DIGITAL MUSEUM EXPERIENCE:

EXPLORING OPPORTUNITIES IN MIXED MEDIA STORYTELLING

USING AUGMENTED REALITY

by

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Abstract

This research project explores opportunities for mobile augmented reality (AR) applications as an alternative means of viewing artifacts. Augmented reality is a promising technology that can greatly improve a visitor's interactions with artifacts and their contextualized information. However, many museums hesitate to adopt AR due to concerns of gimmickry, detraction of the museum experience, and user cognitive overload (Marques & Costello, 2018). In this project, the usability and perceived usefulness of mobile AR is investigated through a comparative case study of existing AR applications for museums. Using the findings from the case study, a mixed-media storytelling mobile AR application is prototyped to demonstrate how mobile AR can enhance public engagement and improve access to cultural artifacts. By fulfilling the aim of the project, AR can be more readily accepted for museums. This project presents new insights to usability evaluations and the development of mobile AR apps for digital museum experiences.

Keywords: Digital Museum, Archival Material, Digital Preservation, Digitization, Augmented Reality, Mobile Augmented Reality Application, Mixed Media Storytelling, and Digital Media

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Introduction

Research Motivations

With rapid developments in digital technologies in the past decade, cultural heritage institutions and museums have an incredible opportunity to present and interpret their artifact collections in more accessible, exciting, and innovative ways. In recent years, museums have made extensive efforts to establish a digital presence and digitize their collections for online access via various digital media, such as online exhibitions, virtual tours, 360° videos, etc. This multi-media approach enables artifact collections to be digitally accessible when physical or in-person access to museums is constrained (Bekele et al., 2018). Despite this increased adoption of digitization, there remains a largely unmet opportunity to go beyond simply replicating or recreating the traditional museum experience in the digital space (The Art Newspaper, 2020). Many museums have yet to take on an innovative approach to the digitization of their artifact collections – this may be due to limited funding and resources. However, museums have an opportunity to create engaging interactive digital content that encourages meaningful learning, exploration, and discussion of cultural heritage. Creating highly engaging digital content for digital museum experiences may also increase visitation and user engagement with artifact collections. A study on museum visitation and visitor demographic conducted by the Smithsonian Institute (2006) speculates that creating more engaging and rewarding experiences in both physical and digital museums can attract a larger percentage of visitors of all ages (p.6).

Museums are experiencing a paradigm shift from their initial function as traditional ‘static storehouses’ into ‘active learning environments’ (Hooper-Greenhill, 1994). The role and definition of museums can be defined as cultural institutions that “acquire, conserve, research,

communicate, and exhibit the tangible and intangible heritage of humanity and its environment for education, study, and enjoyment" (The International Council of Museums, 2018. p. 3). However, the definition and role of museums evolve with the demographic changes and new technological trends or fads that may emerge (Smithsonian Institution, 2006). One of these upcoming trends is the emergence and potential case uses of AR technology for interactive museum experiences. Since the early 2000s, museums have researched and experimented with augmented reality (AR) technologies to provide immersive experiences (Marques & Costello, 2018). Although AR technologies can greatly improve the interaction between visitors, cultural artifacts, and their contextualized information, the museum community continues to be unconvinced of the perceived usefulness of AR technologies (Marques & Costello, 2018; Weng et al., 2011). Cultural heritage institutions and museums are hesitant to fully adopt AR due to speculations of technical and social challenges and concerns of gimmickry, detraction of the museum experience, and user cognitive overload. These various concerns regarding the use of AR applications for cultural institutions and museums may be based on assumptions and misleading anecdotes rather than empirical evaluation and data. There are numerous works of literature and studies written about AR technologies for the cultural heritage sector, but the number of systematic evaluation studies and evaluation models on how to maximize the usability and perceived usefulness of mobile AR are limited. Also, there is no widely accepted evaluation model for assessing the usability of mobile AR applications.

Despite the substantial breadth of development and research of AR technology, there is limited research in the systematic evaluation studies on the usability and efficacy of AR, especially mobile augmented reality (Damala, 2009; Lee et al., 2012). This research project

addresses the need for the development of an evaluation model for mobile AR applications by empirically investigating the effects of mobile AR technology on digital museum experiences.

Research Questions

This research project examines opportunities for mixed media storytelling using augmented reality technology in the context of cultural heritage. In particular, this project investigates the perceived usefulness and efficacy of mobile AR applications as an alternative means for viewing artifacts. This research project empirically investigated two main questions:

1. How can mobile AR technology improve access to cultural artifacts that are fragile, rare, expensive, or overall inaccessible to the majority of visitors?
2. How can mobile AR technology, paired with mixed media storytelling, enhance public engagement with cultural artifacts?

Research Methodology

The research questions of this project are investigated through a comparative case study of existing mobile AR applications used for viewing artifacts in museums. The mobile AR applications chosen for the study include the ReBlink app created by Impossible Things for the Art Gallery of Ontario (AGO), the ArtLens app created for the Cleveland Museum of Art, and the Skin & Bones app created for the Smithsonian Natural Museum of Natural History's Bone Hall Exhibit. These three mobile AR apps have gained relative success in integrating augmented reality into the museum experience and have received international recognition and awards. This comparative case study cross-examined the three mobile AR apps through analysis and synthesis of the notable similarities, differences, and patterns, particularly with a focus on the usability and

user experience. The findings from the comparative case study are further explored in the development process of a mobile AR app prototype, ARGO.

The development process of the mobile AR app prototype of ARGO adhered to the human-centered design (HCD) methodology. The HCD methodology, also known as the user-centered design (UCD) methodology, is a philosophy coined by Donald Norman that aims at placing the end-user and their needs at the center of the design process (Campese et al., 2020; Harte et al., 2017). It has been used as a guideline for designers to achieve good usability outcomes when designing user interfaces in product development (Campese et al., 2020). This research project followed the three phases of HCD adapted from the structured methodology proposed by Harte et al. (2017) for rapid pace development and ensuring user needs are considered throughout the design process. The three phases include: "(1) establishing the context of use and user requirements, (2) expert inspection and walkthroughs, and (3) usability testing" (Harte et al., 2017. p.5). By adhering to an HCD approach in development, this research project aims to place user needs in the center of the development process and reveal novel findings on the interactions and habitual behaviours of users in augmented reality experiences.

Through a comparative case study analysis and human-centered design (HCD) approach in development, this research project provided further insight into the systematic usability evaluation and the design process for the development of mobile AR apps in the context of cultural heritage and museums. A visual flowchart illustrating the process of both the comparative case study and the human-centered design approach is presented in Appendix A.

Research Outline

The following paper outlines the development process of the research project *ARGO* while examining and analyzing research, trends, and upcoming products towards the advancement of AR within the digital museum space. This research paper begins with a literature review of relevant background information and a comparative case study of existing mobile AR application used by museums. The comparative case study is followed by a review of the human-centered design (HCD) methodology, the development process of the research project prototype, and an evaluation of the research project. This research paper is concluded with a summary of findings, a review of limitations, and discussion points on the future of evaluating the usability and developing mobile AR apps for museums.

Literature Review

History of Augmented Reality

The first known conception of augmented reality (AR) emerged in the early 1950s when cinematographer, Morton Heilig, published a paper titled "*The Future of the Cinema*" and proposed his vision of the cinema experience as an activity that engages all five senses: touch, smell, taste, sight, and hearing (Carmigniani et al., 2011). In 1962, Heilig subsequently built the "Sensorama", a mechanical prototype of what he envisioned as an immersive experience for theater (Carmigniani et al., 2011). Between 1966 to 1968, Ivan Sutherland, an American computer scientist, invented the first head-mounted display for merging computerized information with reality and the first augmented reality system (Berryman, 2012). Since its inception in the early 1950s, augmented reality has continued to garner interest in a myriad of industry sectors, including healthcare, manufacturing, architecture, education, games, entertainment, tourism, and the arts and cultural heritage museums. Research and development of AR technology are speculated to be pivotal in the paradigm shift towards ubiquitous computing (Olsson et al., 2012). While augmented reality has garnered interest in research and development in various industry sectors, augmented reality remains a relative novelty. There is a need for greater depth and understanding of the experiential and emotional impacts of augmented reality within the cultural heritage context.

Augmented Reality Technology

Today's most accepted definition of augmented reality is provided by Ronald T. Azuma (Bekele et al., 2018, Goff et al., 2018). Azuma (1997) defines augmented reality as any technological system that combines the real and virtual, provides real-time interactivity, and

registers real and virtual objects in three-dimensions (p.356). In other words, augmented reality is a real-time, direct view experience of the physical environment that has been enhanced by superimposed computer-generated objects and contextualized information (Carmigniani et al., 2011). In the Reality-Virtuality Continuum proposed by Milgram and Kishino (1994), the relationship between AR and VR – both variations of mixed reality – is defined under an overarching view of a real environment compared to a virtual environment. Since AR overlays digital content over the physical environment, AR is deemed closer to a real-world environment than a virtual world (Goff et al., 2018). Since its conception in the early 1950s, various types of augmented reality have emerged, some of which include marker-based augmented reality, marker-less augmented reality, projection augmented reality, and superimposition reality. Various technologies have also been developed for implementing AR experiences, including optical projection systems, holographic display systems, head up displays (HUD), head-mounted displays (HMD), and various wearable or handheld devices. AR devices, such as the Magic Leap One and Microsoft HoloLens, can seamlessly mix digital content with the real-world environment (Miller et al., 2019). Notably, the majority of recent applications of AR are based on mobile devices, such as smartphones and tablets (Goff et al., 2018).

Mobile Augmented Reality Applications

One of the most rapidly growing research areas in AR is mobile augmented reality (Azuma et al., 2011). The ubiquity and affordability of smartphones and tablets make mobile devices an ideal platform for developing AR applications. Mobile AR superimposes virtual objects and contextual information into the real-world environment, but without constraining users to a specific area (Höllerer & Feiner, 2001). Ideally, users can take mobile AR wherever

they desire to go and at their convenience. The two most dominant platforms for developing mobile AR applications are hardware-based mobile AR and app-based mobile AR (Qiao et al., 2019). Recent augmented reality research and development have been fueled by the advancement in these three key technologies: AR devices, AR Software Development Kits, and improvements of smartphone and mobile device (Qiao et al., 2019). Although there has been substantial progress in mobile AR research and development, there are still limitations to be considered. For example, app-based mobile AR lacks cross-platform support and requires users to take additional steps to install and download (Qiao et al., 2019). Also, mobile AR that is hardware-based tends to be rigid and costly (Qiao et al., 2019). Although many industry sectors are keen on adopting mobile AR, there remains a need for more research on how to use mobile AR to deliver compelling experiences (Azuma et al., 2011). For this research project, a marker-based AR application for mobile devices will be explored for digital museum experiences.

Mobile Augmented Reality Applications for Museums

The majority of museums, unfortunately, cannot exhibit all their collections to the public due to several reasons, such as limited space, limitations in traditional approaches, the fragility of the artifacts, or the lack of funding and resources available (Wojciechowski et al., 2004). Even when museums do exhibit their collections and artifacts, museum visitors often experience some form of interaction constraints (Wojciechowski et al., 2004). These constraints may include the inability to see, touch, feel, and in some cases hear and smell, the artifacts and collections from desired angles or distance due to the nature of the object or its fragility. In addition, today's cultural institutions and museums are faced with the challenges of attracting new audiences and catering to the needs, interests, and expectations of modern-day tech-savvy museum visitors

(Gutiérrez et al., 2008). A study conducted by the Smithsonian Institute (2006) suggests that museums in the year 2020 will have two large audiences: an aging audience with accessibility expectations and needs and a younger audience with an interest in highly entertaining and engaging exhibitions (p.4). To meet the needs of this demographic, museums must shift from their traditional and conservative attitudes towards technology and embrace opportunities to present and interpret their collections in more accessible, appealing, and exciting ways.

Mobile AR is a promising technology for cultural heritage museums because it offers powerful, highly engaging, and cost-effective solutions for visitors to interact with their collections in both an informative and entertaining way. Mobile AR can effectively enhance navigation, interaction, and orientation in museums, especially when there are limited space and resources or the nature/fragility of the objects makes it difficult for public viewing (Angelopoulou et al., 2012). Popular uses of mobile AR in presenting and interpreting in cultural heritage museums include 3D visualizations, virtual restoration, gamification, location-based interpretation and guiding, and virtual character-based interpretation. Rapid advancement in smartphone and mobile phone AR has encouraged a wider embracement of mobile AR, but there remains skepticism by the museum community. This may be due to the lack of research on the usability evaluation of mobile AR applications. The majority of research in the cultural heritage field has primarily been focused on the description and presentation of AR applications rather than evaluating the interaction between users, the AR applications, and the museum experience (Kyriakou & Hermon, 2018). The current concerns by the museum community on adopting technologies, such as augmented reality applications, are likely to be based on misleading assumptions and anecdotes rather than empirical data (Marques & Costello, 2018). Further

research on the usability evaluation of mobile AR applications in the cultural heritage field is needed before mobile AR can be readily adopted by museums.

Evaluation of Mobile AR Applications for Museums

Emerging technologies, such as mobile AR applications, present great potential for transforming the traditional museum experience into an innovative and engaging one; however, designing, developing, and maintaining an AR experience for museums can be both a resource-consuming and time-consuming experience (Damala, 2009). A successful mobile AR experience for museums require an interdisciplinary approach and an extensive iterative design process (Damala, 2009). Proper evaluation and assessment of these AR experiences are essential for museums to learn about the interaction and user engagement. Before museums can readily adopt mobile AR, a better understanding of the technology, users of the technology, and the museum experience is needed. Thus, careful examination and evaluation that tests the usability and effectiveness of mobile AR for the artifact-viewing experience are needed.

It is important to design products that create good and delightful experiences (Garett, 2006; Norman, 2013). Good user experiences encourage continuous use and increase customer loyalty. This can also be applied to mobile augmented reality applications. Although the breadth of museum evaluation and studies of visitor demographics and behaviours have increased over the years (Economou, 1997), there are still very few studies on the user-based evaluation of AR. Many museums use a mixed-approach – both qualitative and quantitative – to evaluate (Damala, 2009). There is no widely accepted evaluation guideline, model, or methodology for evaluating the usability of mobile AR for museums. Currently, many museums borrow evaluation strategies

and methods from other related fields to evaluate mobile AR, but there has yet to be a widely accepted usability evaluation strategy specifically for AR.

There are various suggestions proposed for the evaluation of mobile AR usability. Some examples include popular data collection methods, such as interviews, direct observation, questionnaires, and case studies. Each of these suggestions and strategies – both qualitative and quantitative – have their advantages and disadvantages and may be applicable for certain cases and not others. Other suggestions can be specific to achieving certain goals in AR. For example, Höllerer and Feiner (2001) suggest that the benefits of mobile augmented reality will only be achieved if the user interface (UI) maximizes the relevance and minimize the confusion of the virtual material relative to the real world. There is yet to be a usability evaluation method specific to the usability of mobile AR in the museum field. For this research project, the human-centered-design (HCD) will be used throughout the design and development of the mobile AR app. HCD is a design approach that "puts human needs, capabilities, and behaviour first, then designs to accommodate those needs, capabilities, and ways of behaving" (Norman, 2013, p.8). The HCD approach has four main phases: (1) define the target user and the context of use, (2) specify the needs of the user, (3) design and develop solutions, and (4) assess and evaluate the solution (Harte et al., 2017, p.3). For the purpose of rapid prototyping and keeping user needs at the center of the development process, this research project will adhere to a modified approach to HCD proposed by Harte et al. (2017) that consists of the following three phases: "(1) establish the context of use and user requirements, (2) expert inspection and walkthroughs, and (3) usability testing" (p.5). To see a visual flowchart of the methodologies, refer to Appendix A. By using this modified HCD approach, this research project strives to gain further insight on how to

develop effective evaluation strategies for mobile AR by close examination of the behaviour of users engaged in mobile AR for the artifact-viewing experience.

Digital Cultural Heritage and Authenticity

The cultural heritage community is progressively seeking new ways to improve visitor engagement by employing modern technological innovations (Tscheu & Buhalis, 2016). Cultural heritage institutions and museums have expanded their scope of enabling technologies to also include immersive technologies (Bekele et al., 2018). Reunanen et al. (2015) describes digital cultural heritage (DCH) as "tangible and intangible cultural heritage entities that have been created or transformed into a digital media format" (p.2). Cultural heritage benefits significantly from immersive technologies as it enables users to experience cultural artifacts in a novel way utilizing sensory experiences through various combinations of real and digital content (Bekele et al., 2018). As museums abandon their conservative attitudes and shift towards becoming active learning environments by the adoption of immersive technologies, the significance of cultural objects in the form of information versus its physical form is being questioned. Burton and Scott (2003) suggest that rather than focusing on physical objects, the information presented by these objects should become the primary commodity for future museums. However, the authenticity of digital replicas, reproductions, copies, and facsimiles remain a topic of debate within the museum community.

Lowe (2020) defines cultural artifacts and objects to be "repositories of compounded ideas, thoughts, materials, evidence, transaction and actions of time" (p.16). This repository of ideas and emotional meanings associated with cultural artifacts and objects can loosely be

termed as *the aura* of the object (Lowe, 2020). Critics and skeptics debate the use of digital reproductions for engaging with cultural artifacts on the concern of authenticity and detraction from the museum experience. Does engagement with digital replicas and copies lessen the aura, excitement, or desire for real and physical experience with it? Does using digital replicas or copies jeopardize the notion of what is *real* to the extent of devaluing the authentic experience of the museum? Despite the vast discussion within the cultural heritage community, the aura of cultural artifacts can also be debated to remain relatively intact whether it separates an original from the copy (Lowe, 2020).

An interesting example of the value and significance of a digital copy/reproduction being questioned is examined in the essay, *3D Data, Public Access, Freedom of Information Laws,* written by Cosmo Wenman. This essay is part of a collection of essays assembled by the Factum Foundation that accompanied the Materiality of the Aura: New Technologies for Preservation Exhibition in Palazzo Fava, Bologna. In this essay, Wenman investigated why the Egyptian Museum and Papyrus Collection in Berlin did not publicly share its full colour, high-quality 3D scan of one of the most iconic portrait sculptures ever produced, the Bust of Nefertiti. The Bust of Nefertiti is one of the most copied and reproduced works of ancient Egyptian art, however, the Stiftung Preußischer Kulturbesitz (SPK) as known as the Prussian Cultural Heritage Foundation, were adamant on not sharing their high-quality 3D scan with the public despite the artifact being licensed under German freedom of information laws (Wenman, 2020). The SPK reasoned that sharing copies of the 3D scan and data would jeopardize their commercial interest, but Wenman convinced the museum to share its 3D scan since it is considered a work in the public domain. Wenman eventually received a copy of the Nefertiti scan from the museum, but to his surprise,

with a copyright claim and a creative commons license that prohibits commercial use of the data stamped into the underside of the digital model. Wenman concludes his article with a statement that it is absurd and immoral for museums to claim copyright in a digital *copy* of work licensed in the public domain. Although this article was focused on examining the public interest and demand for 3D data in cultural heritage institutions, this particular case also alludes to the notion that digital copies/reproductions can also be considered an object of high value and significance by museums and consumers. Advancements in technology, such as 3D scanning and photogrammetry, enable museums to create high-quality digital copies/reproductions of cultural artifacts. Although a digital copy/reproduction cannot replace its original, it can improve the accessibility and public engagement to cultural artifacts.

Digital technologies play a pivotal role in democratizing access to cultural heritage for a shared global stage (Aguerre, 2020). Technology should be utilized to enhance and deepen the appreciation, preservation, and understanding of artifacts. The primary focus of digitization in museums should not be whether digital replicas and copies can perfectly replicate artifacts, but whether it can add value to the original. To some extent, authenticity is in the eye of the beholder and replicas are not a new phenomenon in the cultural heritage sector (The Art Newspaper, 2020). Replicas can have their own unique history (The Art Newspaper, 2020) and further add to the story and discussion of cultural artifacts.

Storytelling and Narrative Engagement in Museums

Storytelling is a critical part of how museum communicate and connect with visitors. The ultimate goal of any cultural institution and museum is to engage visitors in its stories (Nielsen,

2017). Storytelling provides powerful methods for engaging with audiences and evoking curiosity, memories, and feelings (Nielsen, 2017). Recent developments in digital media have changed the way museums can communicate and connect with visitors. Although digital media has been used in the communication practices of many museums, it has yet to be fully integrated as part of the storytelling experience in museums (Nielsen, 2017). The challenge for cultural institutions and museums is to leverage new forms of technology and digital media without detracting from the storytelling experience and integrity of the content (Wyman et al., 2011).

A multimedia approach to storytelling may pose as a solution to seamlessly integrate digital media with traditional storytelling techniques. Multimedia can be defined as any combination of visual graphics, text, audio, animation, or video delivered by computer or other digital means (Vaughan, 2010). Multimedia can be used for the purpose of creating a multi-platform story, wherein the same story is told in different media or devices. For the purpose of this research project, storytelling that uses a multimedia approach is termed as *mixed media storytelling*. In this paper, mixed media storytelling is defined as storytelling through the use of various mediums (text, graphics, audio, animation, and video) in a mixed media format to create an immersive digital experience. The following research project features a mixed-media storytelling experience using augmented reality and a combination of media including, animation, sound, text, and digital graphic overlays.

Comparative Case Study

Review of Methodology

To meet the objective of the project, observational research was conducted on existing mobile AR museum applications to understand how and why certain features and design practices may influence the perceived usefulness of mobile AR applications for viewing artifacts. Observational research adhered to the comparative case study methodology adapted from Delwyn Goodrick. Goodrick (2014) defines a comparative case study as an in-depth study of two or more cases to produce greater depth and understanding of the causes of the underlying principles (p.1). This research project followed Goodrick's proposed six steps of comparative case studies: (1) determine the purpose of the evaluation and key evaluation questions, (2) identify initial propositions or theories (3) determine the types of cases to examine and how the case study process will be conducted, (4) define how the evidence will be collected, analyzed and synthesized, (5) consider and test alternative explanations for outcomes, and (6) summarize findings (Goodrick, 2014). To see visual flowchart of comparative case study methodology, refer to Appendix A, Figure A-1.

This comparative case study (CSS) is conducted on the following three mobile AR apps designed for engaging with museum artifacts: the Skin & Bones app, the ReBlink app, and the ArtLens app. These mobile AR apps were selected because they each have gained relative success in the museum community and demonstrate unique augmented reality experiences for users in remote access. This study compares the three mobile applications by qualitative observation on the user experience and user-interface of the mobile AR apps. This comparative case study examines the similarities, differences, and patterns found between cases to develop a

holistic view of how mobile augmented reality may further be implemented by museums for enhancing meaningful engagement with artifacts. The focus of this observational study is to examine how these cases approach improving and enhancing the viewing experience of artifacts in remote access. In this study, the observer takes on the role of the participant, and qualitative data is gathered based on the observer's experience and observations while using the selected mobile AR apps in remote access. This comparative case study analysis may not reveal all that needs to be understood about implementing AR into the artifact-viewing experience, however, the findings from this study will be used to inform the design and development process of this research project.

Skin & Bones App Case Study

Skin & Bones is a free mobile AR app created for the Bone Hall exhibit at the Smithsonian's National Museum of Natural History in Washington, DC. The app aims to revitalize the exhibition experience and serve as an option for visitors interested in exploring beyond what is available in the physical space (Smithsonian, 2015). The app presents an augmented reality experience on a selection of 13 animals whose skeletons are displayed in the Bone Hall (Smithsonian, 2015). The app includes additional media (text, audio, and video) of the animal's natural history story, the scientists that study them, and the scientific ideas they represent. The app also features augmented reality experiences with 3D tracking, animated 3D models, and activities in the form of games and quizzes (Smithsonian, 2015). The app additionally serves as an interactive tour guide of the exhibit and has a remote access option for visitors who are not in the physical space of the museum.

The Skin & Bones app demonstrates some of the challenges of creating an AR experience in a mobile AR application for remote access. To engage with the AR feature of the app in remote access, users are required to download or print photos of the skeletons from the app. The photos are images of the skeletons as seen in their display in the exhibit and serve as image targets for the app to detect, track, and augment content over. Upon detection of the image targets in the camera feature, realistic 3D models of what the animals looked like when they were alive are overlayed directly over the image of the skeleton. It is important to note that the 3D model overlay is rigidly anchored to the position and angle of the skeleton as visible in the photo. Consequently, users cannot move or scale the model to examine the artifact and can only view the 3D model from a limited angle range when using the printed image as a target image. The audio clips, videos, and animations of the 3D model featured in the app notably start playing immediately upon camera detection. Users do not have control over when the animations of the 3D models or other media begin. There are also no buttons or visible instructions that indicate that users can replay of the media content. It was later discovered that tapping anywhere on the screen of the camera view would replay the additional media content. For some skeleton artifacts, users are always required to watch a short information video before accessing the AR feature, regardless if the user has already watched it and simply desire to use the AR feature again. Lastly, in the camera view for the AR feature, the app can only detect one image target at a time and will only detect the image target corresponding to the artifact featured on the page the camera view is accessed from. Another interesting point to note during this observational study is that holding a mobile device with one hand while trying to interact with the 3D objects on screen with the other hand is a difficult task. Users are notably tempted to interact with the 3D models through the touch screen of the mobile device. This can be seen by users trying to tap,

slide, and pinch their fingers on the touch screen of their mobile device to interact with the 3D models, however, the app does not allow that capability.

The AR feature in the Skin & Bones app was not used to its full potential and overall design is problematic. The user interface of the app is not intuitive. The buttons in the camera view are slightly too large and clutter the screen view. Users have limited control over the interactive aspects of the app and users cannot freely examine the artifact closely from all angles, especially from behind and below. Although users are encouraged to use the touch screen of their mobile device on the pages leading up to the AR feature, the app does not allow interaction through the touch screen during the augmented reality feature. Consequently, when users are engaging with the AR feature, users are notably seen as distant observers of the experience due to limited interaction with the 3D models and additional media. Some other details to note, the animations and videos had clear and visible subtitles, however, it does not appear to be a feature that can be turned off or on.

ReBlink App Case Study

ReBlink is a mobile AR app created by Toronto-based digital artist, Alex Mayhew, and his company, Impossible Things, for the Art Gallery of Ontario (AGO) in Toronto, Canada. The aim of ReBlink is to invite visitors to look at historical paintings through a unique 21st century lens (Impossible Things, n.d.). Using augmented reality, ReBlink re-interprets and presents a new narrative of older classical paintings in the Art Gallery of Ontario's permanent collection. This app aims to overcome the perceived gimmick of AR technology and pave way for deeper user engagement (Impossible Things, n.d.).

ReBlink was chosen for this study because it demonstrates unique insights on how mobile AR technology can be used to garner the interest of museum visitors. Although ReBlink is an app intended to be used in-person at the AGO exhibit, users can still use it remotely via accessing high-quality images of the paintings for the AR experience on the website of the Impossible Things. Upon opening the Reblink App, an instructional video shows the users how to use the app. The app encourages visitors to hold the camera view of mobile smart devices to a selection of European and Canadian paintings. Once the paintings are framed and detected in the camera view, a seamless overlay animation of the painting and music emerges. Users can see the traditional portraits and landscapes in the paintings visually transform to fit into modern-day scenarios. For example, one of the paintings that is part of this exhibition is a British portraiture painting called *The Marchesa Casati* created between 1878 to 1961 by Augustus Edwin John. It features a red-haired lady adorned in a white dress standing in front of a green, nature-like landscape. When this painting is seen through the ReBlink app, the lady figure in the painting can be seen holding a selfie stick and posing to take selfie pictures of herself. Other figures in a selection of other traditional portrait paintings can also be seen in these juxtaposing scenarios, such as holding mobile phones and taking selfies or drinking coffee in front of a laptop through the ReBlink app. Users can also tilt their mobile devices for an AR portal perspective view into the frame of paintings. The app uses augmented reality to transform the viewing experience of these Canadian and European paintings into an exciting and explorative activity for visitors. This exhibition received popular media coverage and has toured over 180 outlets worldwide (Impossible Things, n.d.).

The app's interface was fairly easy to use. Upon opening the app, users are greeted with an animation explaining how to use the app and the default screen is the camera view for the AR experience. There is one button in the top right corner of the screen of the camera view for instructions on how to use the AR feature. It is important to note that the use of AR in the ReBlink app was intended for an artistic interpretation that focused on transforming the surface visual representation of the paintings to entertain and catch the attention of visitors. Arguably, the use of AR in ReBlink felt more of a gimmick. It did not focus on close examination of the paintings or extrapolating from the original message or significance of the paintings. For example, the name of the paintings and their origins, messages, and stories were not visible or expressed upon at any point in the AR experience for remote access. To find details of the paintings, one would have to search for this information outside of the mobile AR app. Unlike the Skin & Bones App, images of the paintings and images targes cannot be downloaded or printed from the app for remote access viewing. During this case study for the ReBlink app, the paintings were displayed on a computer screen while the user held a mobile device with the ReBlink app in front of the screen. Users have to find the images online on the Impossible Thing's website but defining details of the paintings were noticeably omitted on the website. The ReBlink app appears to be more focused on creating an exciting AR experience, rather than using AR as an effective way to create meaningful engagement with these paintings.

One concern of using augmented reality for museums is detraction from the museum experience. Does using augmented reality distract users from engaging with the artifact in a meaningful way? Although the AR experience in ReBlink was visually engaging with the use of animations and sounds, it was not used in a way that effectively reciprocated meaningful

learning, exploration, and discussion of cultural heritage. Users did not learn about the significance or the stories behind paintings from the experience. AR was also not used to its full potential as an alternative means to engage with the paintings. Similar to the Skin & Bones app, users cannot interact directly with the artifact during the AR experience. Users can tilt their view of the animated paintings in a limited range of angles while using the app. AR was not effectively used to transform the role of the visitor from the traditional role of a distant observer to the desired active learner of these artifacts.

ArtLens App Case Study

The ArtLens App was created for The Cleveland Museum of Art (CMA) as a digital pocket guide resource for visitors to use before, during, and after a visit to the museum (The Cleveland Museum of ART (CMA), n.d.). The goal of the ArtLens app is to eliminate the need for paper maps in museums (CMA, n.d). Using the app, visitors can browse the CMA's collection, design individual tours, share favourited works, and access the CMA's open-access collection. Users can also scan a selection of 2D and 3D artworks for an AR experience that provides additional curatorial and interpretative content. It also features an interactive map as a guide to navigate the museum and uses Bluetooth technology to connect to the ArtLens Exhibition interactives and the ArtLens wall — a 40-foot, multi-touch, MicroTile wall. Although this application has many features, this comparative case study will focus on examining its AR feature and how it is used for visitors to engage with artifacts in remote access.

According to The Cleveland Museum of Art's website, the CMA's entire collection and is available on the ArtLens app and is regularly updated to have the most up-to-date information

on each artifact. Scannable artworks for the AR feature are identified with a “scan this artwork” banner at the top of their individual pages. It is important to note that users have to click on individual artworks to see on its individual page if it has an AR feature, unlike the Skin & Bones app where it is easy to identify which artworks are scannable by a small icon seen over the image and users can also open a separate gallery list of all the artifacts with AR features. Compared to Skin & Bones and ReBlink, the ArtLens app does not overlay 3D models, animations, or sounds. Instead, the app overlays images and text with contextualized information on certain features of the artwork. Although this app presents interactive AR features that are focused on close examination of the artifacts than the other two apps, there are some noticeable barriers with using the AR feature the way it is currently designed. The default camera view is noticeably less cluttered with UI elements compared to the Skin & Bones app, however, once a scannable artwork is detected, the number of elements overlaying the painting on the screen felt distracting from the experience. An example of this can be seen when interacting with an oil painting titled, *Elizabeth Shewell West and Her Son, Raphael,* created in c. 1700 by Benjamin West. On the top left-hand corner of the screen, users can see the title of the painting, the date it was created, the name of its artist, the medium, a favourite button, and a share button. On the bottom left-hand corner of the screen, there are 3 large buttons with an image and title. Each of these large buttons has a visible line linking to certain features of importance in the painting detected on screen. When the user moves their mobile device, the app will adjust the lines to always line up to the painting’s features. Tapping on these blocks opens a pop-up with a close-up image and text description of the feature of importance. On the top right-hand corner is a close button and the in bottom right-hand corner is a learn more button. These take up almost half of the screen space and it was difficult to focus on the painting with so many UI elements overlaid on the screen. A

10.5-inch I-pad Pro was used during this comparative case study. Holding the mobile device in one hand to frame the painting into the view of the camera, while using the other hand to interact with the elements on the screen, was a difficult task. However, compared to the Skin & Bones app and ReBlink app, the AR elements do not disappear from the screen after the painting is no longer in view of the camera. It allows the user to not have to constantly have to hold their mobile device to the painting when interacting with the AR feature. Lastly, compared to the Skin & Bones app and the ReBlink app, the ArtLens app was more difficult to install and open. It took several tries to successfully open the app. Noticeably, several other people have expressed experiencing difficulties downloading and opening the app in online reviews of the app.

Summary of Comparative Analysis

This comparative case study investigated how mobile AR apps can improve access and enhance public engagement with cultural artifacts. Although AR has been experimented in many museums over the past decade, AR remains a relative novelty (Marques & Costello, 2018). For AR to be adopted by consumers for ubiquitous use, AR experiences need to be designed to the habitual behaviours and preferences of users, not to the way users are desired or expected to behave and perform. This comparative case study revealed many instances where the design of the mobile AR app interface and AR experience did not align with how users would naturally engage with the technology at hand. For example, the Skin & Bones app and ReBlink app augments 3D models over the artifact. One of the notable frustrations demonstrated during the comparative case study was that users cannot interact with these models through the screen. The user can be seen tempted to tap, pinch, and slide their fingers across the screen for interaction, but these apps did not allow that affordance. These applications did not effectively utilize the affordances of touch screens. This was a habitual behaviour seen during the comparative case

study. Other noticeable findings included the importance of designing the UI elements in the AR feature as an intuitive and seamless interface that does not hinder the experience. User cognitive overload and detraction of the museum experience is one of the concerns of using AR in museums.

How can the mobile AR app experience be better designed for user interaction? Don Norman (2013) in his book titled, *The Design of Everyday Things*, states that there are numerous reasons for the deficiencies in human-machine interaction (p.6). For example, it may be from limitations of available technology or from self-imposed restrictions in the design and production due to limited funding or lack of resources (Norman, 2013). Norman (2013) suggests that most of these deficiencies are due to a lack of understanding of the design principles for creating effective human-machine interaction (p.6). Many new technologies are designed with this mindset that if users were to use the technology to the way it is designed, then it will work as expected. However, it is important to note that machines are not human. Machines cannot adapt to unexpected situations and troubleshoot for human error. Machines simply follow a set of straightforward, rigid instructions and rules set by their designers and developers. A machine's usability is merely a reflection of how well its designers and developers understand the needs and human behaviours of its users. If these machines are designed and built without accounting for how humans may act and interact with it, successful adoption by consumers is unlikely. Therefore, when people struggle with using technology, it needs to be understood that it is caused by the design of technology and not the people trying to use it. To overcome this, designers and developers need to accept and understand human behaviour the way it is, not the way they wish it to be (Norman, 2013, p.6). Technologies, especially new technologies, need to

be designed to fit the needs and behaviours of its users in order for it to be successfully adopted for use. And not force users to adapt to the technology. Designing for AR experiences is challenging because users are expected to engage with digital elements that overlay a physical environment. Users notably behave differently when engaging with digital elements versus physical elements. Each of these environments has its own set of user habitual behaviours to account for. Also, it is important to note that humans may not be familiar with engaging in both environments simultaneously. Before AR technology can become ubiquitous, more research is needed in studying human behaviour with augmented reality experiences.

Through analysis and synthesis of the similarities, differences, and patterns observed between the selected three mobile AR applications, this study revealed some notable findings on the user experience and usability of mobile AR apps as an alternative means to viewing artifacts. This comparative case study examined the behaviours of users when interacting with augmented reality experiences and the challenges they face when used in the form of a mobile AR app within the cultural heritage context. It is important to note that this comparative case study was a qualitative study and may not reveal all there is to the use of mobile AR apps in the context of cultural heritage. The findings from this comparative case study are used as guidelines for the research project in the following section.

Research Project: ARGO

Project Objectives

The overarching aim of this research project is to explore mobile AR applications as an alternative means for users to meaningfully engage with artifacts that are inaccessible for public or in-person viewing. The literature review and comparative case study suggest that mobile AR applications can be used to improve access and enhance the experience of viewing artifacts for remote access. However, the design and development of mobile AR applications need to focus on adapting to actual human behaviour rather than how users are desired to perform or interact with the AR experience. This following research project, ARGO, is presented as a proof of concept to be further developed and explored.

About ARGO

ARGO is a mobile AR application designed for users to interact with high-quality 3D models of various artifacts using marker-based image targets in the form of interactive printed materials. The project goal of ARGO is to present and interpret museum artifacts in an attractive manner through storytelling that would provide users with an incentive to learn more about cultural heritage. To achieve this goal, ARGO provides interactive scenarios, wherein addition to passive information browsing, users can also be involved in interactive activities. The app features a collection of ancient South Asian bronze vessels, metal vases, and glazed ceramics from the Minneapolis Institute of Art. For the purpose of this research project, the prototyping process focused on the following three artifacts: the Zun Owl Vessel in the Shape of an Owl, the Jia Wine Vessel, and the ‘You’ Wine Vessel in a Double Owl Shape. For a description and additional details of the artifacts featured in the prototype refer to Appendix C, Figure C-1.

Target Audience and User Persona

Due to time constraints and social/physical distancing restrictions of COVID-19 at the time of this research project, primary data was not collected for defining the target audience and demographic. The target audience and user persona of this research project were defined using conclusions drawn from existing demographic studies of museum visitors.

A study conducted by the Smithsonian Institution (2006) on museum visitorship and demographic change speculate that future museums will experience a more diverse museum audience, particularly a larger number of non-white visitors among their younger audience (p.10). The organization also speculates that future museums will have two main audiences to cater to; an aging older audience with accessibility needs and a younger tech-savvy audience with a need for exciting, theatrical exhibits (p.4). Another study conducted by the American Association Museum also revealed that many of the younger generation (generally defined between age 16 to 25) want more immersive, interactive, and participatory activities from museums (Farrell & Medvedeva, 2010, p.23). Younger museum visitors desire to be more than distant observers looking in (Farrell & Medvedeva, 2010, p.23). The studies suggest that future museums will be challenged with diversifying museum audiences, improving the accessibility to artifacts, and catering to the desire for more entertaining and interactive exhibits.

Thus, the target audience for ARGO are users between the age of 16 to 29 from diverse ethnic backgrounds (Asian, Hispanic, African American…etc.) interested in learning about cultural heritage. Ideally, ARGO is used as an alternative way for meaningful learning of cultural

heritage for users in remote access. A user persona based on these findings were made as part of the development process of ARGO. To see the final user persona, refer to Appendix D, Figure D-1.

User Experience Map and Wireframes

To further establish the context of use and the user requirements of ARGO, a user experience map was created as part of the development process (See Appendix D, Figure D-2). Using the user persona created in the previous section, this user experience map demonstrates how users would engage with ARGO from the point of view of the user. This user experience map is based on the customer journey map model proposed by the Nielsen Normal Group. Journey maps combine storytelling and visualization to create a holistic view of a customer's experience by compiling user goals, actions, mindsets, and emotions into a visual timeline (Kaplan, 2016). This user experience map examines a user's journey with ARGO in four phases, including consideration, acquisition, service and retention. This user experience map also highlights possible points of frustration that may be experienced by users. The findings and insights discovered during the development of the user experience map was used to inform the design of the wireframes and layout of the prototype.

The comparative case study also revealed several key points on the usability and user experience of mobile AR applications for museums. Based on the findings of the comparative case study, the following list of design guidelines was created for the development of this research project's prototype:

- **Minimal UI Design:** The number of interfaces (UI) elements in the AR camera view should be kept to a minimum. Only necessary UI elements should be included, and it

should be implemented in an intuitive, seamless way that does not hinder the experience. As mentioned in the comparative case study findings, too many UI elements can cause user cognitive overload and may be distracting to the AR experience.

- **User Needs & Behaviour:** One of the biggest concerns of using AR is gimmickry and detraction from the museum experience. To successfully integrate AR technology for museums, the experience should be designed to the behaviours, preferences, and needs of the visitors.

- **Users as Active learner:** Rather than an outsider observer looking in, users should be active learners in the experience. AR technology should be used to enhance the experience in a meaningful, explorative, and engaging way.

The high-fidelity wireframes and layouts of ARGO were created in Adobe Illustrator and finalized in Adobe XD for prototyping. See Appendix D, Figure D-3 – D-4 for sketches, wireframes, and final layouts of the ARGO app.

Design & Development

Prototype Development

To build a testable prototype for this research project, two prototypes were created: Prototype A – a prototype of the mobile AR app interface, and Prototype B – a prototype of the AR feature experience. Prototype A was built using Adobe Illustrator to finalize the visual graphics and layout and Adobe XD for user testing. Prototype B was created using Unity and the Vuforia Augmented Reality SDK plugin was used. High-quality 3D models of artifacts were sourced with permission from the Minneapolis Institute of Art's creative commons zero (CC0) collection. Additional background, texture, and audio were sourced from the Unity asset store and altered to fit the experience. Blender, Adobe Illustrator, and Adobe After Effects were also used to edit and create the multi-media content. Printable image targets in the form of collectible cards were created in Adobe Illustrator. For a description of the technologies, applications, and assets used to create the prototype see Appendix B, Figure B-1 to B-2.

User Testing

An informal user testing was conducted on the two prototypes of the AR app. It is important to note, the data gathered from this informal user study was used solely for informing the development process of the mobile AR prototype and for assessing if the project deliverables meet the project objectives. No data on the demographic details of the user-testing participants were collected or shared for additional research purposes. For prototype user testing, this research project following the Neilson Norman Group's approach to qualitative user testing and utilized the "Think-Aloud" method where the participants are asked to narrate their actions and thoughts as they perform tasks. Examples of tasks would include, find the AR camera button or

scan the image target to reveal the 3D model...etc. Observational notes are taken throughout the user testing sessions on the participant's behaviours, goals, thoughts, and motivations by observing the participant's facial expressions, body language, length of time he/she took to complete a task. The facilitator of the user testing session did not guide or help the participants complete their given tasks. The goal of user testing is to "identify problems in the design, uncover opportunities to improve, and learn about the target user's behaviours and preferences" (Moran, 2019, para. 2). The findings from this qualitative user-testing will assess the usability of the research project and provide further insight into usability evaluations on mobile AR applications.

For the user testing, three participants between the ages of 18 to 30 took part in the user testing of this project. The two prototypes were tested on a 10.5-inch I-pad pro with printed image targets in the form of collectible cards for the AR experience. In Prototype A, several notable observations were made that hinted at opportunities to improve the design of the mobile AR app. Although all the participants successfully were able to navigate through the app's interface, there was some hesitation and confusion as to where specific buttons and text were located at first glance. Participants gave notable feedback for improvement in the design of the mobile AR application. Feedback included enlarging the size of typography for better legibility, adjusting colors of buttons for better visibility, using more image instead of text for instruction, enlarging the size of the buttons for better accessibility, and consolidating the print and download button in the AR camera view for a less cluttered user interface. These observations and feedback were noted for adjustments in version two of Prototype A.

In Prototype B, observations on the participants' behaviour indicated the need for several improvements to the UI design of the AR experience. One of the capabilities of the AR feature is the ability for users to interact with the 3D model. After the image target of the artifact is detected in the AR camera view, a 3D model of the artifact appears on the screen. If users tap on the model, then can move, scale, and rotate the model for an optimal viewing experience. However, during user testing, participants were notably confused on whether they successfully tapped the 3D model on the touch screen of the I-pad to activate the touch inputs and gesture handling capabilities for scaling, moving, and rotating the 3D model. To improve this interaction, it was suggested to use a visible marker or response, such as a slight glow around the model or slight enlargement of the model, to indicate the object is selected. The 3D model would also sometimes be stuck in a fit position of the screen when the image target is no longer in sight of the camera view or the 3D model is dragged too far. This is a noticeable bug/error that needed to be fixed for the next prototype iteration. Lastly, another noticeable observation was made on the usability of the "Play" AR button. This AR button was designed so that when users physically hover their hand over the digital button augmented above the image target card, it would activate the associated animation and audio/visual media. For example, hovering a hand over the "Play" AR button for the Zun Owl Vessel's image target card will animate the top lid of the Zun Owl Vessel 3D model to open and close while an audio clip about the origins and story of the artifact will play. It was observed that the users were unaware of this capability. Users were repeatedly tapping on the screen of the I-pad in an attempt to activate the button, rather than physically hovering their hand over the image target card. One participant attempted to physically hover their hand over the image target, but it was also observed that the participant experienced difficulty balancing the I-pad with one hand while attempting to press the button

with the other hand. This observation leads to the revelation of the impractically of an AR button for this AR experience. It was not an intuitive action displayed by the participants and it proved to be problematic and hindered the experience. For the second version of Prototype B, the AR button is activated through tapping on the touch screen, rather than by physically hovering a hand over the image target. However, due to time constraints, version two of Prototype B and Prototype A has yet to be finalized and undergo another round of user testing.

Despite some of the bugs and errors that were encountered during the user testing, some notable comments made by participants during the user testing included positive feedback on the high-quality production and educational impact of the experience. Participants also expressed a positive desire to use the application again. It is also important to note that the user testing of the prototype faced several limitations due to time constraints and the unique circumstances of the global pandemic of COVID-19. User testing of the mobile AR prototype experienced an insufficient sample size of the target demographic due to social/physical distancing restrictions of COVID-19. Consequently, this limitation affected the iteration process in the development of the mobile AR prototype. The final prototype of this research project is subject to further research and development. See Appendix E for images and supporting visual materials of the final prototype.

Conclusion

Summary of Results

Successful integration of mobile AR technology in museums will be pivotal in shifting consumer perspectives of AR as a frivolous gimmick to a valuable commodity. This research provides empirical evidence that mobile AR applications, paired with mixed media storytelling, can effectively improve access and public engagement with cultural artifacts. Findings from this research project suggest that the positive adoption of an AR experience for museums can extend from research in the habitual behaviours of end-users and the development of AR experiences as an extension rather than a replacement of the museum experience. This research project also emphasized the need for more in-depth research on the usability evaluation of mobile AR applications for museums.

Summative Evaluation of ARGO

This research project suggests through prototyping an impactful mobile AR experience that meaningful learning, exploration, and discussion of cultural heritage can be achieved by participants when interacting with digital 3D models of artifacts in a mixed media storytelling narrative. An informal user testing of the prototype revealed positive feedback by participants on the usability of the mobile AR app, however, the mobile app's interface and AR experience require further development before it can be viable for use in museums. Further user testing and development of the prototype are also needed to produce conclusive findings on the perceived usefulness of AR in the context of cultural heritage and the successful adoption of AR in museums as a means for viewing artifacts.

Review of Limitations

Due to time constraints and the unique circumstances of the global pandemic of COVID-19, primary data was not collected at the expected breadth for this qualitative research. Consequently, this research project relied on the findings from pre-existing studies and conclusions were extrapolated from self-reported data in a comparative case study of existing mobile AR applications. As limited resources were available due to this unique situation, limitations were imposed on the research project. In addition, the informal user testing of this research project was subjected to insufficient sample size and affected the development and iteration process of the research project. To further explore the opportunities for mixed media storytelling using augmented reality, more user testing is needed to be done.

Conclusion and Future Work

Although AR has been experimented with and used by museums since the early 2000s, AR technology remains a relative novelty (Marques & Costello, 2018). At the time of this research paper, there are notably limited studies on the adoption of AR in museums and visitor behaviour in augmented reality experiences for museums. This research project proposes that one of the reasons for the low user adoption of AR is due to limited research in user behavior with AR experiences in museums. The majority of current AR experiences are designed with a pre-conceived expectation of participant behavior, rather than being designed to the actual behavior, needs, and preferences of participants. Mobile AR applications should be designed around how participants naturally behave and their habitual behaviours with the technology. Viewing cultural artifacts in augmented reality should not replace the need to touch and interact with the original object, but rather be used to enhance one's experience. This research project demonstrated how augmented reality combined with storytelling can be used to transform the

access and public engagement with cultural artifacts in a meaningful way that aligns with the current trend of making museums content more engaging and interactive. Augmented reality can become a tool for cultural institutions and museums to increase engagement with their collections. This prototype can be also further developed to be used in the physical space of museums. This research project serves as a proof of concept to be further explored.

Appendix A – Research Methodology

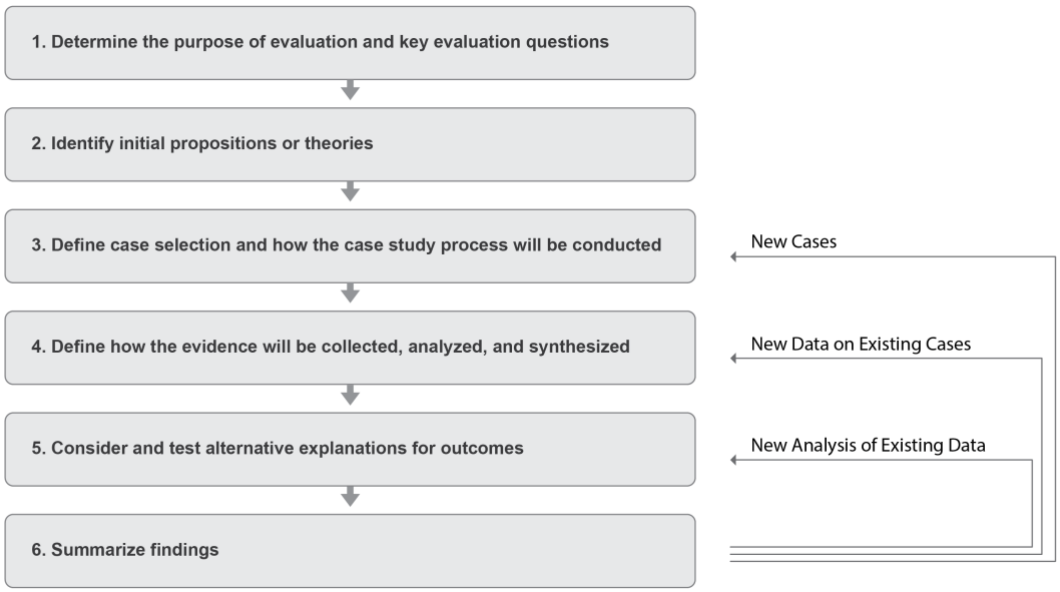

Figure A-1. This chart shows the research entry points and the methodological process of the research project. This chart is adapted from the Logic of Comparative Case Studies model by Goodrick Delwyn (2014).

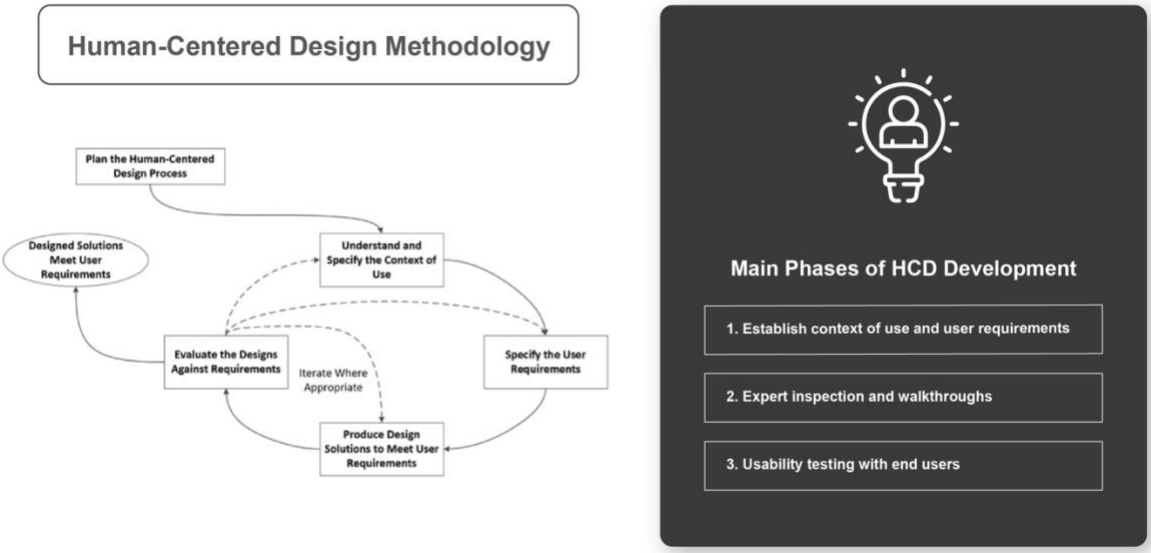

Figure A-2. The Human-Centered Design Process. This figure shows the development process undertaken throughout the research project. This figure is adapted from the HCD model by Richard P. Harte (2017).

Appendix B – Description of Technologies, Applications, and Assets Used

Technologies and Applications Used in the Development Process	
Technology	**Description**
Adobe Illustrator CC	A software for creating vector graphics.
Adobe XD CC	A vector-based user-experience design tool for web and mobile apps.
Adobe After Effects CC	A digital motion graphics, visual effects and compositing application.
Adobe Audition	A digital audio toolset for creating, mixing, editing, and restoring audio content.
Blender	A 3D computer graphics software toolset.
Unity	A cross-platform game engine.
Vuforia Augmented Reality SDK	An augmented reality software development kit for mobile augmented reality apps

Figure B-1. Chart of Technologies Used Throughout the Development Process.

Unity Assets Used for Development of Prototype		
Unity Asset	**Creator**	**Description**
Lean Touch	Carlos Wilkes	Unity asset pack for stimulating and visualizing touch inputs, gesture handling, DPI handling, UI integration, and object selection inside the Unity editor. Link: https://assetstore.unity.com/packages/tools/input-management/lean-touch-30111
Fantasy Wooden GUI	Black Hammer	A 2D User Interface pack. Link: https://assetstore.unity.com/packages/2d/gui/fantasy-wooden-gui-free-103811
Free Casual Game SFX Pack	Dusty Room	A collection of sound effects licensed CC Zero (CC0) for game development. Link: https://assetstore.unity.com/packages/audio/sound-fx/free-casual-game-sfx-pack-54116
Vector Images & Icons	Freepik	The user experience map and Adobe XD prototype uses vector images and icons from Freepik at www.flaticon.com for non-commercial use.

Figure B-2. Chart of Assets Used for Development of Unity Prototype

Appendix C – Description of Artifacts Featured in the Prototype

Artifact Name	Date & Country of Origin	Artist	Description
Zun Wine Vessel in the Shape of an Owl	13th-12th century BCE, China	Unknown	A bronze wine vessel used by Shang-dynasty aristocrats during ritual ceremonies. Credit: Bequest of Alfred F. Pillsbury
'You' Wine Vessel in double-owl shape	12th – 11th century BCE, China	Unknown	A bronze wine vessel decorated with the form of two owls back-to-back. Credit: Bequest of Alfred F. Pillsbury
Jia Wine Vessel	12th century BCE, China	Unknown	A "S" shaped bronze wine vessel decorated with a dragonized taotie and rising blades with stylized cicadas. Credit: Bequest of Alfred F. Pillsbury
Fanghu Wine Vessel	5th – 4th century BCE, China	Unknown	A bronze vessel with a complex recessed geometric pattern inspired by highly stylized interlaced dragons. Credit: Bequest of Alfred F. Pillsbury
Ding Food Vessel	5th century BCE, China	Unknown	Bronze vessel with inlaid silver décor. Credit: Bequest of Alfred F. Pillsbury
Gui Food Vessel	11th century BCE, China	Unknown	A gui featuring looped handles rendered in the form of an elephant's head and trunk. Credit: Bequest of Alfred F. Pillsbury
Kalong Vase with Fish	14th – 16th century, Thailand	Unknown	A Northern Thai kiln with the body of the vase featuring imagery of a fish darting in a sea of water plants. Credit: Gift of Mona W. Brown
'You' Wine Vessel	11th century BCE, China	Unknown	Bronze inscribed vessel published as one of a pair in the Xiqing Gujian, the 18th century imperial catalogue of bronzes belonging to Qianlong dynasty emperor (r.1736 – 95). Credit: Bequest of Alfred F. Pillsbury
Vase	18th Century, China	Unknown	An enamel, copper alloy vase derived from the bronze hu vessel but made in cloisonne. Credit: Gift of Ruth And Bruce Dayton

Figure C-1. Chart of selected artifacts featured on the mobile app. All of the featured artifacts and their additional material (images, 3D models, audio recordings) is licensed in the public domain under Creative Commons Zero (CC0) by the Minneapolis Institute of Art.

Appendix D – Design and Development Process

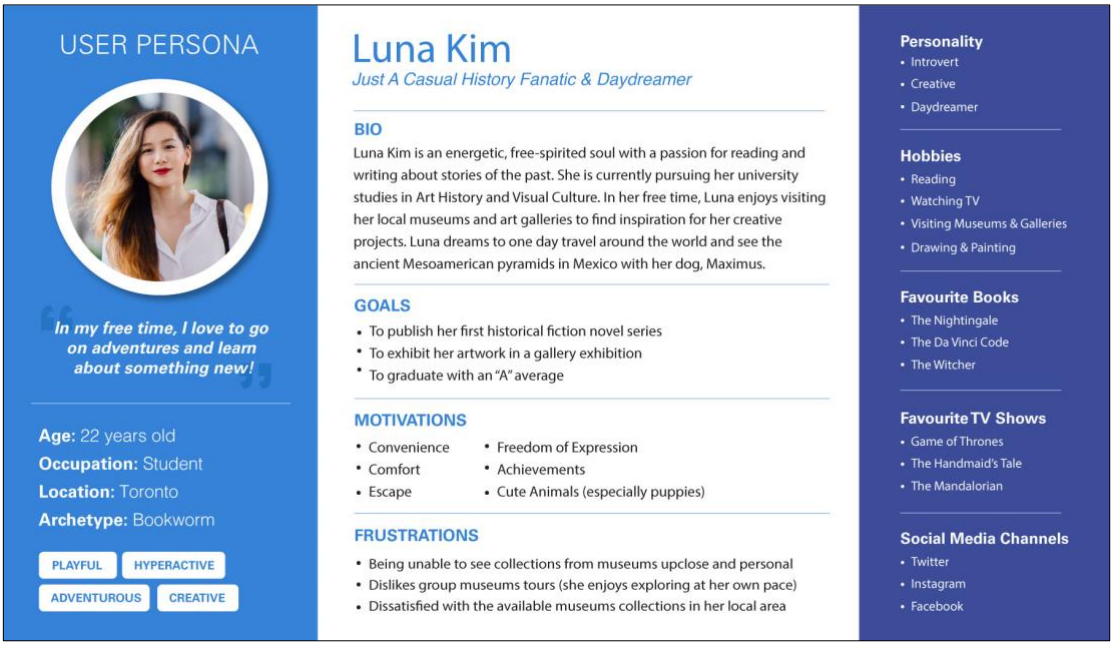

Figure D-1. User Persona. This figure showcases a semi-fictional character based on the target demographic using the app.

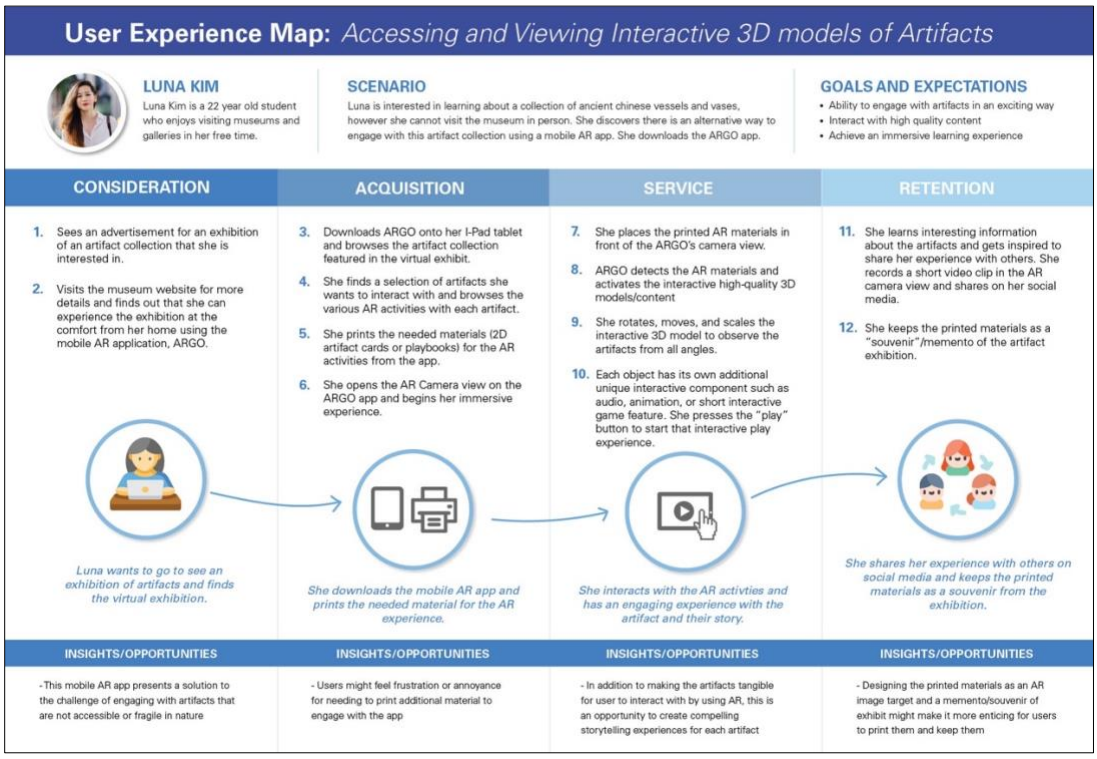

Figure D-2. User Experience Map. This figure demonstrates the expected user experience finding and using the app from the perspective of the user persona.

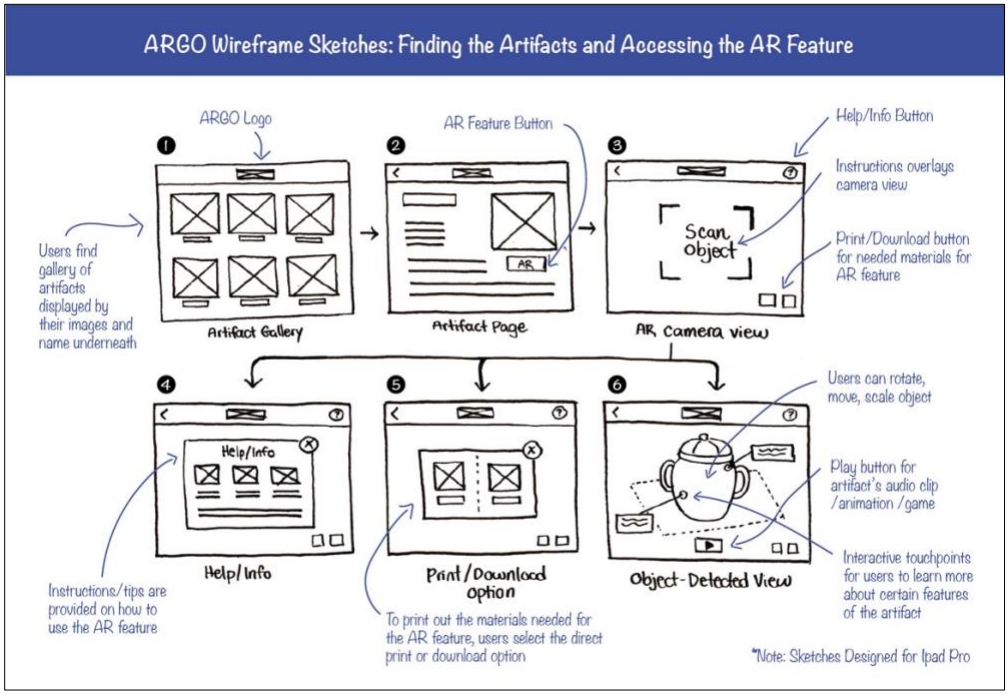

Figure D-3. ARGO Wireframe Sketches. This figure maps out the key layouts and user flow of the mobile AR app.

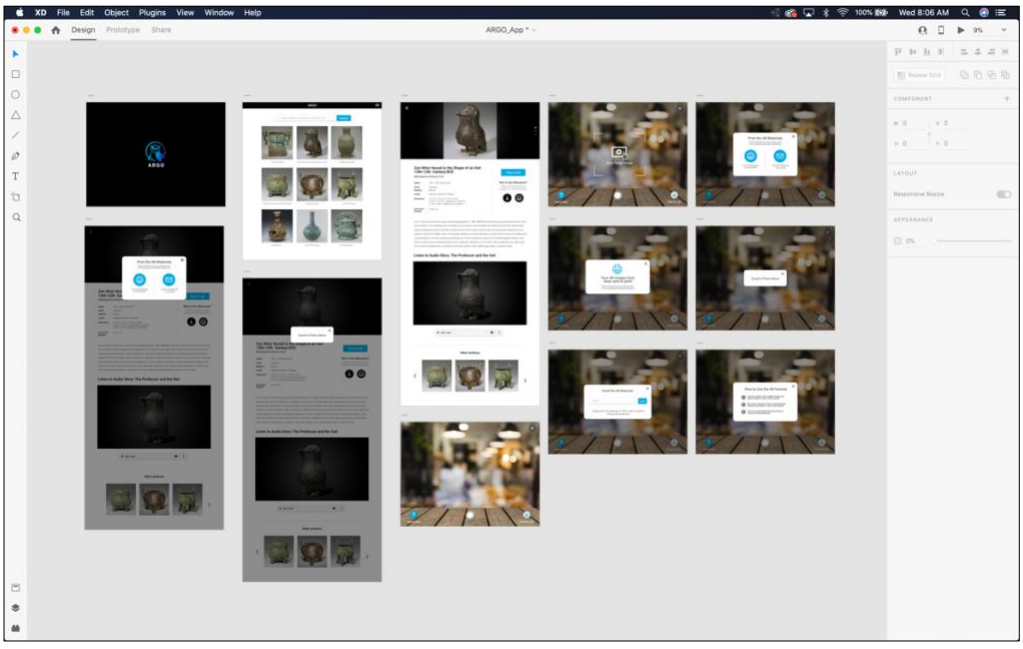

Figure D-4. ARGO Adobe XD Wireframe for Prototype A. This figure showcases the layout of the key pages of the app created digitally in Adobe XD for prototyping.

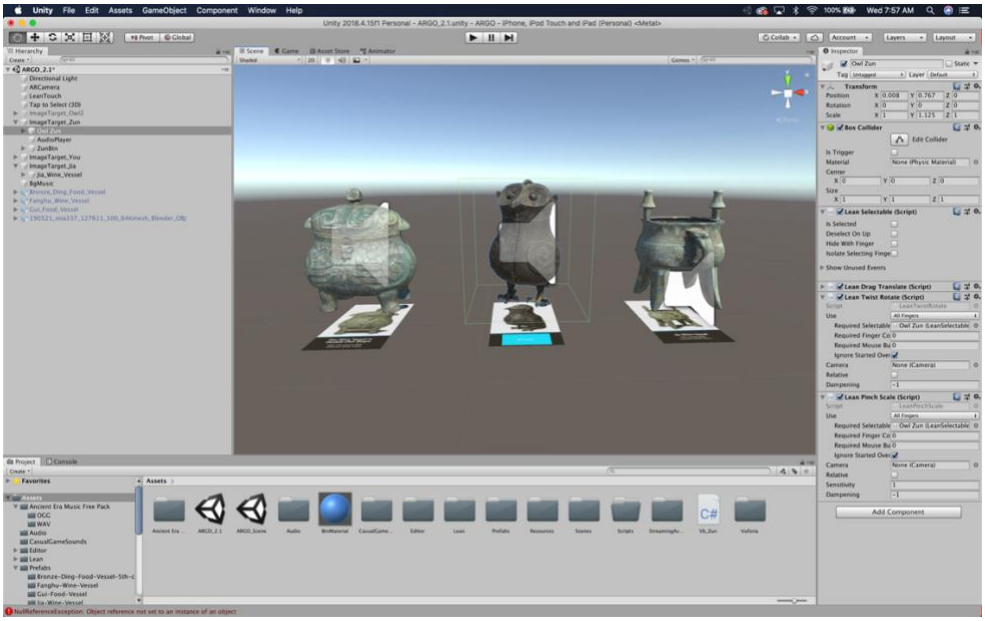

Figure D-5. Screenshot of 3D Scene created in Vuforia for Prototype B. This figure showcases the 3D models of the artifacts set with their respective image targets prints in Unity.

Figure D-6. Screenshot of Jia Wine Vessel in Vuforia target image card and 3D model activated in ARGO prototype.

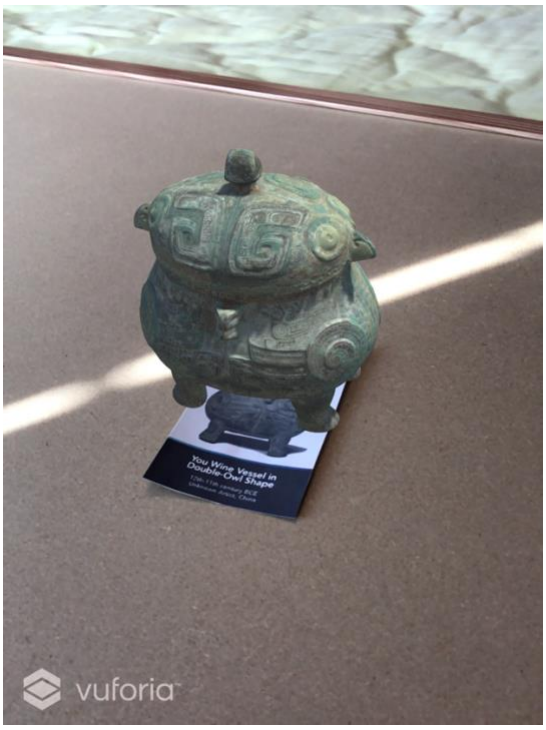

Figure D-7. Screenshot of You Wine Vessel in Vuforia prototype for ARGO app. This image shows the target image card detected and the interactive 3D model activated in ARGO prototype.

Figure D-8. Screenshot of Zune Wine Vessel in Shape of an Owl in Vuforia prototype for ARGO app. This image shows the 3D model activated with an AR play button for animation and audio sound in ARGO prototype.

Appendix E – Final Prototype and Supporting Visual Materials

Figure E-1. ARGO Logo. This figure shows the logo of the ARGO app on an I-pad device.

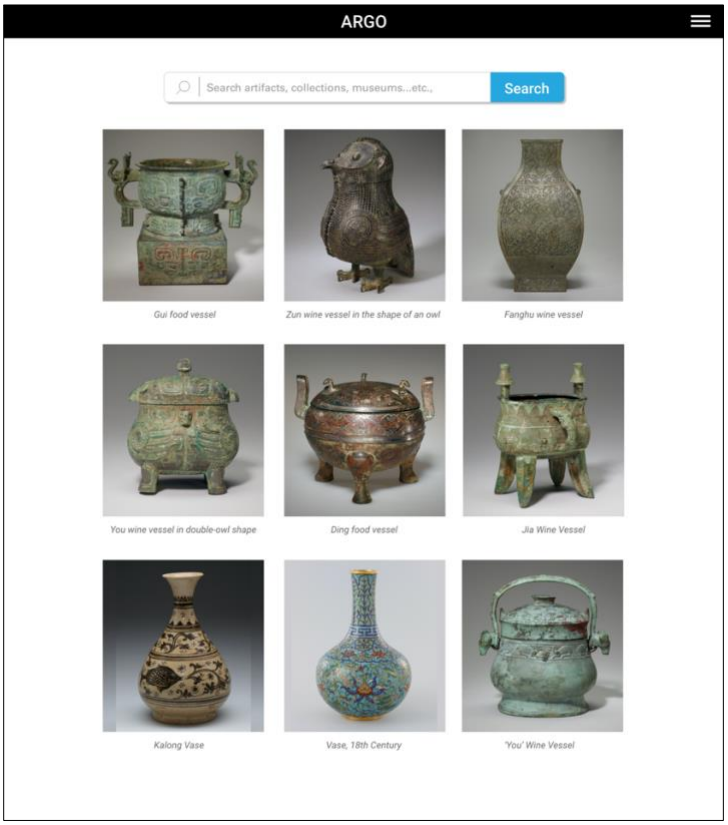

Figure E-2. Artifact Gallery Page. This figure shows the selection of artifacts for AR viewing experience on the app.

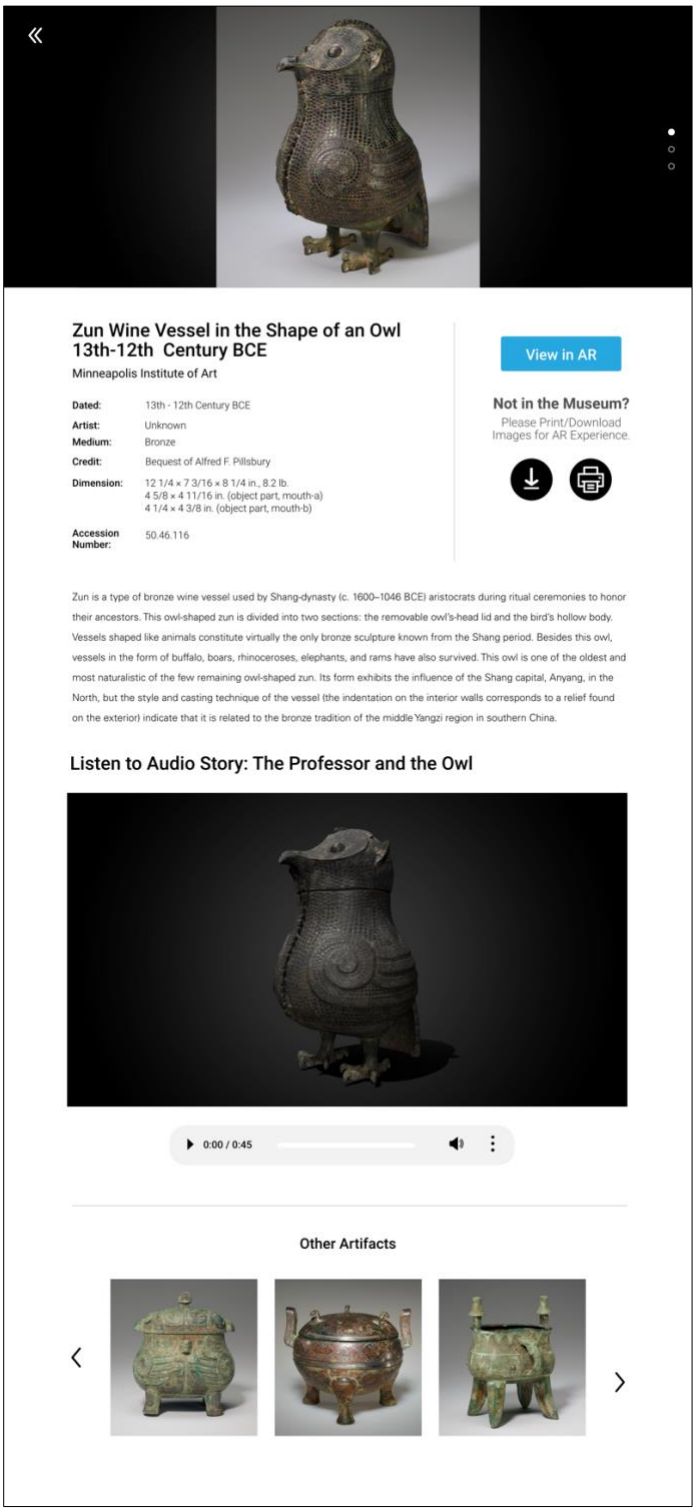

Figure E-3. Artifact Information Page. This figure shows a sample of the page to start the AR experience on the app.

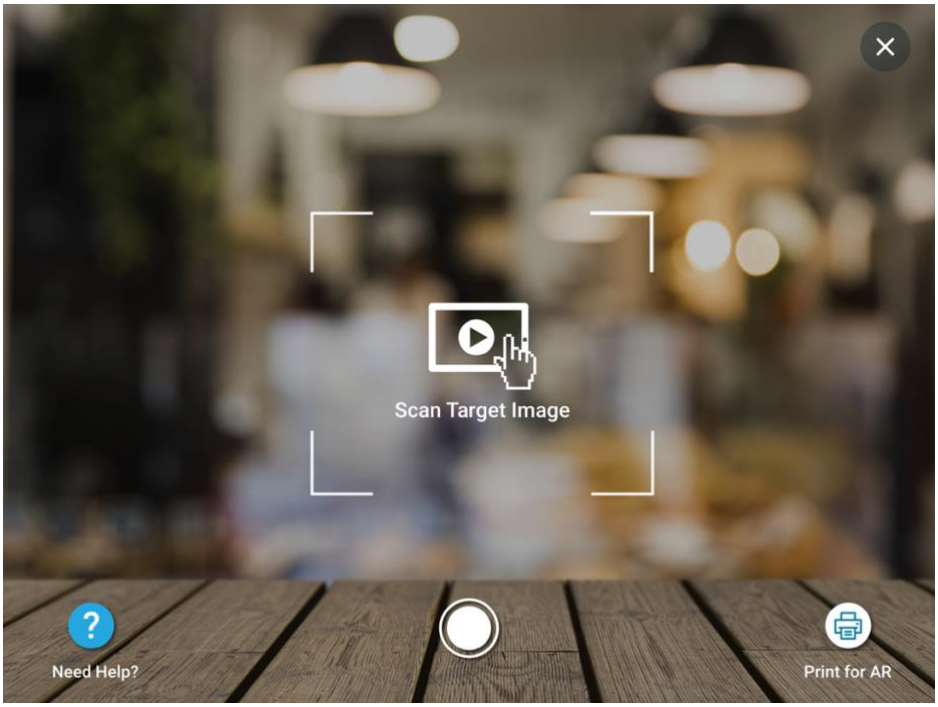

Figure E-4. AR Camera View. This figure shows the features in camera view, including an overlay of instruction prompts, a button for printing the materials needed for the AR experience, a camera button to take photos, and a button for additional information/instructions.

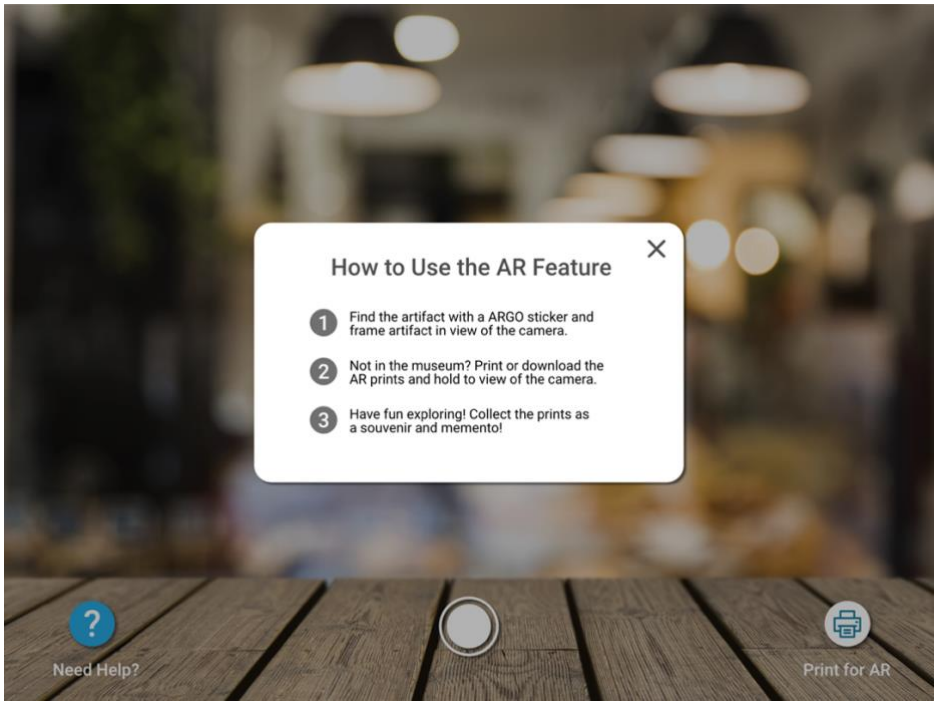

Figure E-5. Instructions from the Need Help Button. The figure shows the instructions for the AR feature that users will see using when using the app.

Figure E-6. AR Image Target Cards. This figure showcases the design of the AR collectable cards to be printed for the AR activities. These cards serve as image targets for ARGO's AR features and the images have been edited for optimal augmentable recognition in Vuforia's target manager.

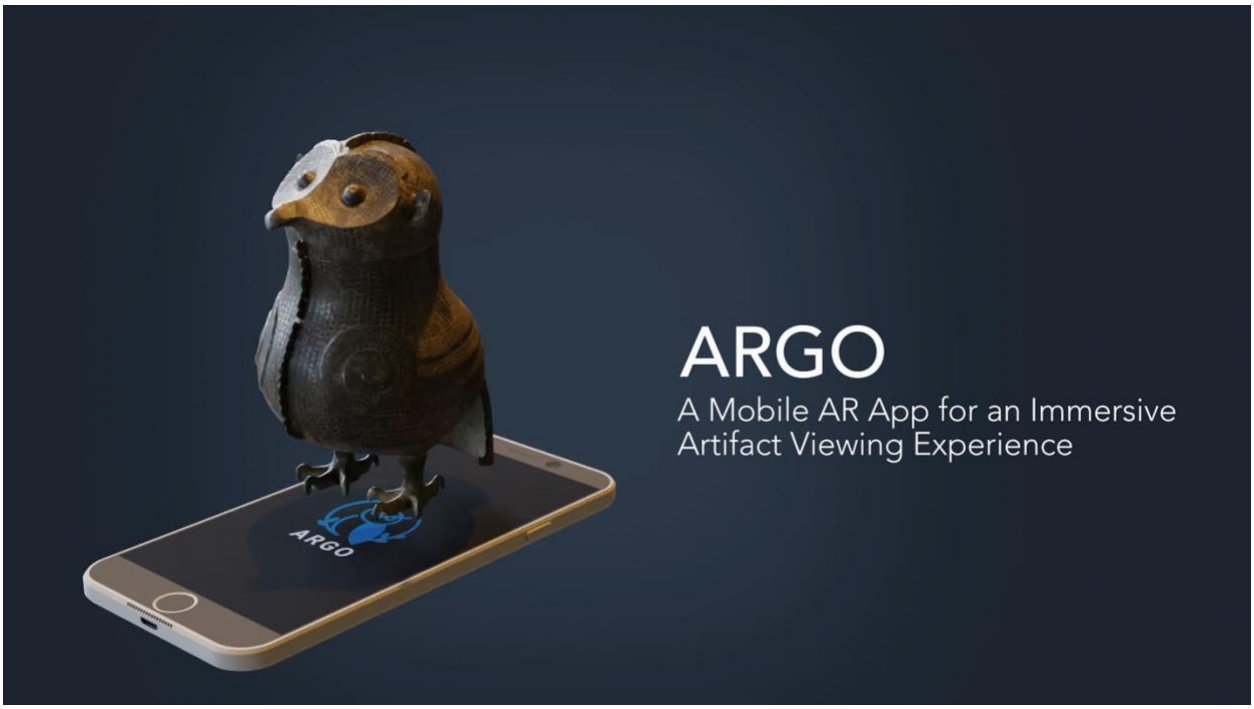

Figure E-7. ARGO Banner. This figure is a still image from an animated video created as advertisement material for the project.

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