at the museum can...
   (a) For Each
      i. ...create more memorable visitor experiences
      ii. ...improve marketing presence and competitiveness
      iii. ...can attract new target markets
      iv. ...positively affect working experience
      v. ...improving job security
      vi. ...adding value to the visitors' experience
      vii. ...increase visitors' intent to return
      viii. ...increase visitors' attention to the exhibitions
      ix. ...add more content to the exhibition
      x. ...trigger visitors' interest in the exhibition
      xi. ...trigger visitors' interest in the exhibition topic
      xii. ...help visitors explore the exhibitions in a new light
      xiii. ...increase footfall numbers
      xiv. ...enhanced visitor engagement
      xv. ...enrich visitor memories

xvi. ...bring the exhibition to life
xvii. ...enhance visitors' emotional attachment
xviii. ...enhance visitors' social interaction
xix. ...personalize the visitors' experience
xx. ...help visitors to memorize exhibition
xxi. ...help visitors learning
xxii. ...help reaching the purposes of the museum
xxiii. ...preserve and retain museum exhibits
xxiv. ...positively affect the museum environment
xxv. ...positively affect museum stores and cafeterias economy
xxvi. ...positively affect spending at the local community
xxvii. ...improve the museum accessibility
xxviii. ...make museum less accessible

(b) Choices

i. Strongly disagree
ii. Somewhat disagree
iii. Neither agree nor disagree
iv. Somewhat agree
v. Strongly agree

6. Are there any other potential benefits that you can think of with AR/VR experience at a museum? Please, describe with a couple of sentences.

   (a) Text Input

7. Are there any other potential challenges that you can think of with AR/VR experience at a museum? Please, describe with a couple of sentences.

   (a) Text Input

8. In your opinion, must visitors be charged additionally for the AR/VR experience?

   (a) No additional charges
   (b) 0-10% of the original museum admission
   (c) 10-25% of the original museum admission
   (d) 25-50% of the original museum admission
   (e) More than 50% of the original museum admission

9. In your opinion, how may the implementation of the AR/VR experience be funded? Please, select all the applicable funding sources.

   (a) I do not know
   (b) Internal museum funds
   (c) Museum stakeholders

(d) Governmental grants

(e) Grant from sponsors/donors

(f) Crowdfunded by local community

(g) Crowdfunded by visitors

(h) Crowdfunded using online platforms

(i) Other (Please, specify) - Text Input

E.5 Gamification

To gamify a museum experience, one may add an interactive educational game. For example, the Cairo museum experience was gamified by adding an interactive game AR game. Gamifying experience also means adding game-like features to it. For example, in the Yerevan Geological Museum, a visitor can receive points for each mineral they guessed during the tour and convert these points towards the museum merchandise.

1. Please, rate how much you agree or disagree with the following: Gamifying a museum experience must include following types of experiences:

   (a) For Each

      i. Text Quiz
      ii. Interactive Quiz
      iii. Quest
      iv. Combat/Fight Simulator
      v. Explorative
      vi. Building
      vii. Storytelling
      viii. Visual Novel
      ix. Treasure Hunt

   (b) Choices

      i. Strongly disagree
      ii. Somewhat disagree
      iii. Neither agree nor disagree
      iv. Somewhat agree
      v. Strongly agree

2. Please, rate how much you agree or disagree with the following: Gamifying at the museum experience can...

   (a) For Each

      i. ...create more memorable visitor experiences
      ii. ...improve marketing presence and competitiveness
      iii. ...add value to the visitors' experience
      iv. ...increase visitors' intent to return

v. ...increase visitor attention to the exhibitions
vi. ...add more content to the exhibition
vii. ...trigger visitors' interest to the exhibition
viii. ...trigger visitors' interest to the exhibition topic
ix. ...help visitors explore the exhibitions in a new light
x. ...increase footfall numbers
xi. ...enhance visitor engagement
xii. ...enrich visitor memories
xiii. ...bring the exhibition to life
xiv. ...enhance visitors' emotional attachment
xv. ...enhance visitors' social interaction
xvi. ...personalize the visitors' experience
xvii. ...help visitors to memorize the exhibition
xviii. ...help visitors learn
xix. ...help reach the purposes of the museum
xx. ...positively affect spending at museum stores and cafeterias
xxi. ...improve the museum accessibility
xxii. ...make the museum less accessible

(b) Choices

i. Strongly disagree
ii. Somewhat disagree
iii. Neither agree nor disagree
iv. Somewhat agree
v. Strongly agree

E.6 Visitor Categories

1. Which visitor categories do you think an AR/VR experience may attract the most? Choose two.

   (a) Kids (5-12)
   (b) Teenagers (13-17)
   (c) Young Adults (18-35)
   (d) Middle Age (36-55)
   (e) Older Adults (56+)

2. Which visitor categories you think a gamified experience may attract the most? Choose two.

   (a) Kids (5-12)
   (b) Teenagers (13-17)
   (c) Young Adults (18-35)

(d) Middle Age (36-55)

(e) Older Adults (56+)

3. Please, explain your answer with one or two sentences.

   (a) Text Input

E.7 Substituting Artifacts

Modern exhibitions are rarely static. An exhibit can be loaned to be temporarily included into another exhibitions and collections, or an exhibit may be temporarily missing due to restorations or lack of space caused by ongoing thematic exhibitions. In the USA, Native American artifacts may also be removed by tribal demand. As a result, an exhibit may not be on display at the moment of your visit.

There are different methods to substitute an unavailable exhibit. Images or video of the exhibit can be put in its place. A physical replica can be made, or, with Augmented Reality (AR), one can also view a virtual 3D replica of the exhibit. The virtual 3D replica can be either created by hand, or be an exact 3D scan generated by an expensive scanner.

1. An exhibit of high significance for you is substituted by...

   (a) For Each

      i. Image/Video
      ii. Physical replica
      iii. Virtual AR replica model
      iv. Virtual AR 3D scan model

   (b) Choices

      i. Extremely dissatisfied
      ii. Somewhat dissatisfied
      iii. Neither satisfied nor dissatisfied
      iv. Somewhat satisfied
      v. Extremely satisfied

2. An exhibit of average significance for you is substituted by...

   (a) For Each

      i. Image/Video
      ii. Physical replica
      iii. Virtual AR replica model
      iv. Virtual AR 3D scan model

   (b) Choices

      i. Extremely dissatisfied
      ii. Somewhat dissatisfied
      iii. Neither satisfied nor dissatisfied
      iv. Somewhat satisfied

v. Extremely satisfied

3. An exhibit of low significance for you is substituted by...
   (a) For Each
      i. Image/Video
      ii. Physical replica
      iii. Virtual AR replica model
      iv. Virtual AR 3D scan model
   (b) Choices
      i. Extremely dissatisfied
      ii. Somewhat dissatisfied
      iii. Neither satisfied nor dissatisfied
      iv. Somewhat satisfied
      v. Extremely satisfied
4. What aspect of virtual AR 3D replicas do you think is more important?
   (a) Recreating the original look of exhibits
   (b) Recreating the exhibits as preserved
5. Please, rank the following issues of using virtual AR replica models
   (a) The 3D model does not have accurate shape
   (b) The 3D model does not have accurate colors
   (c) The 3D model is not detailed
   (d) The AR app is not user friendly
   (e) The AR experience requires a special device (e.g. AR headset)
6. You now will be asked to compare original exhibits from Moundville Archaeological Park (on the right) and their 3D replicas (on the left). Please, indicate how satisfied you will be with such a 3D replica in an AR experience.
   (a) For Each Approved Exhibit
   (b) Choices
      i. Extremely dissatisfied
      ii. Somewhat dissatisfied
      iii. Neither satisfied nor dissatisfied
      iv. Somewhat satisfied
      v. Extremely satisfied

Appendix F

UI/UX of the Moundville AR Experience

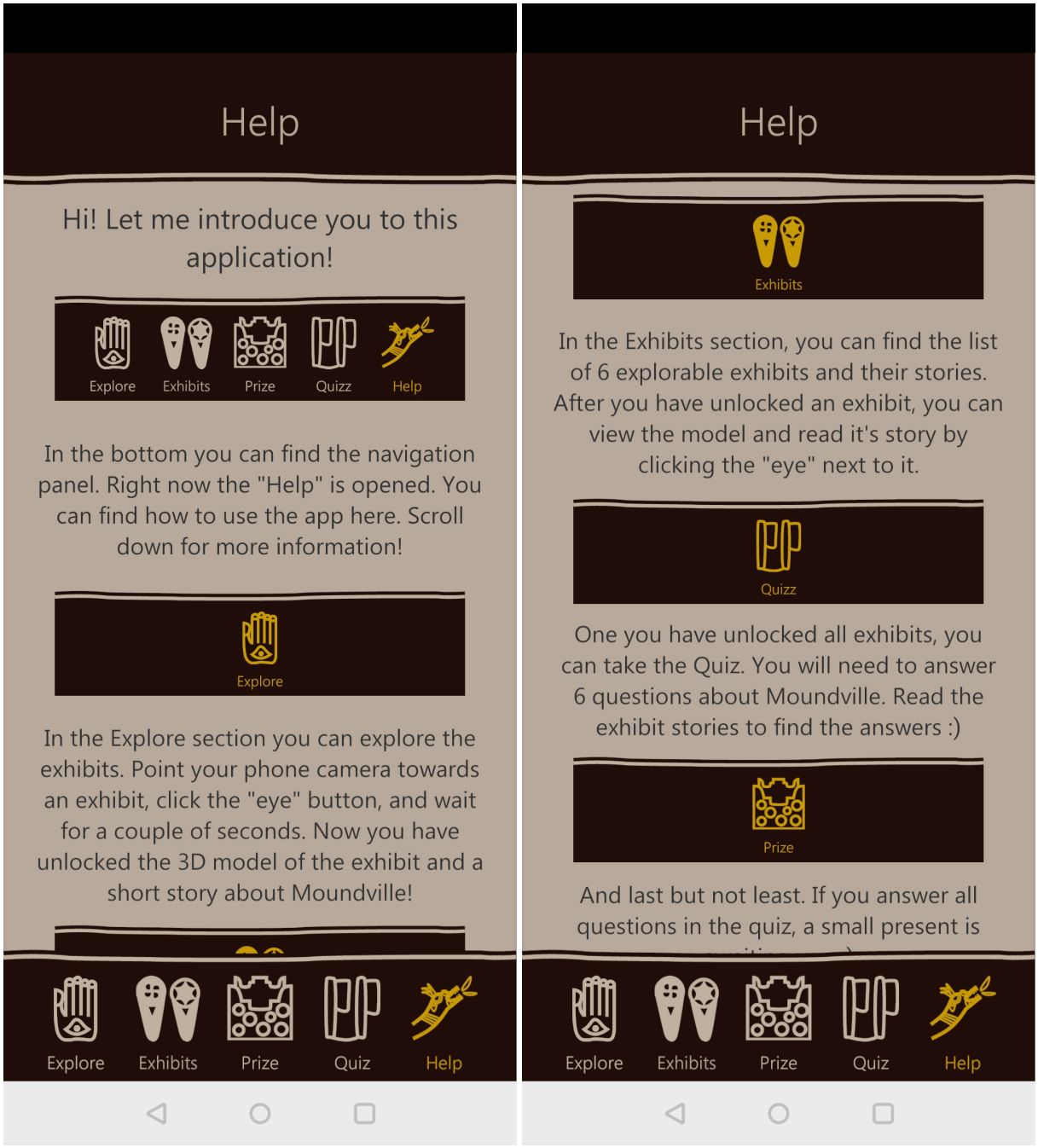


Figure F.1: The Help section of the Moundville AR application, part 1.

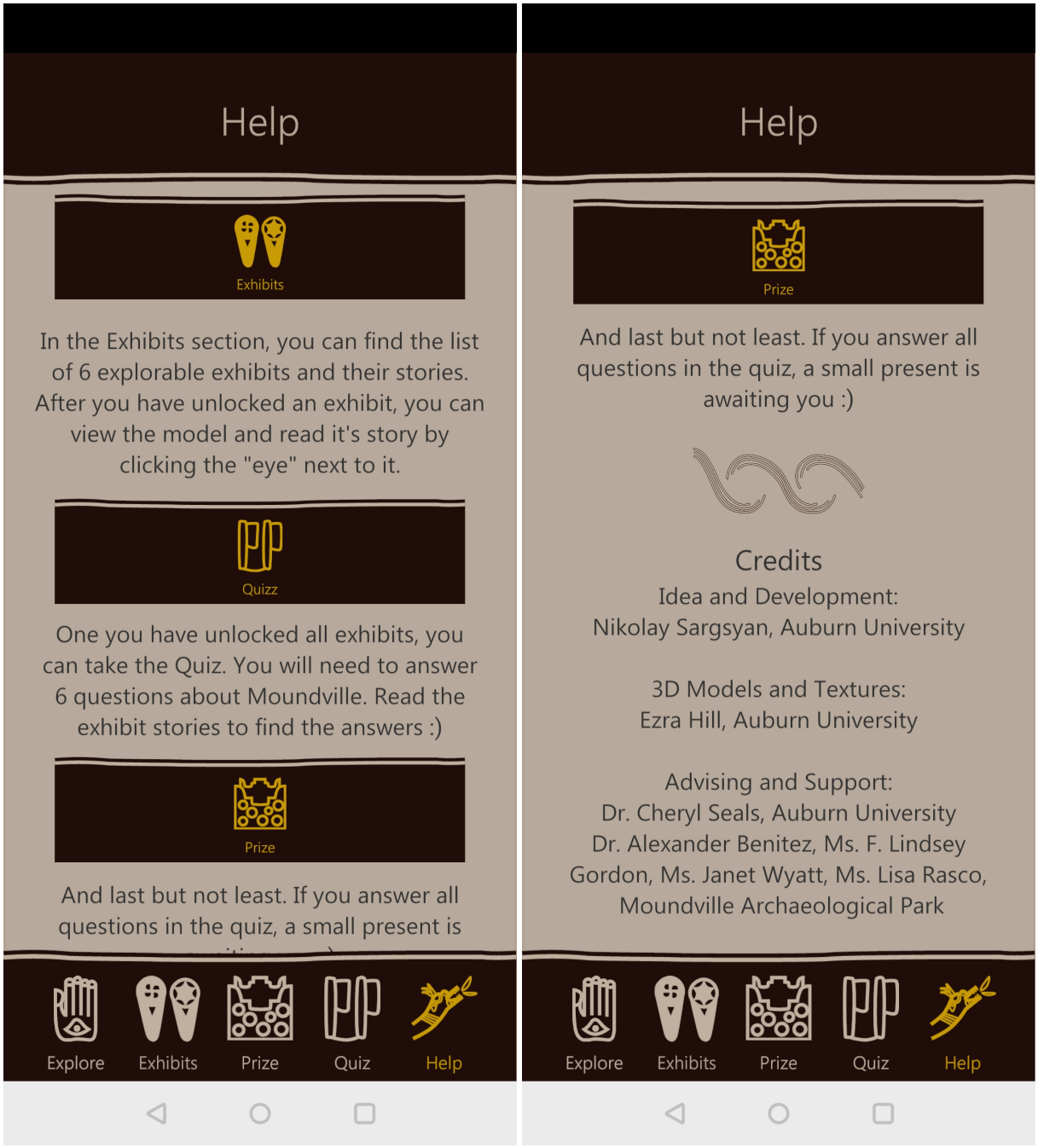


Figure F.2: The Help section of the Moundville AR application, part 1.

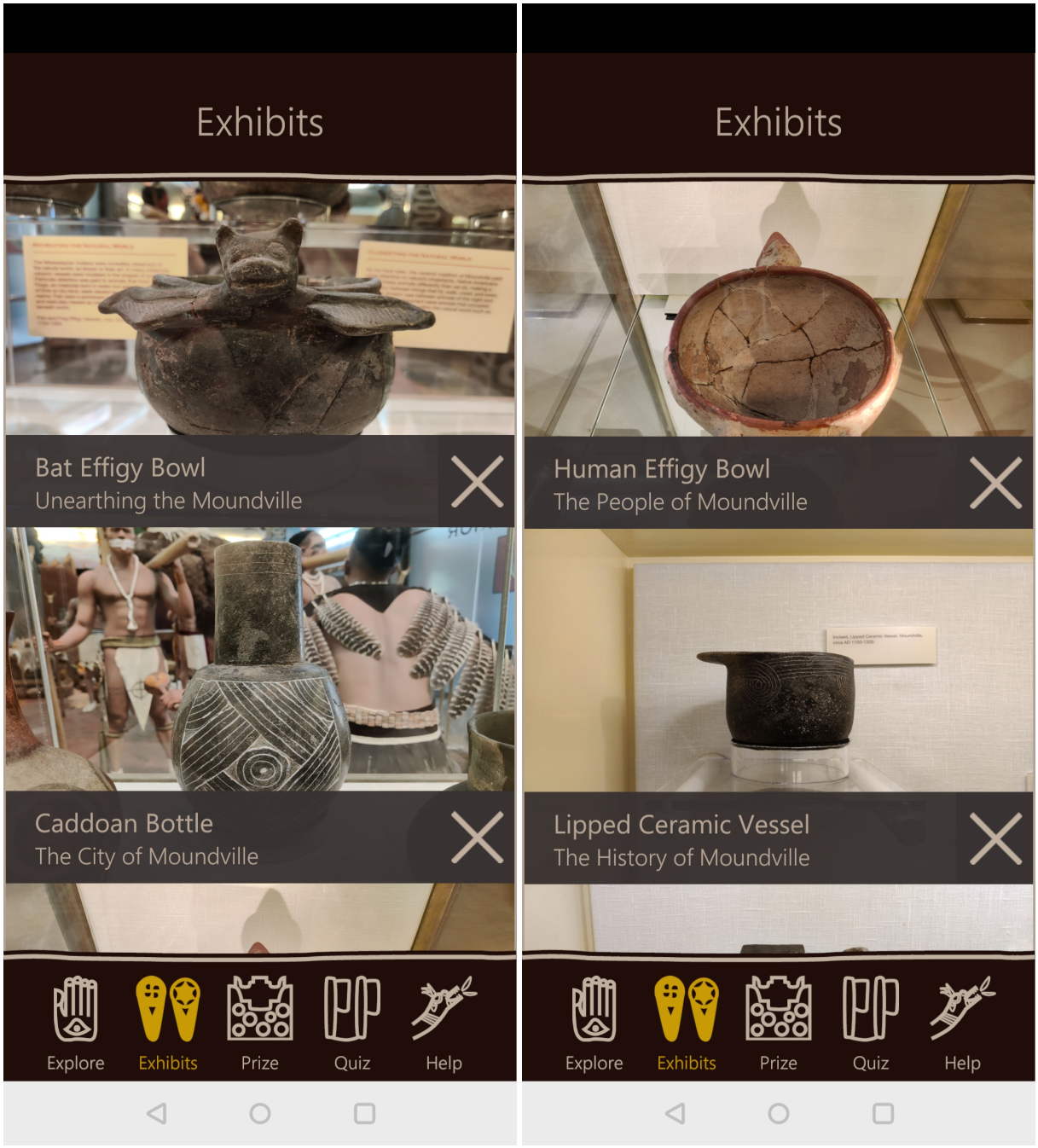


Figure F.3: The Exhibits section of the Moundville AR application, part 1.

Figure F.4: The Exhibits section of the Moundville AR application, part 2.

Figure F.5: The Explore section of the Moundville AR application, the idle (left) and the scanning (right) states.

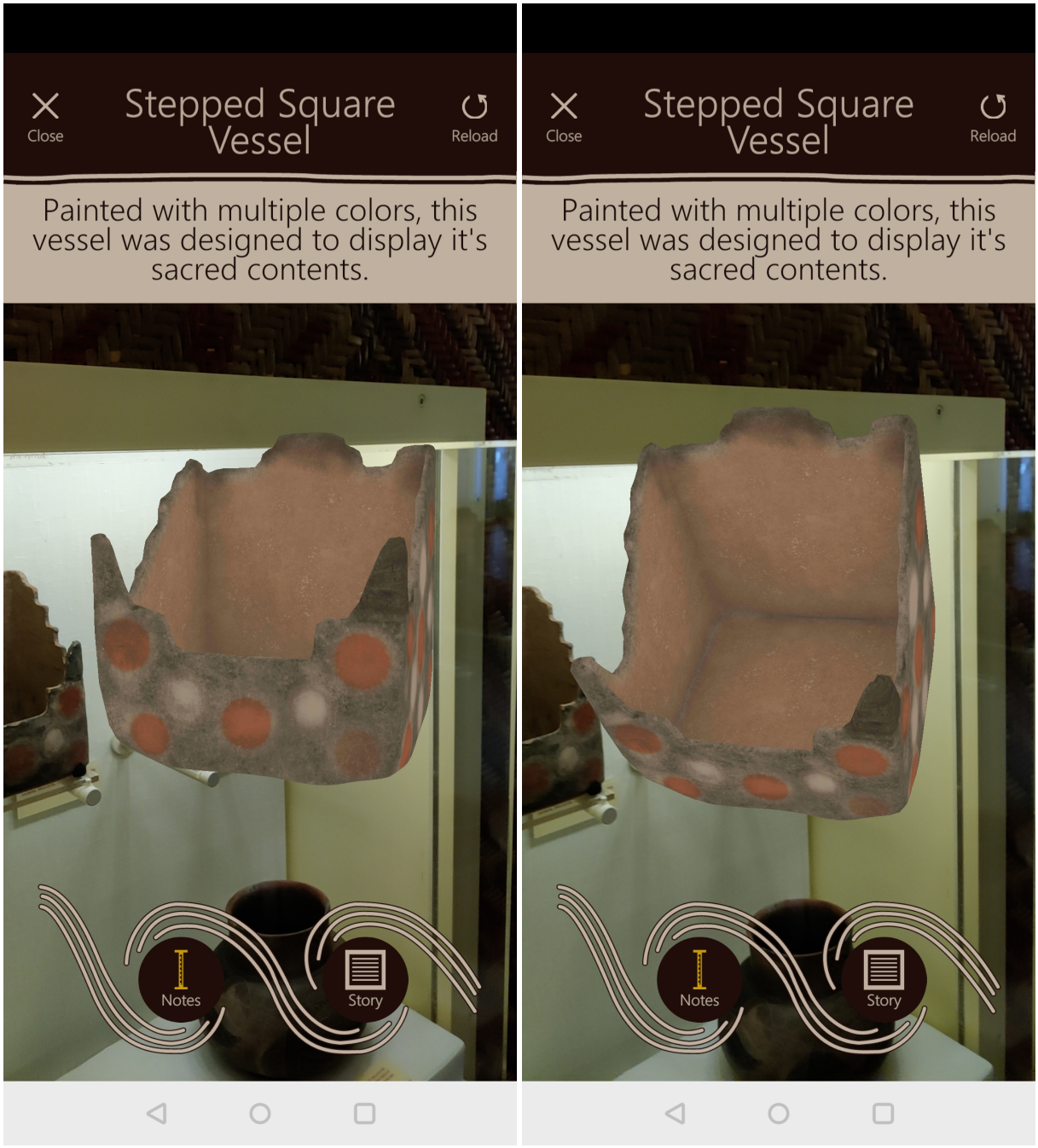


Figure F.6: The Explore section of the Moundville AR application, the view of the 3D model.

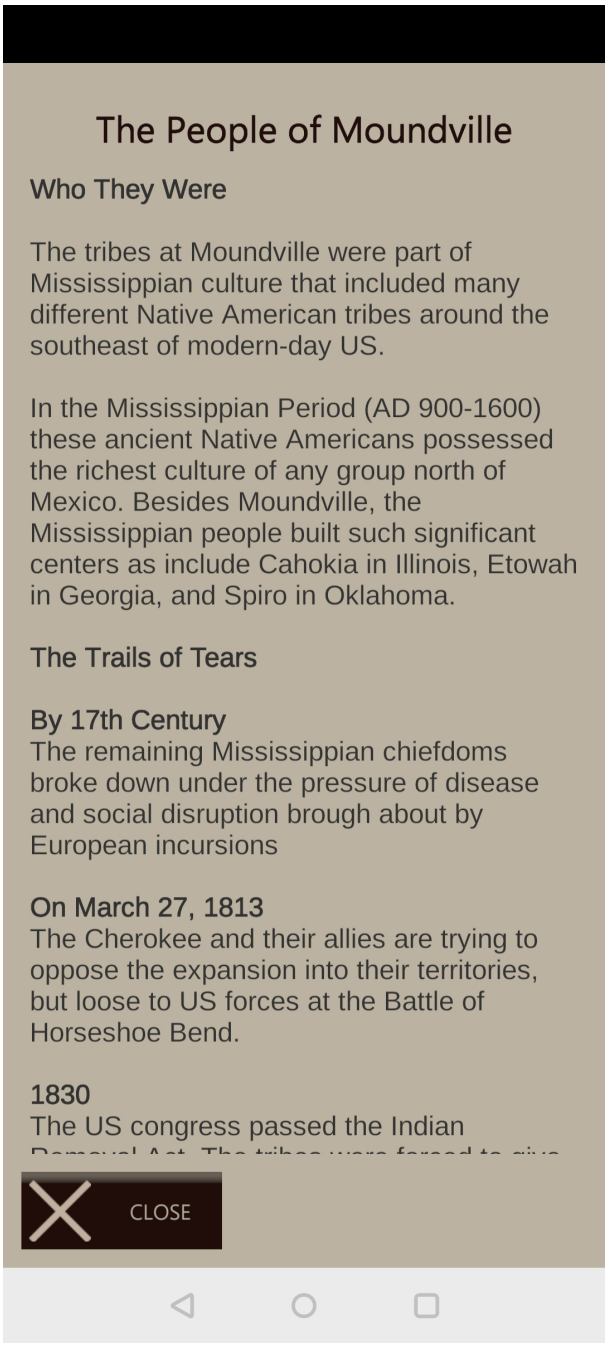


Figure F.7: The story associated with an artifact, accessible from either Explore or Exhibits section of the Moundville AR application.

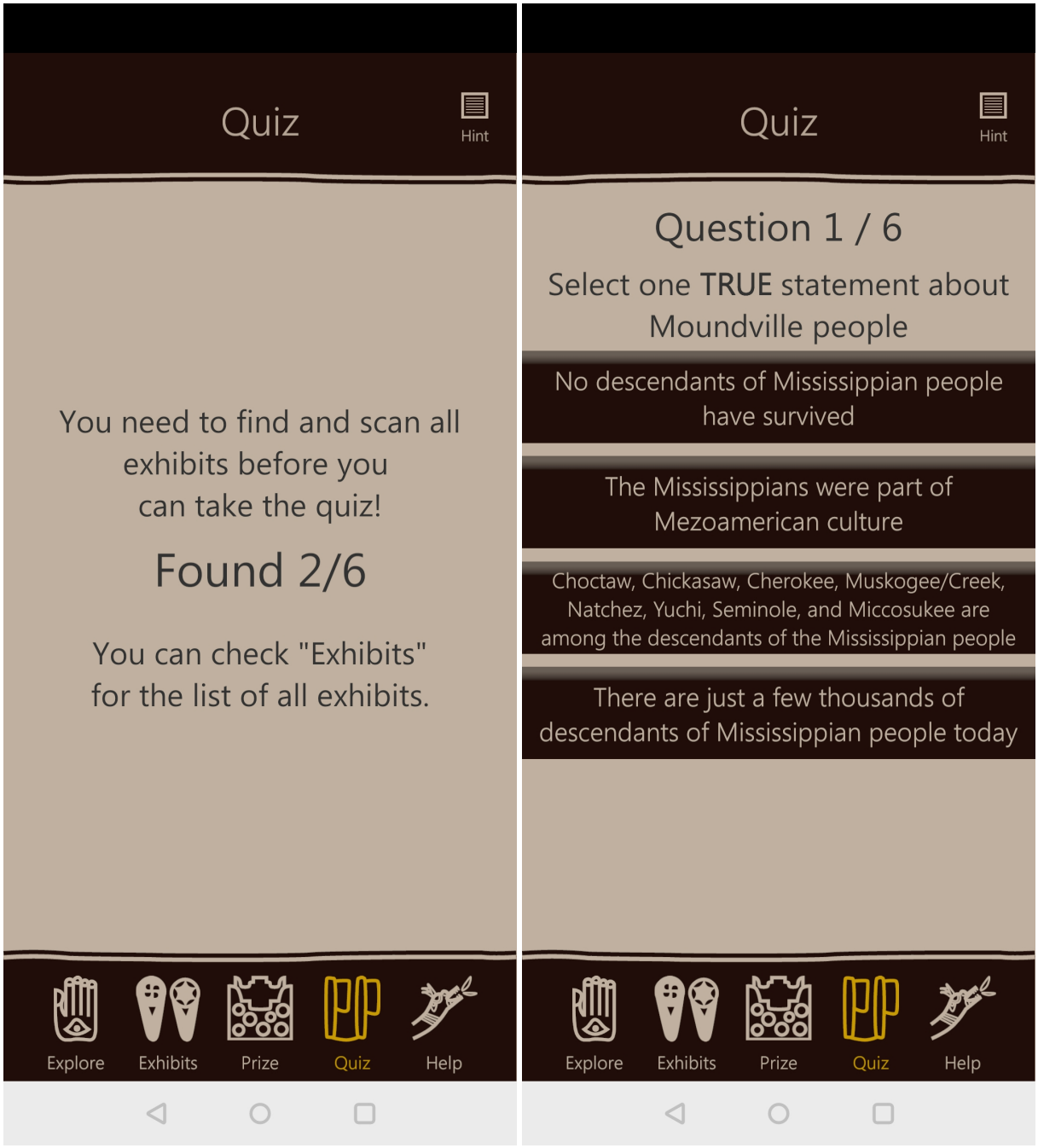


Figure F.8: The Quiz section of the Moundville AR application, part 1.

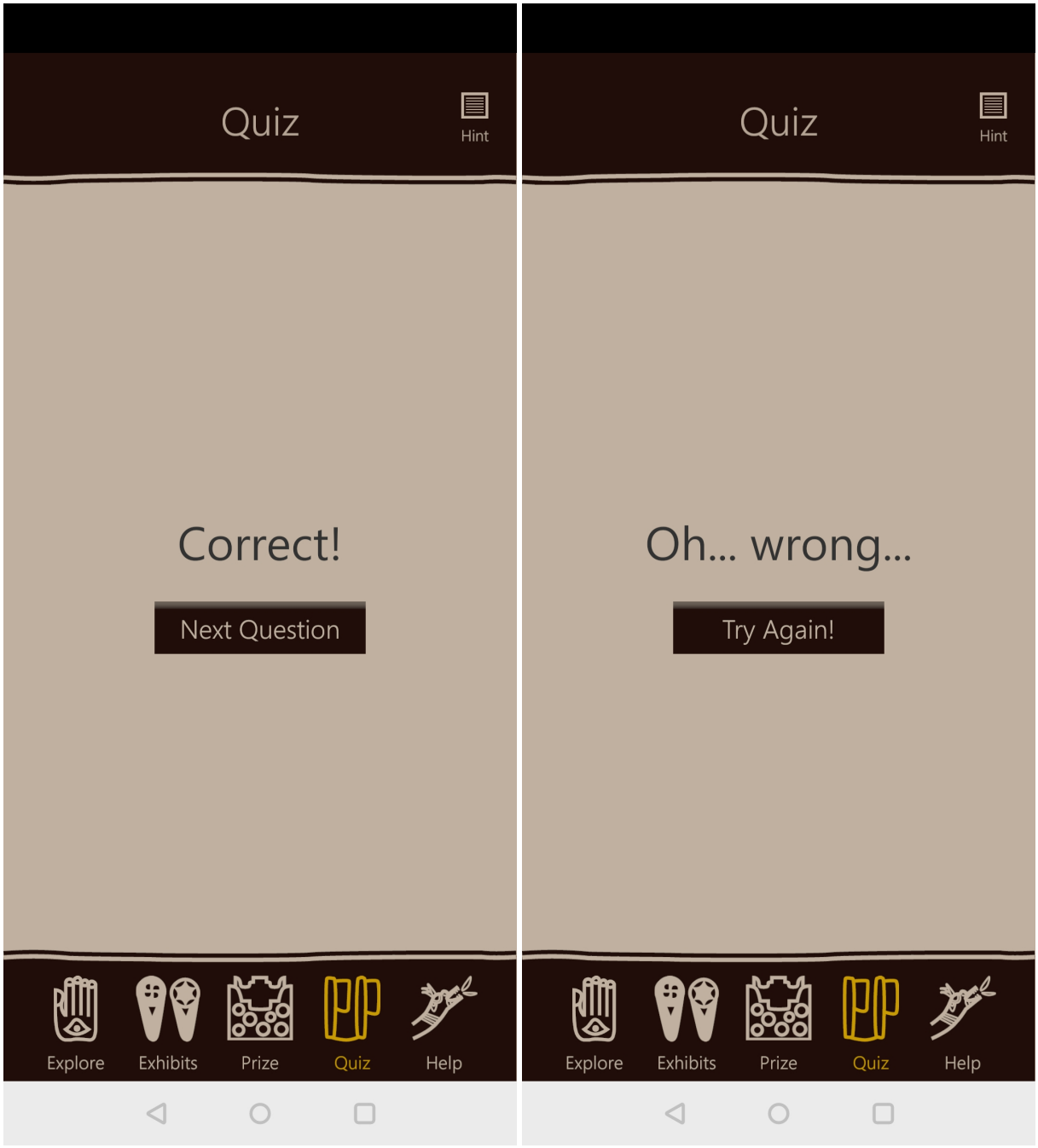


Figure F.9: The Quiz section of the Moundville AR application, part 2.

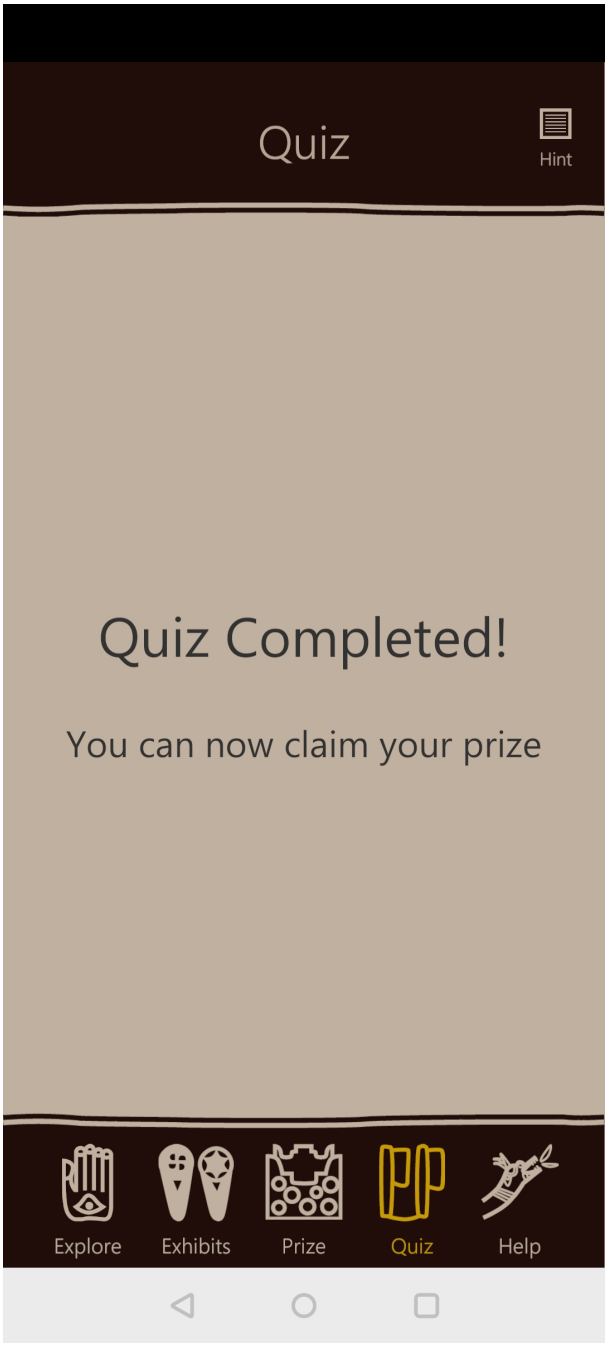


Figure F.10: The Quiz section of the Moundville AR application, part 3.

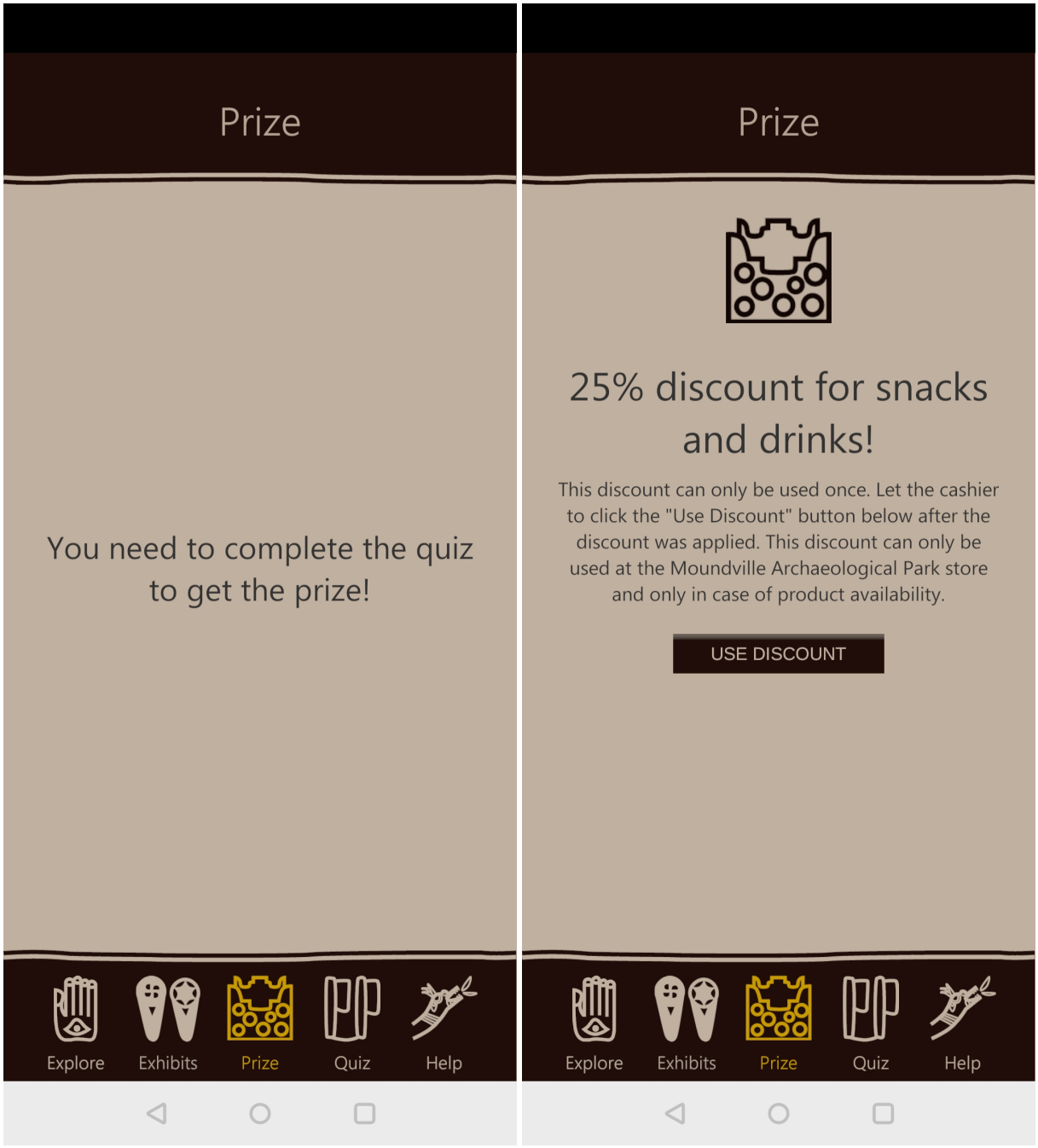


Figure F.11: The Prize section of the Moundville AR application, part 1.

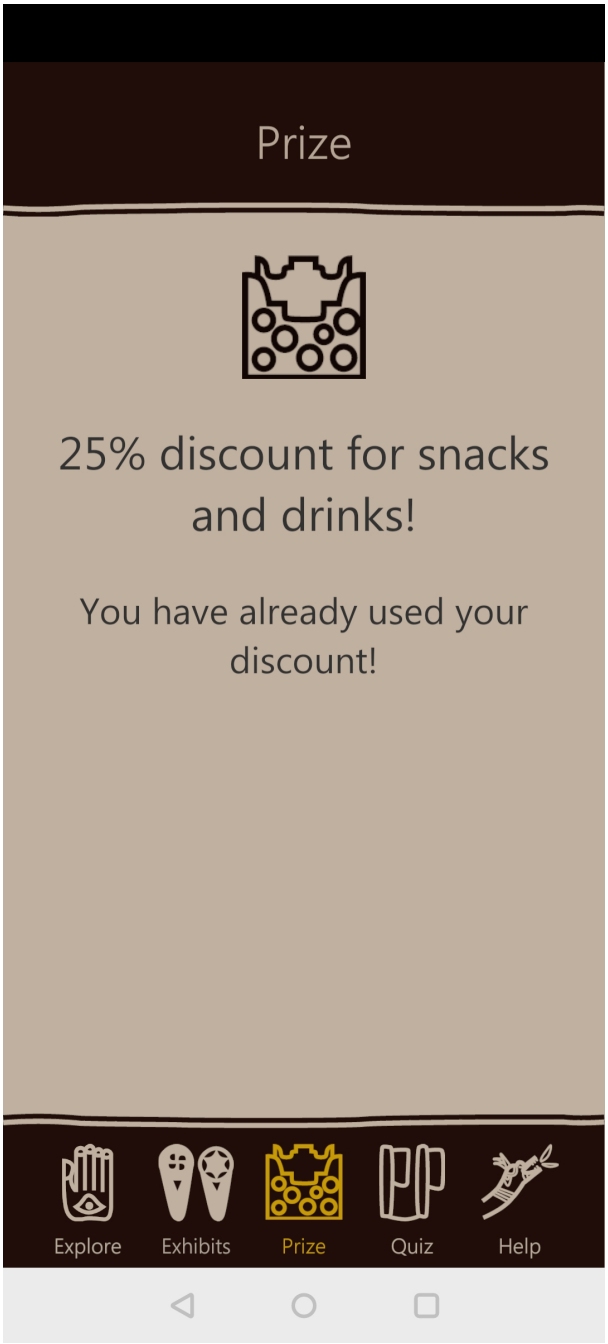


Figure F.12: The Prize section of the Moundville AR application, part 2.

Appendix G

Virtual Environment of the Moundville VR Experience

Figure G.1: The Native American Mississippian house and the adjustened three sisters garden. The educational materials are hidden.

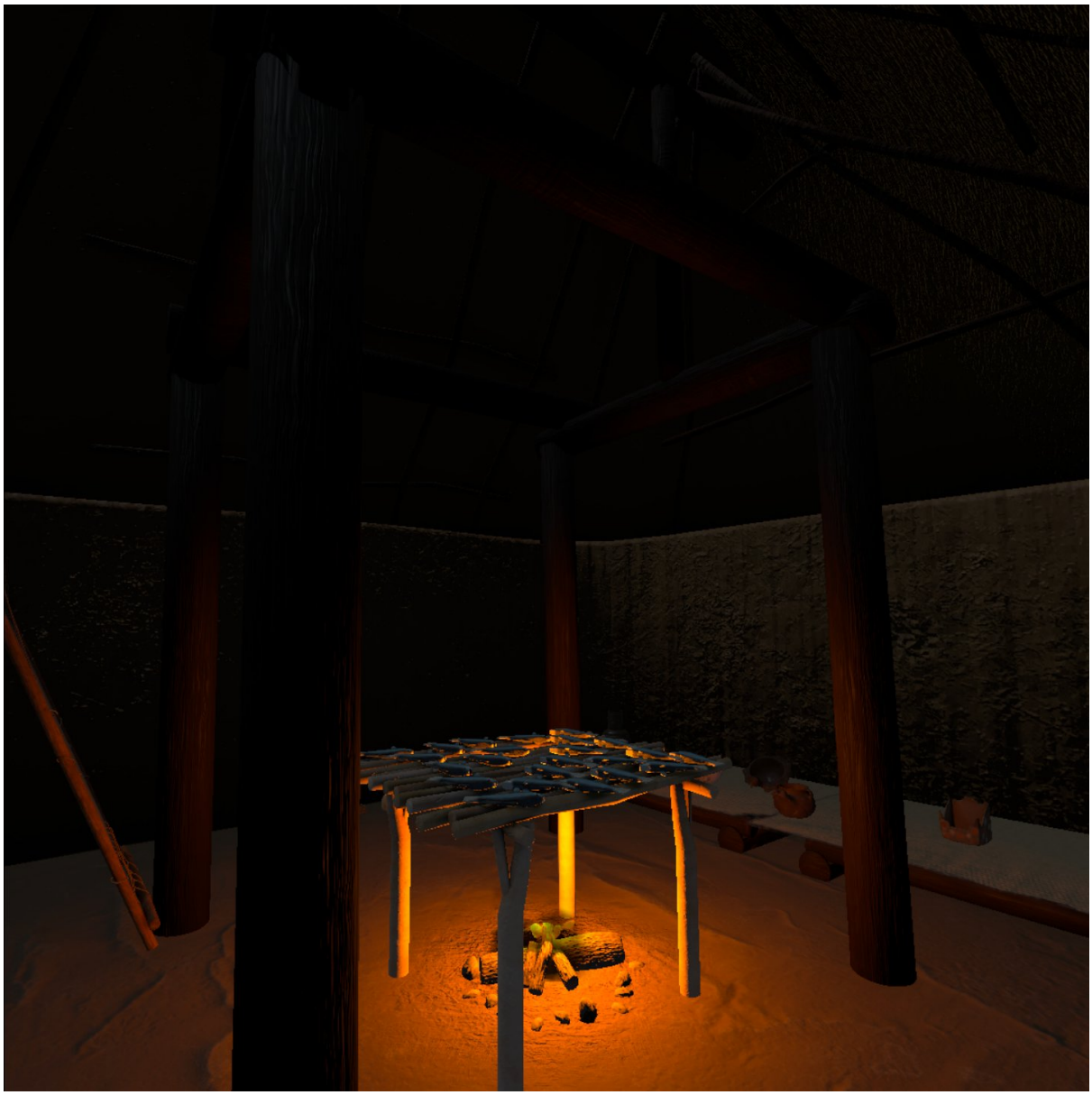


Figure G.2: The insides of the Native American Mississippian house. The educational materials are hidden.

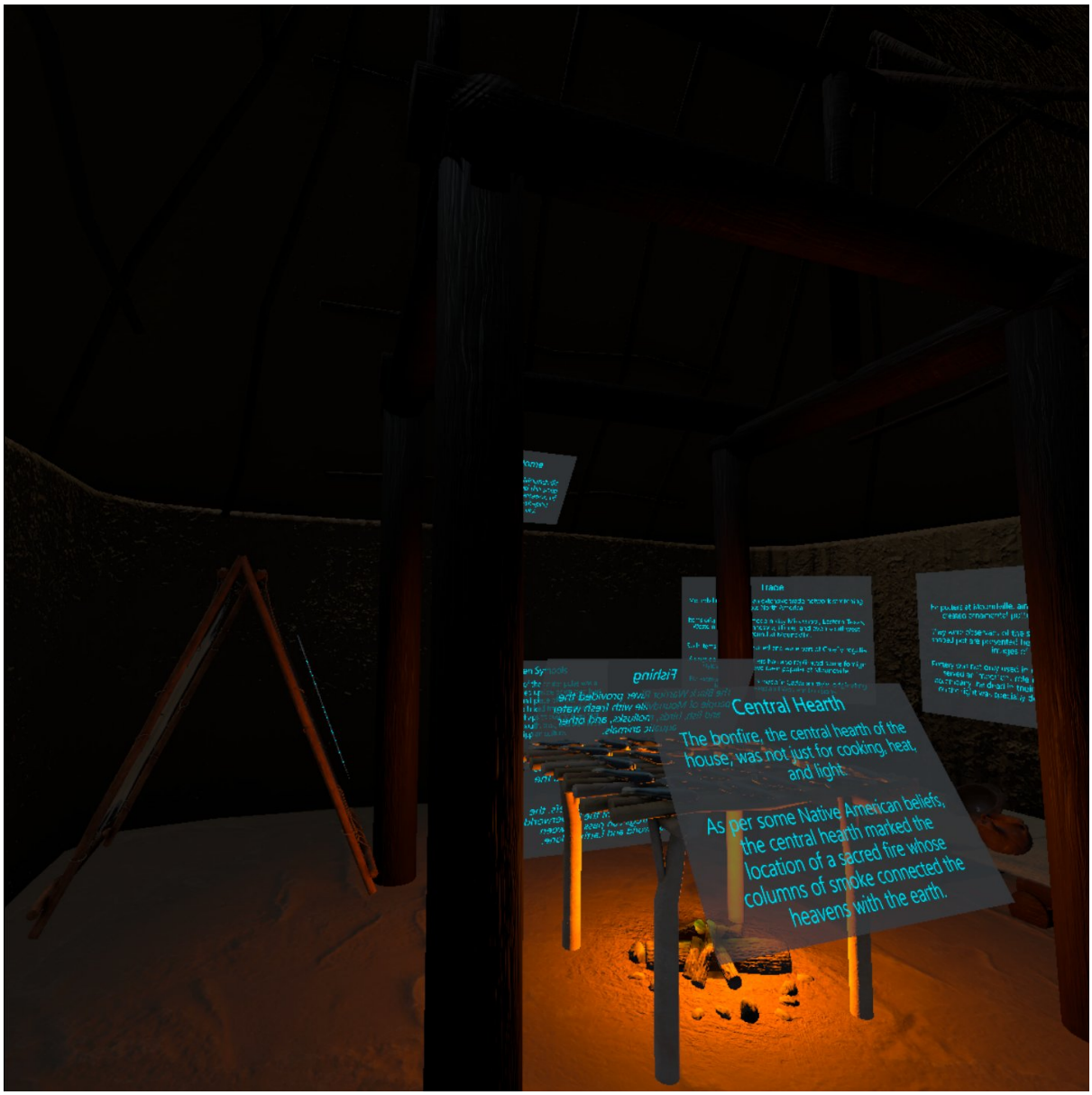


Figure G.3: The insides of the Native American Mississippian house. The educational materials are visible.

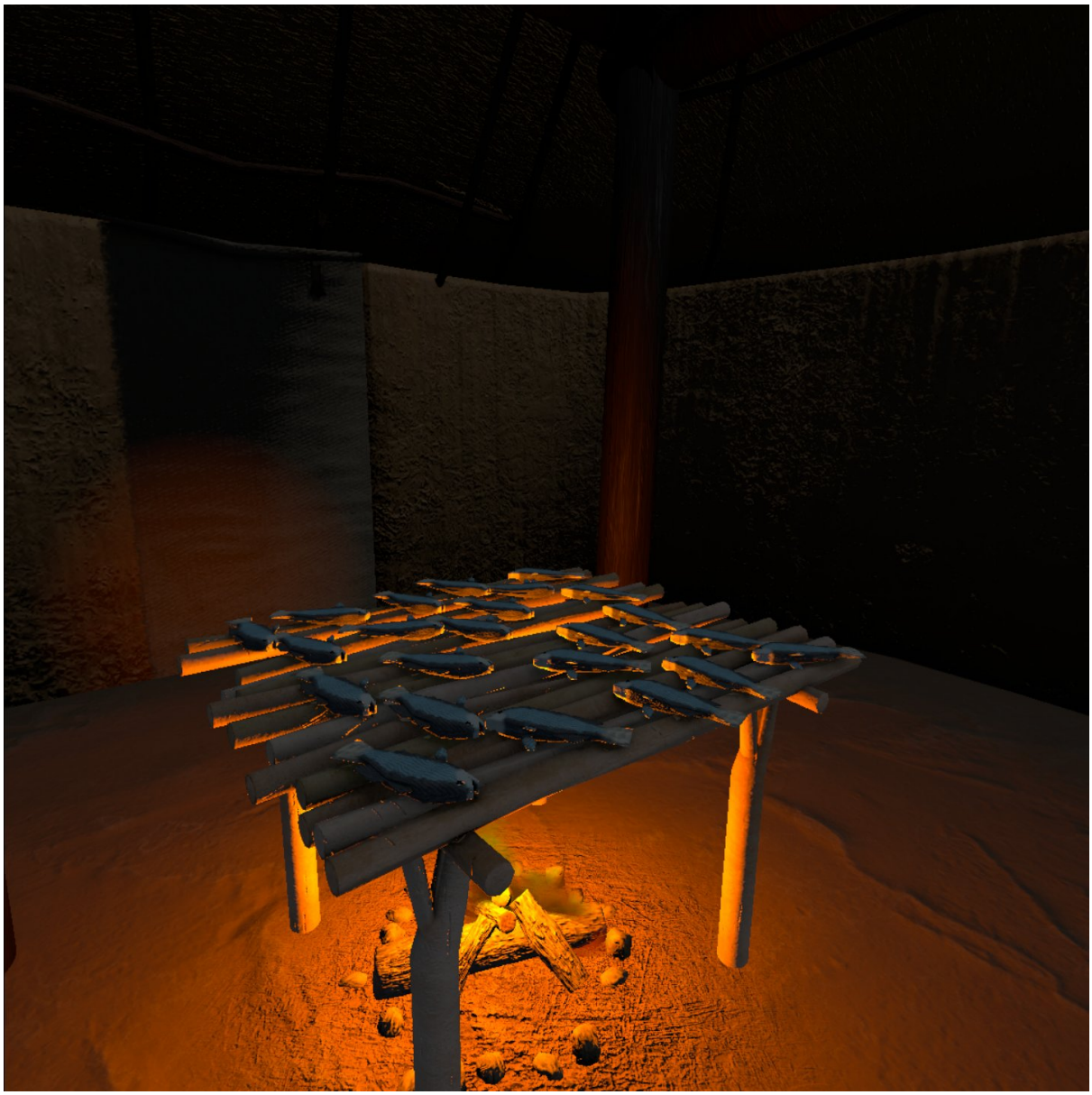


Figure G.4: The central hearth. The educational materials are hidden.

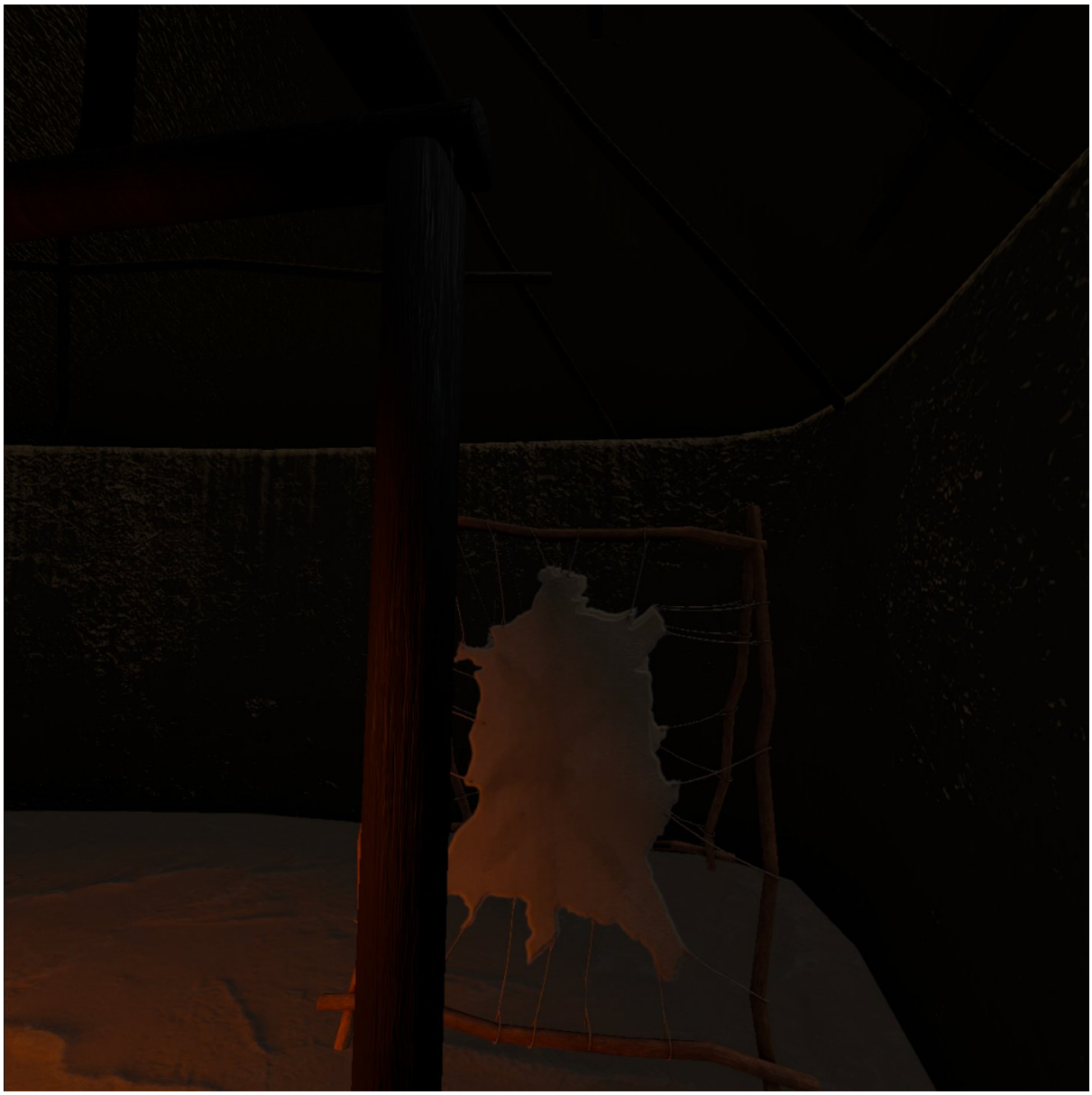


Figure G.5: The hide with an animal skin. The educational materials are hidden.

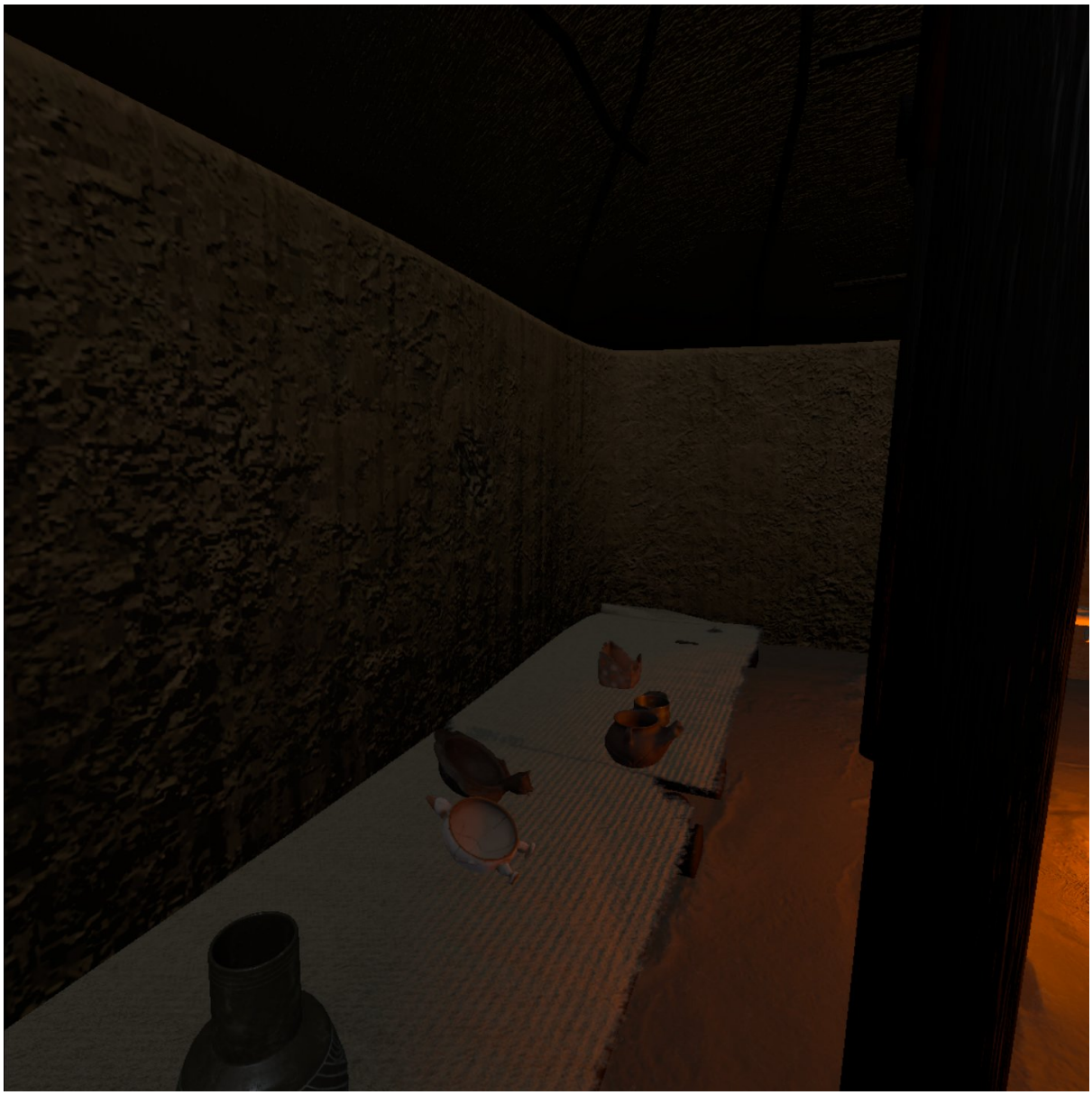


Figure G.6: The beds with artifacts. The educational materials are hidden.

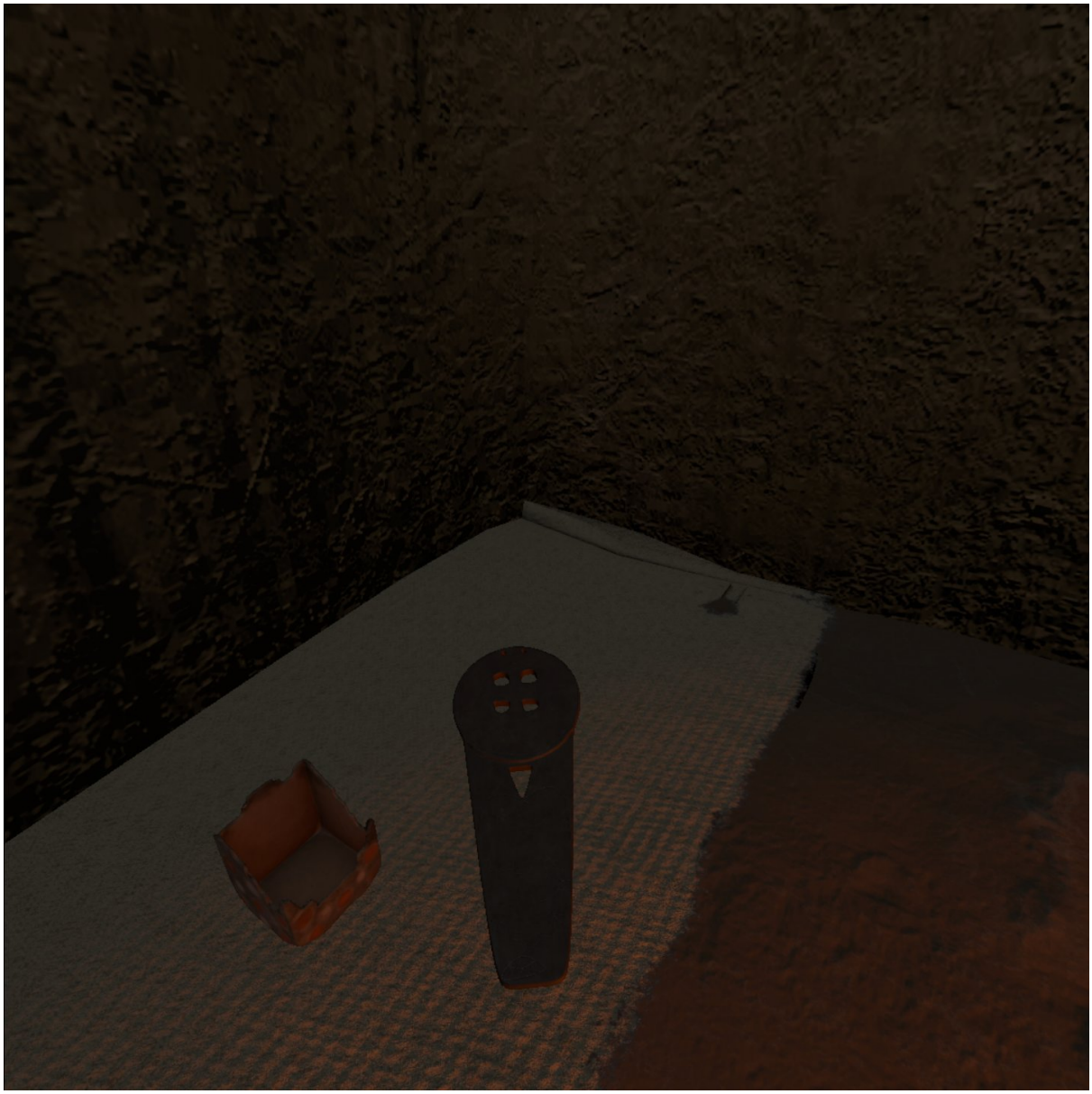


Figure G.7: An artifact picked up by the user. The Oculus Quest 2 screenshot did not save the virtual hand holding the artifact. The educational materials are hidden.

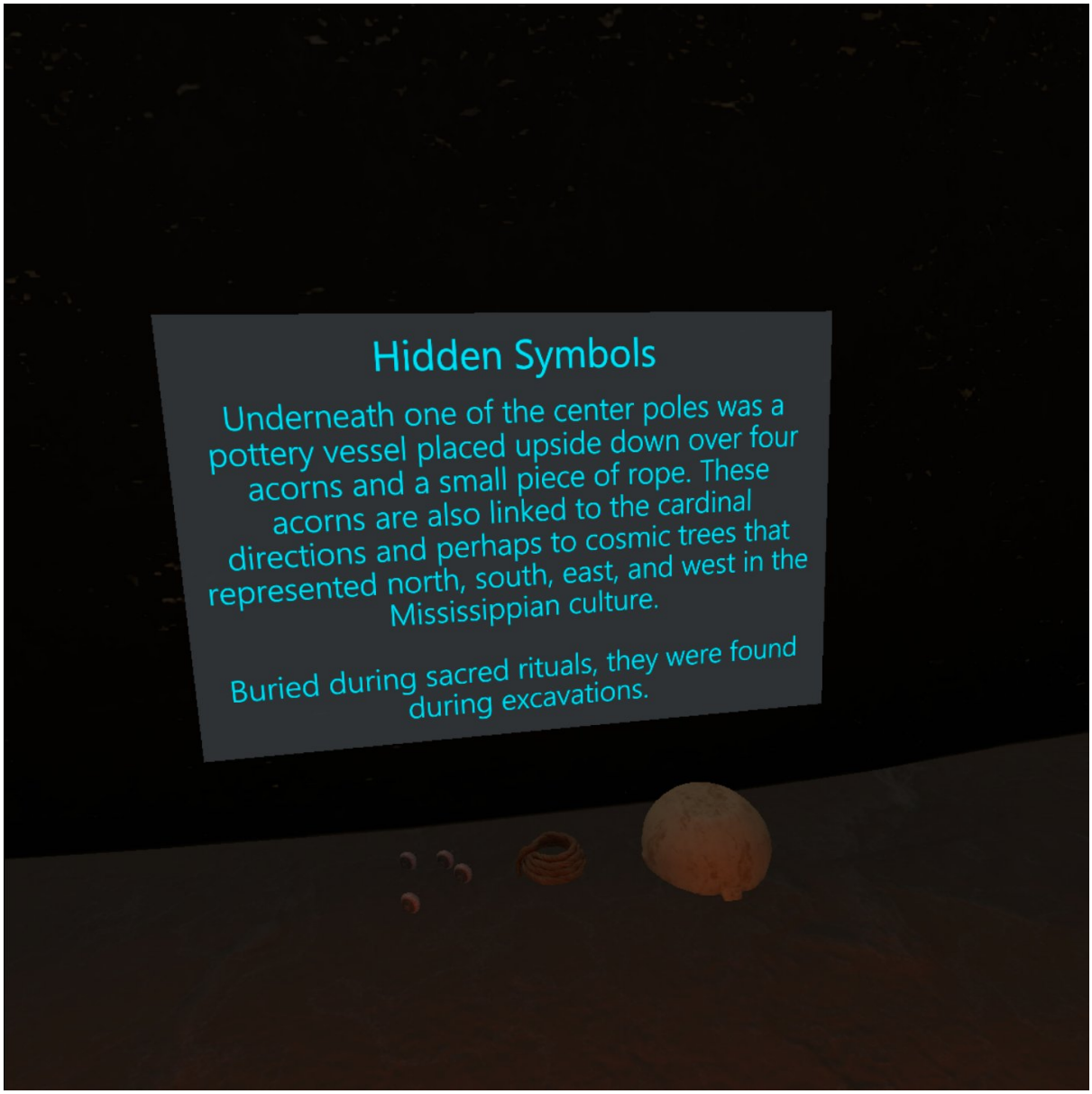


Figure G.8: The symbols buried under the Earthlodge. Although the current house is not an Earthlodge and hence this detail may not be historically and culturally accurate, it was decided to use the existing VR setting to showcase many aspects of Moundville. The educational materials are visible.

Figure G.9: A close view of the squash in the three sisters garden. The educational materials are hidden.

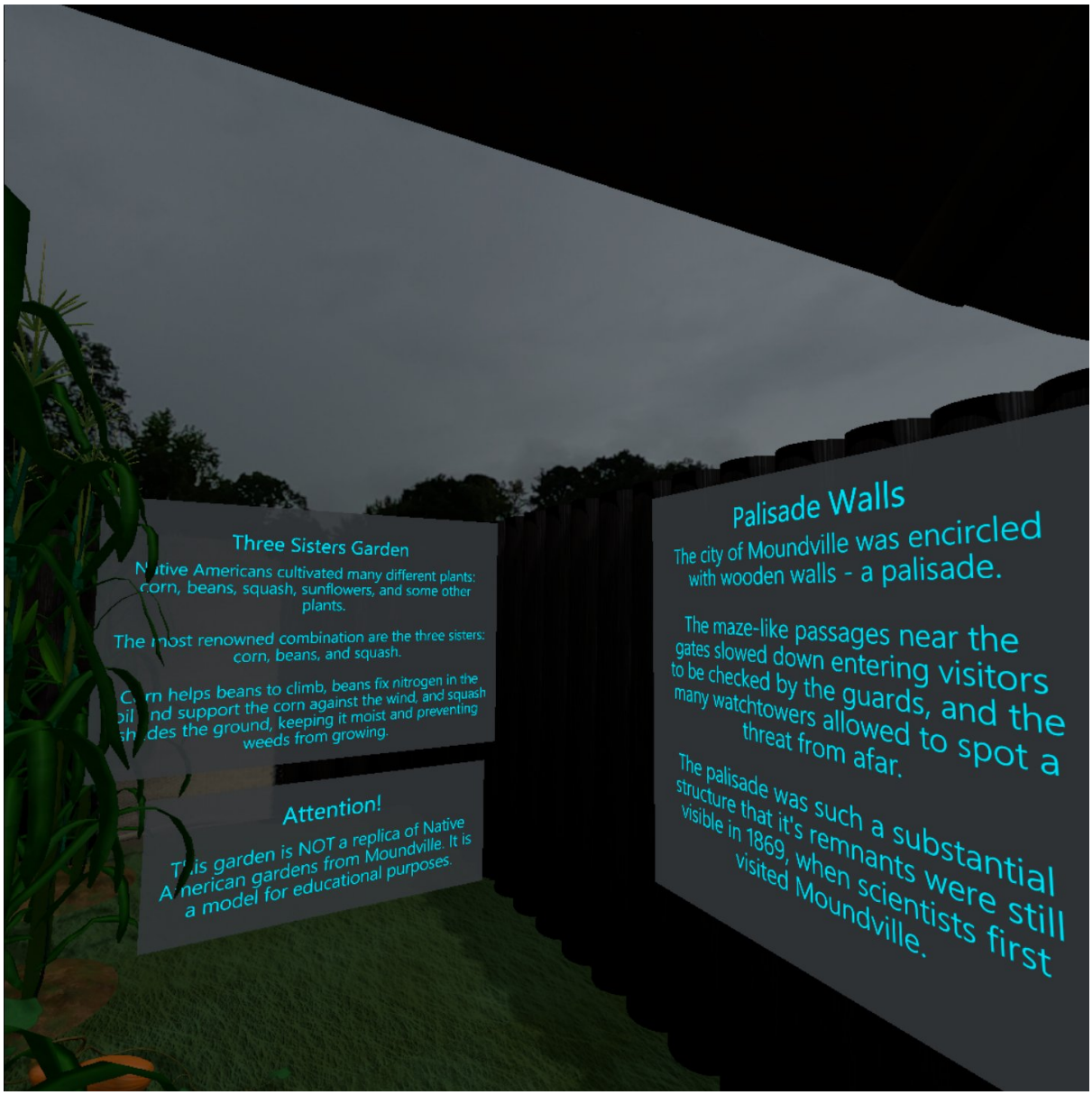


Figure G.10: Three sisters, the educational materials are visible.

Appendix H

The Educational Materials of the Moundville AR Experience

H.1 The History of Moundville

Around 9th-10th century AD

The Mississippian Period of Native American history in southeastern US starts.

The city of Cahokia is found in modern Illinois.

Around Year 1100

The city of Cahokia is at it's apex. It will be the largest and most influential city ever in the Mississippian culture's history.

The walled community of Moundville is constructed. Alas, we do not know the Native American name of the city.

Around Year 1200 AD

Moundville reaches its greatest prominence. With Cahokia in decline, Moundville is the largest city north of Mexico.

Around Year 1300 AD

Moundville is now used more as a political and a religious center and a burial site, rather than a city.

Around Year 1500 AD

Moundville is mostly abandoned

16th century AD

Spaniard Hernando de Soto is one of the first Europeans to arrives to western Alabama. Today, his records are among the evidence that help us to learn about the ancient Native American cultures.

H.2 Unearthing the Moundville

19th Century

The first scientists arrive at Moundville. Parts of the palisade, the wooden walls that once protected the people of Moundville, are still standing.

1905-1906

Clarence Bloomfield Moore performs the first major excavations at Moundville.

1929-1940s

Another major excavation by Walter B. Jones started in 1929.

1939

The current museum was constructed by the Civilian Conservation Corps.

2007 and beyond

A series of excavations were performed by the University of Alabama Anthropology Department.

In total less than 15% percent of the site has been excavated. More than 500 artifacts were discovered. Artifacts from Moundville can be found in many Native American exhibitions in Unites States.

Today, our knowledge of the Moundville people is drawn from Archaeology, Art History, Ethnography, and Folklore.

H.3 The People of Moundville

Who They Were

The tribes at Moundville were part of Mississippian culture that included many different Native American tribes around the southeast of modern-day US.

In the Mississippian Period (AD 900-1600) these ancient Native Americans possessed the richest culture of any group north of Mexico. Besides Moundville, the Mississippian people built such significant centers as include Cahokia in Illinois, Etowah in Georgia, and Spiro in Oklahoma.

The Trails of Tears

By 17th Century

The remaining Mississippian chiefdoms broke down under the pressure of disease and social disruption brough about by European incursions

On March 27, 1813

The Cherokee and their allies are trying to oppose the expansion into their territories, but loose to US forces at the Battle of Horseshoe Bend.

1830

The US congress passed the Indian Removal Act. The tribes were forced to give up their lands east of Mississippi River.

Trail of Tears – 1830s

Thousands of Southeastern Native Americans are forcibly removed and relocated to the west of the Mississippi River. Many did not survive the journey...

The Mississippian People Today

There are currently over a half-million modern descendants of Mississippian people. Choctaw, Chickasaw, Cherokee, Muskogee/Creek, Natchez, Yuchi, Seminole, and Miccosukee are among the descendants of the Mississippian people, including the people of Moundville.

They keep alive some of those ceremonies, dances, chants, and songs whose origins can be found among their Mississippian ancestors. Their baskets-weaving and ceramics, the shell and stone patterns are directly traceable to the artists of ancient Cahokia, Etowah, Moundville, and Spiro.

Even the act of mound building survives as an aspect of preparing the square ground or ritual space for the annual Green Corn Ceremony.

H.4 The City of Moundville

Moundville was ruled by chiefs and noblemen representing the surrounding Native American tribes. The mounds elevated the chiefly houses and religious buildings. The Moundville was ruled by a Paramount Chief, but chiefs of many surrounding tribes leaved together in Moundville, forming a tribal union.

Moundville was a walled community, protected by a wooden palisade. It had towers and tricky mazes and the gates for protection.

The people of Moundville sustained themselves with hunting, fishing, and agriculture. The Three Sisters is an ingenious Native American design where corn, beans, and squash are grown together to support each other.

The people of Moundville were skilled potters. The potters were, almost certainly, female.

Moundville was part of an extensive trade network stretching across North America. Items originating from modern-day Mississippi, Eastern Texas, Western Louisiana, Tennessee, Illinois - whole modern America's southwest - were found at Moundville.

Items from distant lands were regarded as items from the Realm of the Death. They were highly valued and were part of the chiefly regalia. Alongside trade, the potters at Moundville had also replicated some foreign styles that might have been popular at Moundville.

H.5 The Religion of Moundville

This is a brief introduction to beliefs of Mississippian Native Americans.

Three Worlds

The Native Americans at Moundville believed that the world consists of the above (or celestial realm), an earthly plain, and a beneath (or underworld).

The Human Soul

A human has three souls. The one that contains self-awareness remains in the living world near its kin for a brief period after death. It gathers spirit versions of the tools and objects placed in the grave.

The Hand and Eye

When the sky bowl lifts above the line of the horizon, the gathered souls must quickly leap under the sky's solid edge into the celestial realm. This gateway between the celestial realms and the earth disk was symbolized as an open hand with an eye in its palm. Today, we know this hand as part of the Orion constellation.

Path of Souls

Once the portal was crossed, the souls of the dead began their journey by walking along a road or ribbon of light, the Path of Souls, which today is known as the Milky Way. This river of light rotates in the night sky and deposits the souls, after a series of trials, into the Realm of the Dead. The fish-birds lived on the Path of Souls.

The Realm of the Dead

The realm's supernatural ruler could transform into either a great horned serpent or an underwater panther.

Other Creatures

Both Celestial Realm and the underworld were populated with supernatural creatures and monsters: fish-panther, serpent-birds, celestial raptors, winged serpents, and others. The winged serpent was represented by a constellation that we know today as the Scorpio. The fish were seen as creatures of the underworld, and frogs could move between the earthly plain and the underworld.

Spiritual Purification

Sweat lodges were uncovered in Moundville that were meant to cleanse human body and purify the souls. Sweat lodges are still important to Native American rituals today.

In the Art

The people of Moundville reflected the symbology of the world and it's supernatural inhabitants in their art. Look closely at the pottery in the museum, you will see shapes and images of serpent-birds, panthers, celestial raptors, winged serpents, the symbols of the Hand and Eye, Trophy, and many others.

The Role of Moundville

In the minds of Moundville people, the chiefs were seen as political, economic, and spiritual authorities. Different regalia, worn by chiefs of Moundville, was meant to showcase their rank.

The hand and eye theme may have once symbolized the rank of Moundville's Paramount Chief. The stone and copper axes carried by the elite were symbols of their power as warriors, as well as their ability to protect their people from negative supernatural events. The gorget worn around the neck had depicted ritual scenes. The Moundville itself was recognized as a place where the earth and the Realm of the Death are at closest, becoming a spiritual center and a burial place in its later history.

H.6 The Earthlodge

Built on Mound V, it was a ceremonial structure closely linked with rituals and ceremonies associated with the beneath world and of the Realm of the Dead. The earthlodge may have also served as a chiefly council house.

Modeled after the Mississippian cosmos

The lodge's solid roof was a representation of the solid bowl-shaped dome of the sky.

The lodge's four center posts are aligned with the cardinal directions.

The central hearth marks the location of a sacred fire whose column of smoke connected the heavens with the earth.

Underneath one of the center poles was buried a pottery vessel placed upside down over four acorns and a small piece of rope. These acorns are also linked to the cardinal directions and perhaps to cosmic trees that represented north, south, east, and west.

The earthlodge was destroyed by fire, perhaps intentionally set. Scattered among its burned remains, archaeologists recovered fragments of important ritual items such as smoking pipes, copper, and mica. Researchers believe that the destruction of this earthlodge marked the end of ritual activity at Moundville.

Appendix I

The Educational Materials of the Moundville VR Experience

I.1 A Mississippian House

You are currently standing inside of a generic Mississippian house. Different parts of the Mississippian culture had slightly different houses, and one like this is close to what could have been found here, in Moundville. Look around! You will find some interesting items here with their descriptions. To hide all descriptions, click ”B” on the controller. To show the descriptions again, click ”B” again.

I.2 Central Hearth

The bonfire, the central hearth of the house, was not just for cooking, heat, and light. As per some Native American beliefs, the central hearth marked the location of a sacred fire whose columns of smoke connected the heavens with the earth.

I.3 Fishing

The Black Warrior River provided the people of Moundville with fresh water and fish, birds, mollusks, and other aquatic animals. The ponds you see near some of the mounds were created when the soil was used to construct the mounds, and the water accumulated. According to Mississippian beliefs, the fish are the creatures of the Underworld, and the frogs can pass between Underworld and Earthly plane.

I.4 Palisade Walls

The city of Moundville was encircled with wooden walls - a palisade. The maze-like passages near the gates slowed down entering visitors to be checked by the guards, and the many watchtowers allowed to spot a threat from afar. The palisade was such a substantial structure that it’s remnants were still visible in 1869, when scientists first visited Moundville.

I.5 Three Sisters Garden

Native Americans cultivated many different plants: corn, beans, squash, sunflowers, and some other plants. The most renowned combination are the three sisters: corn, beans, and squash. Corn helps beans to climb, beans fix nitrogen in the soil and support the corn against the wind, and squash shades the ground, keeping it moist and preventing weeds from growing.

I.5.1 Attention!

This garden is NOT a replica of Native American gardens from Moundville. It is a model for educational purposes.

I.6 Hunting

Aside from farming and fishing, the people of the Moundville also hunted birds and animals. Not only did hunting provide them with meat, but also animal skin that was used to make clothes and bird feathers that were used for decoration. Sky Dome The people of Moundville may have viewed the solid roof as a representation of the solid, bowl-shaped dome of the sky.

I.7 Trade

Moundville was part of an extensive trade network stretching across North America. Items originating from modern-day Mississippi, Eastern Texas, Western Louisiana, Tennessee, Illinois, and even southwest were found at Moundville. Such items were highly valued and were part of Chiefly regalia. Alongside trade, the potters had also replicated some foreign styles that might have been popular at Moundville. For example, this bottle is made in Caddoan style, originating from Eastern Texas and Western Louisiana.

I.8 Symbols

The chiefs and other important people of the Moundville wore different symbols, known as regalia, to signify and advertise their status. One of such symbols is this stone pendant. Probably belonging to The Maker of Medicine, the stone pendant showcases a hand with an eye. A popular motif at Moundville, it represented the Orion constellation and the gateway between celestial realm and earth disk.

I.9 Pottery

The potters at Moundville, almost certainly females, were highly skilled. They created ornamental pottery of many different shapes and patterns. They were observant of the surrounding world. A bat, a frog, and a human shaped pot are presented here. The potters of Moundville also molded the images of turtles, birds, and alligators. Pottery was not only used in everyday life for storage and cooking, but also served an important role in rituals. Pots were buried in the graves to accompany the dead in their afterlife. The genuine Stepped Square Vessel on the right was specially designed to display its contents during sacred ceremonies.

I.10 Hidden Symbols

Underneath one of the center poles was a pottery vessel placed upside down over four acorns and a small piece of rope. These acorns are also linked to the cardinal directions and perhaps to cosmic trees that represented north, south, east, and west in the Mississippian culture. Buried during sacred rituals, they were found during excavations.

Appendix J

The Quiz Questions from the Moundville AR Experience

1. What are the "Three Sisters"?
   (a) The three main goddesses of Moundville
   (b) The three goddesses of the Realm of the Death in Moundville
   (c) Corn, beans, and squash: three crops grown together by Native Americans
   (d) Corn, potatoes, and tomatoes: three crops grown together by Native Americans
2. What is the "Trail of Tears"?
   (a) The path a soul takes to the afterlife, as per Moundville beliefs
   (b) The name of the burial ceremony practiced at Moundville
   (c) The forced relocation of Native Americans from Mississippi, Alabama, and Florida into reservations by US government
   (d) The forced relocation of Native Americans into Alabama by US government
3. Select the one FALSE statement about Earthlodge
   (a) It was destroyed by fire
   (b) Its solid room represented the dome of the sky
   (c) It was used for ceremonies and as a chiefly council house
   (d) The three center posts represented the three parts of the human soul
4. Select the one TRUE statement about Moundville that we know about from excavations:
   (a) Moundville was an isolated community
   (b) Moundville only connected to nearby villages and chiefdoms
   (c) Moundville was part of a trade network spanning across the modern southeastern US
   (d) Moundville was part of a trade network reaching Aztec lands in Mexico
5. Select the one FALSE statement about Moundville beliefs

(a) The world consisted of three parts: Celestial Realm, Earthly Plain, and Underworld

(b) Path of the Souls, known to us as Milky Way, was the starry path a human soul took after death

(c) Moundville was considered a place with a gateway to the Realm of the Death

(d) The Hand with an Eye symbol represents the Scorpio constellation, and the Winged Serpent represents the Orion constellation

6. Select the one FALSE statement about Moundville regalia

(a) A gorget was worn around the neck by the Moundville ruling class

(b) The foreign items were not worn by Moundville rulers because they were considered a part of the Realm of the Death

(c) The males of the ruling family carry wooden-handled, copper -bladed axes as symbols of their political authority

(d) The regalia showed the worldly and otherworldly attributes of the ruling elite

7. Select one FALSE statement about how Moundville was explored

(a) The museum building was built by Civilian Conservation corps in 1938-1940

(b) The first European, a Spaniard Hernando de Soto, visited Moundville in 17th century

(c) More than 500 artifacts were found in Moundville

(d) The past of Moundville is restored using methods of Archaeology, Art History, Ethnography, and Folklore

8. Select one TRUE statement about Moundville people

(a) No descendants of Mississippian people have survived

(b) The Mississippians were part of Mezoamerican culture

(c) The descendants of Mississippian people are Choctaw, Chickasaw, Cherokee, Muskogee/Creek, Natchez, Yuchi, Seminole, and Miccosukee

(d) There are just a few thousands of descendants of Mississippian people today

9. Select the FALSE statement. The City of Moundville was...

(a) The largest ever Native American city north of Mexico

(b) Abandoned by the year 1600

(c) A part of the Mississippian culture

(d) A walled city, protected by wooden palisade