AUGMENTED REALITY (AR) APP IN ART, ARCHAEOLOGY AND ARCHITECTURE

BY

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BENIN CITY, NIGERIA.

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A PROJECT SUBMITTED TO THE DEPARTMENT OF COMPUTER SCIENCE, FACULTY OF COMPUTING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE (B.Sc.) DEGREE IN COMPUTER SCIENCE, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA.

JANUARY, 2026

DECLARATION

I, **EBIUWAIRO EVBUOMWAN**, do hereby declare that this thesis is entirely my own work and composition. The work embodied in the project has not been submitted for any degree and is not currently being submitted for any other degree. All references made to the works of other persons have been duly acknowledged

EBIUWAIRO EVBUOMWAN **Date**

CERTIFICATION

This is to certify that this thesis was carried out by EBIUWAIRO EVBUOMWAN with Matriculation Number: **PSC0502649** of Department of Computer Science, Faculty of Computing, University of Benin, Benin City, Edo State, Nigeria.

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Date

DEDICATION

This project is dedicated to

the Almighty

and Royalty

ACKNOWLEDGEMENTS

Utmost gratitude to God and my ancestors for divine providence on this academic journey.

I would like to express my appreciation and a special thank you to my amiable project supervisor and Dean, Faculty of Computing, Professor (Mrs) V. V. N. Akwukwuma who ensured I put in my best into this research thesis. And I also extend my appreciation to the Head of Department, Computer Science, Dr. (Mrs) A.R. Usiobafo; my seminar co-ordinator Professor G. O. Ekuobase as well as the academic and non-academic staff of the Faculty of Computing, University of Benin.

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TABLE OF CONTENT

Abbreviations

Acronym	Definition
3D	Three Dimensional
AR	Augmented Reality
Auth	Authentication
BaaS	Backend as a Service
BIM	Building Information Modeling
CAD	Computer-Aided Design
CSS	Cascading Style Sheets
GIS	Geographic Information Systems
HCD	Human-Centered-Design
HDR	High Dynamic Range
IBL	Image-Based Lighting
LiDAR	Light Detection and Ranging
MR	Mixed Reality
MTL	Multi-Threaded Language
NFT	Natural Feature Tracking
OS	Operating System
PBR	Physically Based Rendering
SDK	Software Development Kit
SLAM	Simultaneous Localization and Mapping
SWR	Stake-While-Revalidate
UI	User Interface

VIO	Visual-Inertial Odometry
VR	Virtual Reality
XR	Extended Reality

ABSTRACT

This bachelor's thesis project is intended to study augmented reality (AR) in art, archaeology and architecture. To this purpose, a prototype mobile AR app has been implemented on iOS® and Android® mobile platforms for augmented reality (AR) experiences and demonstrable applications in art: museum art (i.e., immersive artifact viewing experiences in a museum) and street art (i.e., immersive murals on walls, creating an 'open-air' museum). Its home page is https://elikibaar.elikiba.com

KEY WORDS

Augmented Reality (AR), Museum Art, Street Art, Archaeology, Architecture, ARCore, ARToolKit, ViroReact, Human-Centred Design (HCD), Computer Vision (CV), JavaScript, ARKit, and Mobile AR.

CHAPTER ONE

BACKGROUND RESEARCH

INTRODUCTION

Augmented reality (AR) connects and integrates elements of the real world with virtual objects and data. An essential aspect in this computer-generated experience is not only about displaying information but integrating it to a user's perception and, therefore, creating an immersive experience. As a result, the real environment is enhanced for users to perceive additional information in real-time.

OBJECTIVE

The first objective of this research thesis simply is to study augmented reality (AR) in art, archeology and architecture. Furthermore, the second objective is to design and implement ElikibaAR, a prototype mobile AR app for augmented reality (AR) with demonstrable application in art: museum art and street art. ElikibaAR shall be available on iOS® and Android® mobile platforms for augmented reality (AR) experiences in art.

SCOPE

The scope of this research paper is to design and implement ElikibaAR, a prototype mobile AR app for augmented reality (AR) with demonstrable application in art: immersive artifact viewing experiences in a museum (i.e., museum art), and immersive murals on walls, creating an 'open-air' museum (i.e., street art). Its home page is https://elikibaar.elikiba.com

PROBLEM STATEMENT

Museums and traditional digital art galleries lack immersive, spatial context. Artists struggle to showcase work in meaningful physical environment.

SOLUTION

An AR-powered mobile platform that allows artists to place digital artworks in real-world spaces, viewable through smartphones.

IMPACT

ElikibaAR mobile AR app democratizes art exhibition, reduces barriers to entry for emerging artists, and creates new engagement models for art enthusiasts.

CHAPTER TWO

LITERATURE REVIEW

Augmented reality (AR) combines both real and digital content, making them appear to coexist in the same space. Unlike a virtual reality (VR) experience in which the computer generates a whole simulated environment and the user is completely immersed in a virtual world. More often than not, augmented reality (AR) is mistaken for virtual reality (VR). A differentiating attribute of augmented reality is that this computer-generated experience is not only about displaying information but integrating it to a user's perception and, therefore, creating an immersive experience. Hence, it can also be defined by the terms of computer-mediated reality or mixed reality (MR).

The reality-virtuality continuum is a concept proposed by Milgram and Kishino (1994) that relates the objects we see in the real world and the ones we see in digital simulations. The scale runs from the Real Environment (RE) through Augmented Reality (AR), Augmented Virtuality (AV) to a full Virtual Environment (VE).

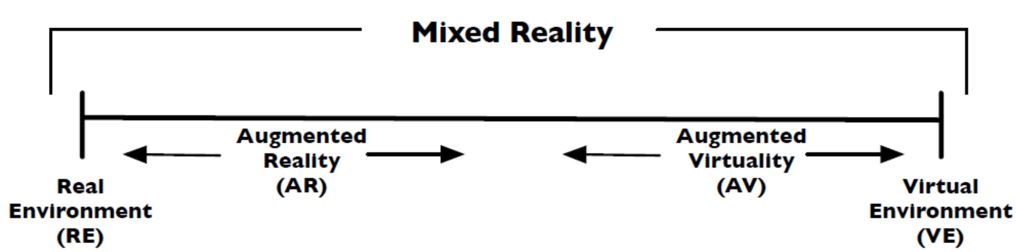


Figure 2.0 Reality-Virtuality Continuum: order of reality concepts ranging from Reality (left) to Virtuality (right)

Augmented Reality enables a user to work in a real world environment while visually receiving additional computer-generated information to support the task at hand (Schnabel et al, 2007:4).

This typically entails overlaying virtual objects onto live video feed from either a web-camera, a Head Mounted Display (HMD) or a mobile device. There are a wide number of applications of this technology: interactive greeting cards (Hallmark, 2010), advertising (such as interactive brochures allowing you to test 'drive' a car (Citroen, 2010)), visualization of computer-generated GIS (Geographic Information Systems) data overlaid onto actual locations (Ghadirian & Bishop, 2008), indoor and outdoor gaming (Bernardes et al., 2008), even heads-up displays in modern aircraft are a form of Augmented Reality (AR) – projecting information onto the pilot's display.

While the term augmented reality (AR) was coined in the early 1990s, the first fully functional AR system dates back to the late 1960s, when Ivan Sutherland and colleagues (1968) built a mechanically tracked 3D see-through head-worn display, through which the wearer could see computer-generated information mixed with physical objects, such as signs on a laboratory wall. For the next few decades much research was done on getting computers to generate graphical information, and the emerging field of interactive computer graphics began to flourish. Photorealistic computer-modeled or generated images became an area of research in the late 1970s, and progress in tracking technology furthered the hopes to create the ultimate simulation machine. It was not until the early 1990s, with research at the Boeing Corporation, that the notion of overlaying computer graphics on top of the real world received its current name.

Caudell and Mizell (1992) worked at Boeing on simplifying the process of conveying wiring instructions for aircraft assembly to construction workers, and they referred to their proposed solution of overlaying computer presented material on top of the real world as augmented reality.

Extended Reality (XR) which encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), offers immersive and interactive experiences and plays an increasingly significant role in architectural design, construction, and education. Potentially, XR technologies can transform architectural education by bridging the gap between theoretical and practical aspects of architectural design; and enhancing visualization capabilities.

With current pace of technological innovation, the disconnectedness of having to hold up a mobile device in order to experience the virtual objects is being mitigated. It is already possible to have an immersive AR experience with transparent glasses with forward-facing cameras that overlay the AR information directly onto one's field of vision.

The three main characteristics that define an augmented reality system according to Azuma (1997) are:

• combination of real and virtual content in a real environment;

• real-time interaction;

• 3D registration of the virtual content in the real environment.

AR systems can track and render or superimpose virtual objects i.e., visual graphics, text, audio or animation and contextual information into the real–world environment according to the position of the camera, users can interact with Mobile AR to solve queries and collaborate with people. The world becomes the user interface. In order to make this possible, markers have to be placed in certain objects or areas of the real environment to activate the combination of real and virtual, through pattern recognition and computer vision techniques (Kato, Hirokazu & Billinghurst, Mark, 1999)

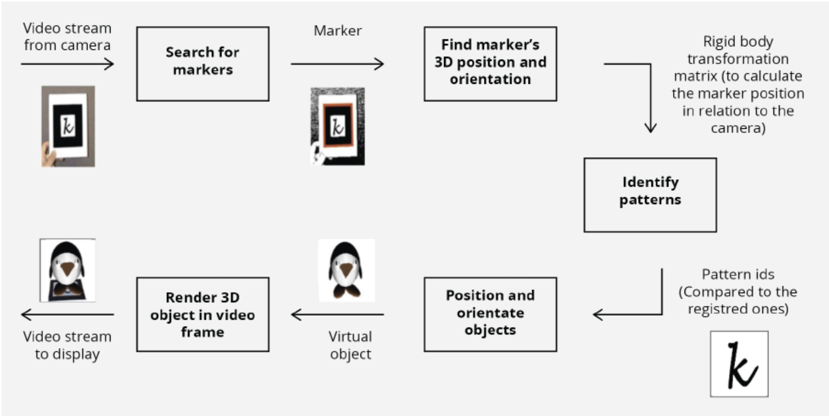


Figure 2.1 Augmented Reality System

Augmented reality is usually associated with adding objects to the real environment; however, it can also remove, replacing them with virtual objects. This is called diminished reality, which is considered a subset of AR (Azuma, 1997). For instance, to remove a chair from the real environment, the system would have to draw a representation of the room (floor and walls) and "paint" them over the chair to eliminate it from the user's sight. In addition to sight, augmented reality can be applied to more senses, such as hearing, touch and smell. For hearing, the user would have headphones, adding synthetic, directional 3D sound, and a directional microphone that would detect the environment noises (Azuma, 1997). 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. Users can interact with it to display related information, to pose and resolve queries, and to collaborate with other people. The world becomes the user interface. (Höllerer & Feiner, 2004). 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 mobile AR app shall be designed for immersive artifact viewing experiences in a museum, and immersive murals on walls, creating an 'open-air' museum. 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. To meet the needs of this young, tech-savvy 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). Digital technologies play a pivotal role in democratizing access to cultural heritage for a shared global stage. Technology should be utilized to enhance and deepen the appreciation, preservation, and understanding of artifacts. 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.

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). 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 simply storytelling through the use of various mediums of virtual objects i.e., visual graphics, text, audio or animation and contextual information in a mixed media format.

In this research thesis, I shall explore the demonstrable application of augmented reality (AR) in the three focal areas viz. art, archaeology and architecture.

Augmented Reality (AR) in ARt

■Museum Art: immersive artifact viewing experiences; and

■Street Art: immersive murals on walls, creating an ‘open-air’ museum

►**Museum Art: immersive artifact viewing experiences**

To create an immersive AR experience in art entails that the artist use digital graphics to give static works of visual art dynamism and volume, as well as to synthesize a real image with a virtual one. The viewer aims his gadget at a painting, sculpture, or a specific point in space and sees through the device screen images of art objects and graphic drawings. The screen of a mobile device shows AR graphics and images, and is captured by the built-in camera. Thus, augmented reality and the environment can be synthesized on the same plane, thus creating an immersive experience. A static artwork is transformed into a dynamic, mobile, volumetric art experience as digital virtual images are combined with physical reality. The viewer of such an artwork becomes a part of this story in an augmented, immersive experience.

Augmented reality in cultural and artistic practice has already become a veritable tool for accurate drawing and modeling of space, especially in spatial arts such as architecture and environmental design. Mobile AR apps have been designed that to proportionally and realistically create or synthesize any volumetric image. A case in point is SketchAR, a mobile app which allows the user to see a virtual image in real space. Artists often use this mobile app to create precise sketches of their designs. On the screen of a mobile device, the user sees the necessary virtual object in the right place in real space, puts paper on the screen, and defines the contours of the image with a pencil. This creates a proportionally and realistically accurate layout or sketch.

Mock-ups of famous artifacts, pictures of paintings and photographs can be used to create AR content. The Mona Lisa project uses AR-technology to create dynamic, mobile AR content from the famous static, intact artwork of Leonardo da Vinci. With the mobile AR app, a viewer of the artwork in the Louvre museum in Paris can not only save images of the masterpiece in a mobile device but also can edit it. The user can try on the Mona Lisa's face. The AR marker is the face of the user who, by changing facial expressions, edits the graphic images which depict the face and emotions of the Mona Lisa on the screen of a mobile device.

Figure 2.2 The “Mona Lisa AR” app

►Street Art: immersive murals on walls, creating an ‘open-air’ museum

Street art is one of the main attractions in several cities, transforming points of interest in cities into open-air art galleries. Street art can be presented in such formats as murals, spray paint graffiti, and stickers. These static art forms can be transformed into a mobile, volumetric art through augmented reality (AR) technology. Combined with AR, street art can amplify its impact, bringing its message to a wider audience. This means that passers-by no longer need to guess the meaning of visual street art, but instead, they can stop and watch its plot using their mobile devices. AR street art is used for advertising posters, commercial presentations, and artistic visual installations. The implementation condition must be the presence of a marker – an object for which a graphic model appears. This can be a monument, an image of the façade of a building, a poster, a store, a banner, etc. For example, interesting AR works were created by the American artist, sculptor, and designer KAWS in different cities of the world.

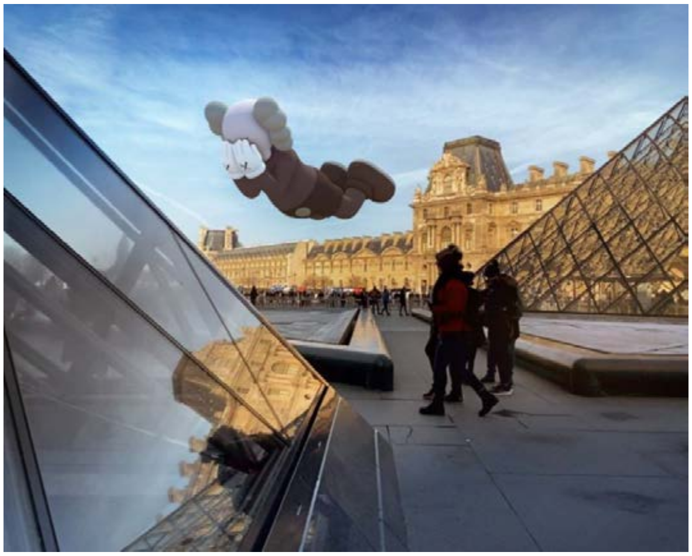


Figure 2.3 KAWS, Companion (Expanded), Paris, 2020

StreetMuseum is a mobile app which uses historic photographic collections of London to allow users wandering around the British capital to point and click with their smartphone at a monument or street scene of their choice to see a view of the same scene from the past (Ellis 2010). StreetMuseum app offers a rear-view mirror in the past, revealing how much has changed all over the years; from Shakespeare to Hitchcock, incredible stories surround the streets of London. The mobile app guides people to nearby historic locations or historic point of interest by a GPS mapping and overlays historical photographs or videos, ranging from 1868 till 2003, onto the live real-world camera view of a mobile device.

Other pioneers of this AR technology in the cultural sector include the Stedelijk Museum in Amsterdam, which used AR both in and outside the building, for example to install digitally created 3D artworks in a local park (Schavemaker et al. 2011).

AR allows heritage institutions to reuse their digitized collections and reposition them on all possible locations in the urban realm on the small personal screens that people carry with them all the time. It also allows organizations to engage in conversation with their audience, as AR links up easily with social media. Through AR, heritage organizations can reach a new audience, usually early technology adopters, and encourage an interest in art that might lead to an actual visit. AR can assist heritage institutions to tell stories about their collections, sites, and exhibitions, enhancing the visitor's experience.

Figure 2.4 StreetMuseum showing the Tea Room at Victoria station in 1950. A boy shining shoes and a group of porters with trolleys waiting for travelers to help with their luggage

Augmented Reality (AR) in Archaeology

■Archaeological Visits: immersive historical and emotional experiences

Immersive historical and emotional experiences through image analysis and annotation.

Archaeological sites are often remnants emerged from excavations, which tend to be included in the urban landscape of the city or even remain hidden in subterranean locations, which are not visible even if they can be visited. Visitors tend not to be satisfied with their visit because they do not find information they would need to understand what they visit and they are unable to imagine how the archaeological remnants they visit are related to the ancient urban landscape. Narrations, which accompany cultural archaeological sites, are at a notional level, generally accurate but not personally involving, and they often imply a lack of interest from the part of more technology-oriented users. Since personalization is a key role in providing relevant information to a multitude of people with different profiles not only experts, technical people, researchers, but the large public in simple, intuitive, immersive and entertaining ways, archaeological visits can become more personal, self-motivated, self-paced, and exploratory; and people will be able to choose what, where, and when to learn. An AR system supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world; thereby aligning real and virtual objects with each other in a real environment. In this research thesis, I propose ElikibaAR, a mobile AR app that uses AR in a cultural heritage setting. ElikibaAR combines historical details with an immersive experience, using Augmenting Reality (AR). The application recognizes a cultural heritage element by image recognition or by positioning and it augments the interface with various layers of information. Users, while framing an object by a smartphone, may interact with various overlaying digital layers. Furthermore, my aim is to learn user's patterns, habits, and preferences while interacting with the application. The goal of this activity is to provide users with tailored information and recommendations through personalization. This is further achieved by adding a story telling to more traditional cultural contents. The same cultural contents may be differentiated to underline different points of view: from quick time tourists to keen scholars. The application interface combines two kinds of elements: static and dynamic.

The static elements, which are always in the front end of the application interface, allow:

- To take a picture.
- To make an information request, in case of an unknown cultural heritage element.
- To activate augmented reality related to a nearby monument. It could be a 3D reconstruction, stock photos or videos.
- To choose the level of details for experiencing the cultural heritage site or monument.

The dynamic elements are made of the overlay of objects on the camera view and are related to the users pose. Each annotated cultural heritage object becomes a point of interest (POI) on an augmented reality map projected on the camera view. By using this map, users could reach the correspondent real cultural heritage object position or make a preliminary exploration of other nearby cultural places. For example, a tourist explores an archaeological area with the application, moving from one annotated cultural heritage element to the other. As soon as an area of interest is reached, the tourist is able to interact with:

(i) general and/or personalized details, storytelling layers, as well as tourist information (visiting hours and tickets fees, etc.) and

(ii) 3D reconstruction, stock photos or videos to augment the perception of the cultural heritage visit.

One of the great challenges in archaeology is hypothesising about and reconstruction of past perception and social behaviour. Some pioneering archaeologists have attempted to explore these issues through the use of Geographic Information Systems (GIS), which enables archaeological simulation, creation and prediction within the computer environment. However, these approaches have almost exclusively been based on vision, and analysis confined to the computer laboratory (Gaffney et al., 1996). At the opposite end of the spectrum, other equally pioneering archaeologists have sought to explore the ancient landscape through the use of phenomenology – conducting their research within the landscape itself (e.g. Hamilton et al., 2006). To these scholars, computer analysis away from the landscape is anathema and totally at variance with their objectives (Thomas, 2008). The importance of embodiment cannot be overstated when thinking about perception of the environment, and this is at the heart of using archaeological phenomenology to explore ancient landscapes. An experience is not limited to what can simply be seen from a point in the landscape, but includes what can be felt, heard, smelt, tasted and touched.

As I will demonstrate, a pertinent application of this is the ability to take a device such as a smartphone to a heritage site, and, by use of the smartphone's in-built GPS and video camera, display reconstructions or information about the site directly over the remains at which one is looking. For instance, one is able to point the smartphone's camera at a stub of real **Benin Wall** and see the virtual reconstruction of that wall at full height. It is then possible to walk around the site in the real world and view that virtual reconstruction from different angles and distances, and even to change the reconstruction to experiment with different colours, designs, heights, and so on. It is also possible to deliver location-dependent sound through attached headphones. The virtual data is held within standard GIS software and so can be manipulated in the normal way, but also viewed and experienced within an embodied environment. The power of an AR reconstruction lies in the full embodied experience which affords a great feeling of presence, unlike a VR reconstruction that does not allow a fully embodied engagement with the past.

Figure 2.5 AR reconstruction of an archaeological wall (Stuart Eve et al. 2012 Augmenting Phenomenology)

The dichotomy between heavily simplified computational analysis in a laboratory (archaeological GIS), which is disconnected from an archaeological landscape itself; and the irreplicable phenomenological analysis (archaeological phenomenology) undertaken within the particular archaeological landscape can somewhat be bridged and resolved using augmented reality (AR) and a number of mixed reality technologies. The result is an embodied GIS, where the data can be explored and experienced in real time and in the real location, with embodied responses to sensory inputs, such as sight, and to a certain extent, sound. The new opportunities offered by using Augmented Reality provide a timely way to combine the strengths of a computer-based approach (reproducibility, experimentation, computer reconstruction) with archaeological phenomenology (embodied experience in the field). The addition of Augmented Reality to phenomenological investigation means we are able to weave new experiences using any kind of virtual object (building reconstructions, vegetation, artwork, stone circles) but embed them firmly (and seamlessly) within the real world, share them with other users in our augmented world and refine them enough to be able to undertake real archaeological research into the past experience of the people that inhabited the archaeological site in question.

Augmented Reality (AR) in Architecture

■Real-time interactive and immersive architectural designs

Architects use a variety of tools to bridge the rift between the imagination of a design and its representation–linking communication and realization. The use of technological advances into the field of architecture has undergone further advances through the use of tools such as building information modeling (BIM), VR (virtual reality), and the use of augmented reality (AR). Each tool places different demands on the designer, and each introduces reinterpretations of the design idea through inherent characteristics and affordances, thus imposing a divergence between the idea and its expression. From an architect's perspective, the connection between the real and the virtual is a natural one, as the development of a design includes thinking in virtual realms about real objects.

The integration of AR in architectural designs has provided engineers with unique possibilities in visualization and simulation; facilitating the creation of designs that are more complex yet precise, with flexibility and scalability. It enhances collaboration among architects, engineers, clients, and construction teams by providing a shared platform for visualizing and interacting with design concepts in real-time. This fosters better communication, alignment of expectations, and collective decision-making, leading to more efficient project execution and higher quality outcomes.

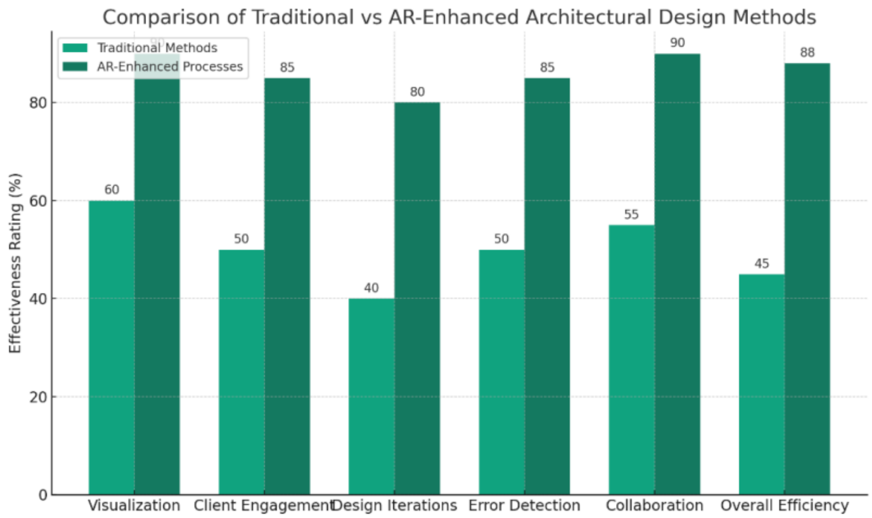


Figure 2.6 Comparison of traditional Vs AR Enhanced Architectural Design methods

The application of augmented reality (AR) in architectural design is mainly concentrated on increasing the visualization process, increasing design correctness, and improving customer input. Architects have the capacity to employ augmented reality (AR) technology in order to display virtual models of structures or structures onto reality. That allows them to present a realistic visual representation of how a design will look inside its intended environment. This capacity allows improved evaluation of elements of design such as proportions, scale, and context. The use of augmented reality (AR) also facilitates real-time alterations to designs, providing a virtual environment for clients and architects to participate in experimenting with various architectural details. Also, augmented reality (AR) plays a vital part in the early detection of prospective design flaws, resulting in enhanced efficiency and precision in layout outputs.

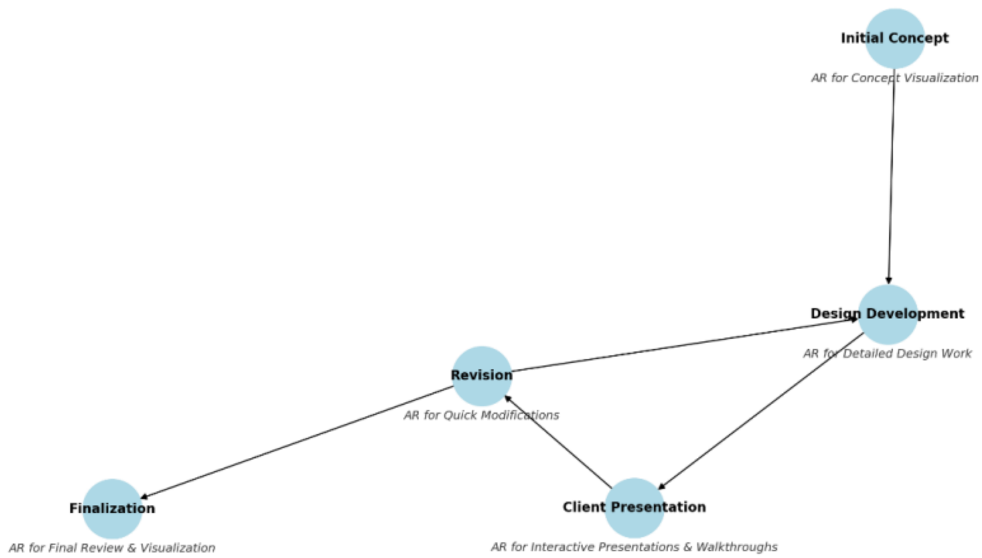


Figure 2.7 Integration of augmented reality (AR) in architecture

The integration of augmented reality (AR) within the field of architecture signifies a significant advancement in the methods by which architects feel, give and implement their design concepts. The concept of spatial awareness refers to the ability of augmented reality (AR) technology to understand and respond to the physical environment within which the user is situated. This process includes the utilization of sensors, cameras, and computer vision algorithms to efficiently define and identify the surrounding environment. The deployment of augmented reality (AR) involves equilibrium of both hardware and software aspects. The main hardware components covered within the current setting consist of cameras and sensors created for the purpose of scanning the surroundings, processors which enable real-time computation, and display devices that include smartphones or virtual reality (VR) glasses, which are used for showing digital overlays. The software component comprises augmented reality (AR) apps that perform the gathering of input data and the resulting creation of virtual overlays. Advanced augmented reality (AR) systems might integrate technology such as machine learning as well as artificial intelligence to boost their recognition and customization capabilities.

Architects can use XR technologies to create immersive design environments, allowing clients, stakeholders, and designers to experience and interact with the proposed design in a realistic and engaging manner, all of which can lead to better-informed decision making and improved design outcomes. With the technique of overlaying digital representations onto physical spaces, AR helps clients to visually perceive the ultimate design within an authentic real-world environment; this creates an immersive, interactive connection to the project beyond the usefulness of conventional computer-aided design (CAD) 2D drawings or basic 3D models displayed on a screen.

AR enables real-time design visualization: designers can successfully modify architectural components, such as wall colors, materials, finishes, and furniture setups, as clients engage with the virtual environment. The adoption of this interactive procedure permits the collective evaluation of diverse design alternatives, hence encouraging a more flexible, agile and adaptable progression of design. The rapid inclusion of client feedback allows for an effective implementation of their preferences and requirements, resulting in a reduction of time and expense associated with further modifications.

The utilization of Augmented Reality (AR) significantly impacts the improved level of communication within the design process, especially when used in a collaborative environment. Communicating effectively is of greatest significance in architectural and design projects, as it enables cooperation and comprehension among such multiple stakeholders as architects, engineers, designers of interiors, and clients.

The adoption of real-time sharing of augmented reality (AR) models allows effective communication and collaboration among all involved stakeholders, independently of their geographical locations, thus minimizing associated time and geographic constraints or expenses. Going forward, integrating augmented reality (AR) into project management applications can facilitate a more optimized, efficient, and effective method for managing intricate design tasks.

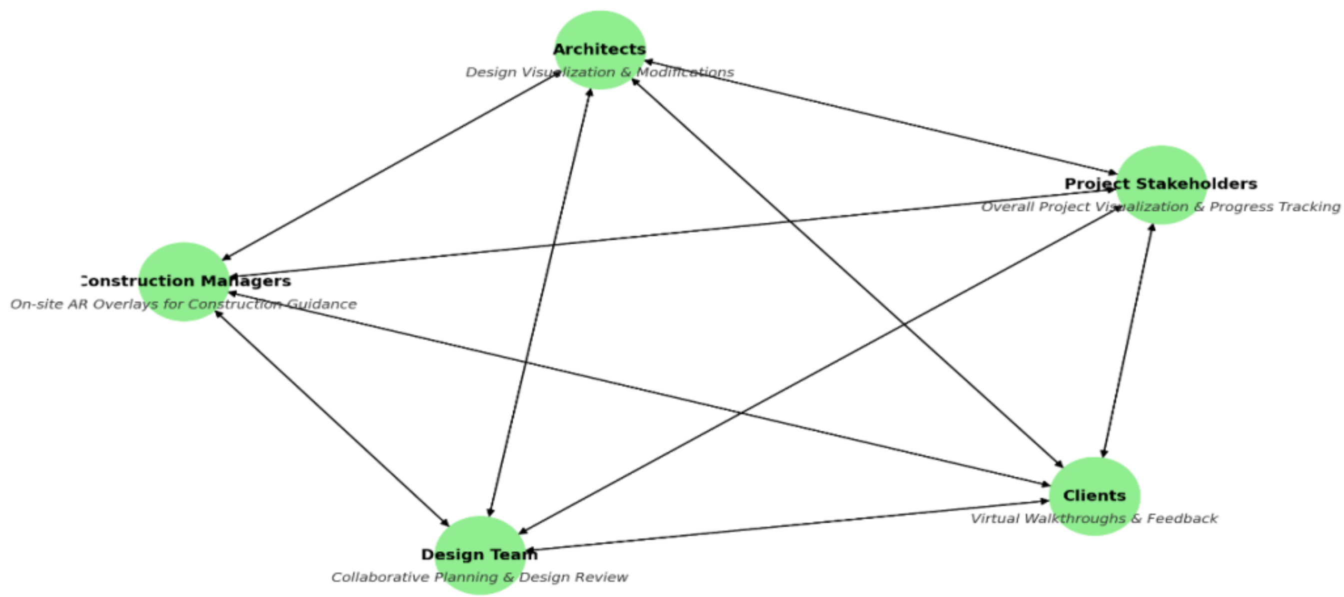


Figure 2.8 User Interaction with AR in Architecture

CHAPTER THREE

RESEARCH METHODOLOGY, DESIGN AND DESCRIPTION

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. 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).

This comparative case study (CSS) is conducted on the following three mobile AR apps designed for engaging with museum artifacts: the ReBlink app, StreetMuseum app, and Project CHESS app (Cultural Heritage Experiences through Socio-personal and Storytelling). 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.

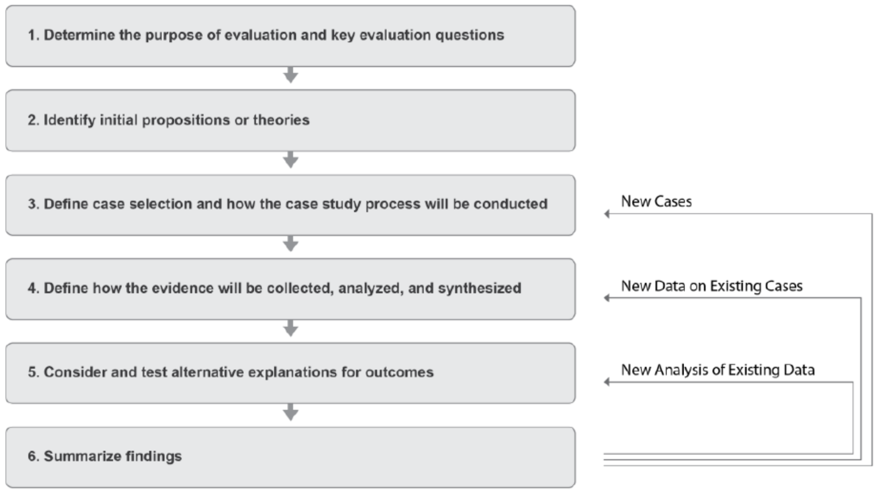


Figure 3.0 This flowchart shows the research entry points and the methodological process of the research project. This chart is adapted from the Logic of Comparative Case Studies model by Goodrick Delwyn (2014).

For this research project, the human-centered-design (HCD) will be used throughout the design and development of the mobile AR app; as a usability evaluation method to assess the behaviour of users engaged in AR for artifact-viewing and viewing of murals on walls.

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".

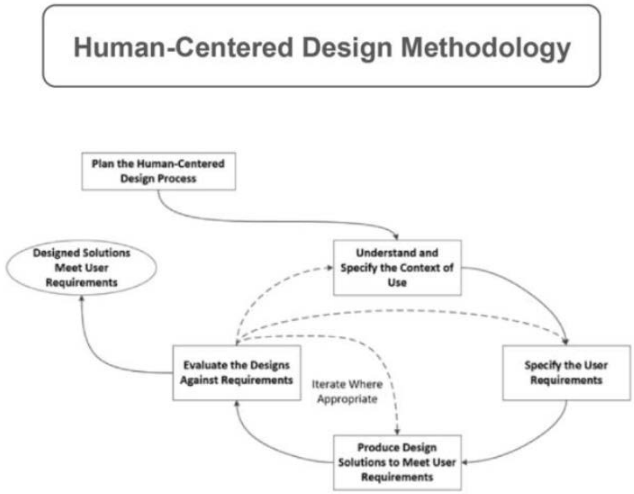


Figure 3.1 The Human-Centered Design Methodology.

Figure 3.2   The Human-Centered Design Process.

The figures show the development process undertaken throughout the research project; adapted from the HCD model by Richard P. Harte (2017).

(i) 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. Using augmented reality, ReBlink re-interprets and presents a new narrative of older classical paintings in the Art Gallery of Ontario's permanent collection. In this application, the subjects of the paintings are seen acting as if they were alive in today's days, such as holding selfie sticks, using smartphones or even listening to music through their headphones. To complete the scenario, the landscapes surrounding them are also reinterpreted to modern days. For example, one of the paintings that is part of this AGO 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. The outcome of having the augmented reality intervention in this art exhibition at the Art Gallery of Ontario (AGO) was extremely positive, attracting a vast number of people, especially young visitors. As the number of visits was increasing remarkably, the museum had to change the exhibition dates which in the beginning were from the 6th of July to the 3rd of December 2017, extending it to April 2018 (Panciroli et al., 2018).

Figure 3.3 ReBlink app AR overlay of the portraiture painting called The Marchesa Casati at the AGO exhibition

(ii) StreetMuseum App Case Study

StreetMuseum is an iOS app developed for the Museum of London by the U.K. independent advertising agency Brothers and Sisters. With this mobile app, users have the opportunity to explore London with the twist of being able to see how certain places looked like in the past. This application came to life when the museum was searching for a digital idea to attract people into the opening of their new Modern Galleries and since they had an incredible amount of content, they decided to share those collections in the streets.

StreetMuseum guides people to certain locations either by a map or GPS and, once reached the destination, it will recognize and overlay onto the device's camera view buildings and certain spaces with historical photographs or videos, ranging from 1868 to 2003. From Shakespeare to

Hitchcock, incredible stories surround the streets of London and this application is a window to the past, revealing how much has changed all over the years. Even though Streetmuseum is only compatible with iPhone and iPad, the museum was aiming at a range of 5000 downloads and, not only this number so far reached 500 000, the visitors to the museum tripled.

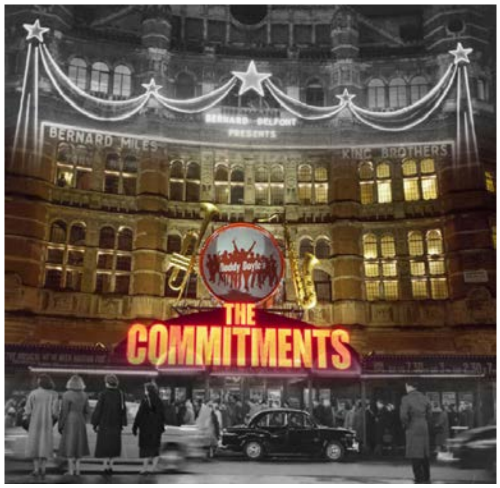


Figure 3.4 StreetMuseum showing the outside of the Palace Theatre at night before an evening's performance (Zolfagharifard 2014)

(iii) Project CHESS Case Study

Project CHESS (Cultural Heritage Experiences through Socio-personal and Storytelling) is an initiative to integrate digital narratives to enrich museum visits through personalized storytelling. This is possible using information about cultural artifacts to create customized stories that guide visitors through their smartphones with games and augmented reality, thus activating the user's sense of discovery throughout the experience.

The CHESS developers team consists of scriptwriters, curators and museum staff, creating the storytelling process by following four steps:

1) Scripting - the author carefully chooses the main attractions and story concepts, followed by the plot sketching and writing the narrative.

2) Staging - the author selects a set of spots and paths in the museum environment and associates them with the written script.

3) Production - audiovisual materials, games, quizzes and augmented reality applications are produced for the script.

4) Editing - the multimedia set is selected and the montage for the script written.

This experience begins as soon as the visitor steps into the museum environment. The user logs in into the CHESS application through his/her device, filling out a short questionnaire that collects his/her preferences and creates a user's profile with personal data and interests.

To personalize an experience for each user, CHESS uses a persona system that matches visitors to personae by aligning their preferences to the author's understanding of the museum types of visits. This correspondence will consequently create a customized visit, building an individual path according to the person's interests in the fictional story parts. Based on the data inserted on the application, the visit is turned into a discovery game, where the museum artifacts are presented through mixed reality, combining real objects with 3D digital elements (Vayanou, M., Katifori, et al.,2014). Additionally, CHESS profiles can adapt to the user's positive or negative feedback, making adjustments and reshaping the script of the path whenever these actions are detected:

• skipping - which is interpreted as a very negative response to the activity, as the user is not interested in the storytelling;

• completion - meaning low positive feedback. The user completed the storyline but there was no further interest in knowing more details;

• selecting menu options - meaning high positive feedback, where the user is interested in knowing more;

• no menu selections - meaning low negative feedback.

Figure 3.5 Project CHESS augmenting artifacts at the Acropole Museum of Athens, Greece

Summary of Comparative Study

This comparative case study investigated how mobile AR apps can improve access and enhance public engagement with cultural artifacts. It 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 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 User Interface (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. 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. The findings from this comparative case study are used as design guidelines for the research project, ElikibaAR as a prototype mobile AR app.

In this research project, a mobile AR app shall be designed for immersive artifact viewing experiences in a museum, and immersive viewing of murals on walls, creating an ‘open-air’ museum using ViroReact: an excellent, open-source library that unifies the most modern underlying AR technologies: ARKit (for iOS) and ARCore (for Android). It is optimized for displaying rich 3D content in a React Native environment and excels at the required Image Tracking (marker-based AR). It enables a single codebase for high-performance iOS and Android applications, significantly reducing development time and cost. ViroReact is similar to ARtoolKit, which is also an open-source tracking library for AR. This technology uses video tracking abilities that trace square marker patterns by a single-camera position and orientation. ARToolKit primarily uses marker-based tracking to overlay virtual content onto the real world. When the camera position is known, 3D models are overlaid on the marker (Amin & Govilkar, 2015).This involves detecting and tracking physical markers with specific patterns, allowing the system to determine the camera's position and orientation relative to those markers. ARToolKit also supports natural feature tracking, which can track features in the environment without needing pre-defined markers.

Historical Context and the Life Cycle of Foundational AR SDKs

The genesis of augmented reality as a programmable medium began in 1999 with the work of Hirokazu Kato at the Nara Institute of Science and Technology. Released via the University of Washington HIT Lab, ARToolKit provided the first open-source computer tracking library capable of overlaying virtual imagery on the physical world in real-time. This initial era was defined by the technical necessity of high-contrast visual markers—simple black squares with unique interior patterns that the software could identify to establish a coordinate system.

The subsequent incorporation of ARToolWorks in 2001 served to professionalize the library, leading to its first mobile appearances on Symbian in 2005 and eventually the iPhone 3G in 2008. The trajectory of ARToolKit took a dramatic turn in May 2015 when it was acquired by the industrial AR firm DAQRI. In a move intended to consolidate the developer community, DAQRI re-released the toolkit as a fully open-source project starting with version 5.2, making features like natural feature tracking (NFT) available without the previous commercial licensing fees. However, the institutional instability of DAQRI eventually led to the project's stagnation. To preserve the legacy of the software, former ARToolWorks executives Ben Vaughan and Phil Lamb established artoolkitX, a modernized variant currently supported by Ethar Inc. and Realmax. Despite these efforts to revitalize the codebase with support for modern APIs like Metal and Vulkan, the underlying paradigm remained rooted in native C++ development, which presented a steep barrier to entry for the burgeoning wave of mobile application developers.

ViroReact emerged as a disruptive alternative by targeting the specific needs of the mobile application ecosystem. Originally developed by Viro Media, the platform was designed to allow developers to build native cross-platform AR and VR experiences using the React Native framework. When Viro Media open-sourced the project in late 2019 under the MIT License, it provided a bridge between high-level web-like development and high-performance native rendering. The library's survival and continued relevance were secured through the formation of the Viro Community in 2020 and its subsequent acquisition by Morrow (ReactVision) in 2025, which committed full-time development resources to ensuring compatibility with contemporary versions of React Native and Expo. This historical transition highlights a shift from academic computer vision research toward a developer-centric model that prioritizes iteration speed and integration ease.

Computer Vision (CV) is the foundational technology that enables Augmented Reality (AR). While AR is the end-user experience of overlaying digital content on the physical world; computer vision acts as its “eyes” and “brain” to process and understand the environment in real time, it provides the data and spatial awareness required for AR systems to blend digital information seamlessly with the physical world.

Computer Vision (CV) is used in AR for several critical functions:

- Object Recognition: Identifying real-world objects (i.e., a specific product, landmark, or a person’s face) to trigger and correctly place digital overlays
- Tracking: Continuously monitoring the position and orientation of the user’s device. This ensures that virtual objects remain “anchored” in place even as the user moves.
- SLAM (Simultaneous Localization and Mapping): A vital CV technique that builds a 3D map of an unknown environment while simultaneously tracking the device’s location within it.
- Depth Estimation and Occlusion: Determining the distance of objects to allow “occlusion,” where an object can be hidden behind a real-world object (like a wall or a person)

- Gesture Recognition: Interpreting hand movements and gestures so users can interact with virtual elements without physical controllers
- Pose Estimation: Determines the device’s position and angle, ensuring virtual content is rendered from the correct perspective
- Environmental Understanding: Detecting flat surfaces like floors and tables so virtual objects can be placed realistically on them

Table 3.0 Life Cycle of Foundational AR SDKs

Milestone Year	ARToolKit / artoolkitX Evolution	ViroReact / ReactVision Development
1999	Initial release by Hirokazu Kato at HIT Lab	-
2001	ARToolworks founded; open-source v1.0 released	-
2005	First mobile implementation on Symbian OS	-
2008	iOS support launched for iPhone 3G	-
2015	DAQRI acquisition and open-source re-release	-
2017	-	Viro Media launches ARCore/ARKit support 10
2019	artoolkitX established to sustain the legacy	Viro Media open-sources ViroReact
2020	Ethar Inc. begins supporting artoolkitX	Viro Community formed for maintenance
2025	Version 1.1.22 maintains native C++ parity	Morrow acquires ReactVision/ViroReact

Features of ARToolKit are discussed as follows.

(i) Marker-based tracking:

ARToolKit excels at recognizing and tracking square markers with unique patterns. It calculates the marker's 3D position and orientation relative to the camera, enabling accurate virtual object placement.

(ii) Natural feature tracking:

ARToolKit can also track natural features in the environment, such as corners or distinctive patterns, without needing specific markers. This expands its applicability to a wider range of scenarios.

(iii) Video and optical see-through AR:

ARToolKit supports both video see-through (where virtual content is overlaid on a video feed) and optical see-through (where virtual content is overlaid directly on the real world through a specialized display).

(iv) Pose estimation:

A core function of ARToolKit is pose estimation, which determines the camera's position (translation) and orientation (rotation) in relation to the tracked object or feature.

(v) Real-time tracking:

ARToolKit is designed for real-time tracking, ensuring smooth and responsive AR experiences.

Rationale for ARToolKit Replacement

I concur that ARToolKit is deprecated and not suitable for a modern mobile application in 2025. Moving to a solution like ViroReact ensures:

1. Superior Performance & Accuracy: Leveraging Apple's ARKit and Google's ARCore for faster, more reliable image tracking.
2. Cross-Platform Consistency: Maintaining a single AR implementation across both iOS and Android.
3. Future-Proofing: Utilizing actively maintained libraries with features that support richer content (e.g., complex 3D scenes and animations).

The Technological Succession in Mobile Augmented Reality: A Comprehensive Analysis of ARToolKit Displacement by the ViroReact Framework

The transition from the foundational computer vision libraries of the late twentieth century to the high-level, declarative spatial computing frameworks of the modern era represents one of the most significant architectural shifts in mobile software engineering. For nearly two decades, the name ARToolKit was synonymous with the very possibility of augmented reality on consumer hardware. However, the emergence of ViroReact, particularly its evolution from a venture-backed proprietary engine to a community-governed open-source standard, has fundamentally altered the development landscape. This shift is not merely a matter of developer preference but is rooted in a fundamental divergence in tracking methodologies, rendering capabilities, and the practicalities of cross-platform maintenance in an ecosystem increasingly dominated by platform-specific hardware optimizations. To understand why ViroReact has effectively replaced ARToolKit in the professional mobile development sphere, one must examine the historical limitations of marker-based tracking, the rise of Simultaneous Localization and Mapping (SLAM), and the efficiency gains afforded by the React Native declarative paradigm.

Architectural Divergence: Native C++ vs. The React Native Paradigm

The displacement of ARToolKit by ViroReact is fundamentally an architectural choice. ARToolKit is a low-level library written in C and C++, which offers maximum performance at the cost of extreme complexity. Integrating ARToolKit into a modern mobile application requires significant expertise in native build systems, memory management, and the bridging of C++ code to Java (Android) or Objective-C/Swift (iOS). This complexity is exacerbated by the diverse range of functions the library offers, which can make initial integration a daunting challenge for teams without dedicated computer vision engineers. ViroReact, by contrast, utilizes a hybrid architecture that separates the concerns of the 3D rendering engine from the application logic. The core of ViroReact is a high-performance native 3D rendering engine that runs on a native thread, utilizing the device's graphical hardware directly. This engine is controlled via a custom extension of React, allowing developers to describe 3D scenes using declarative JSX components. This separation ensures that the application remains responsive; the "heavy lifting" of coordinate calculation and pixel drawing occurs on the native side, while the developer works in a familiar, high-level JavaScript or TypeScript environment.

The Mechanics of the Viro Renderer and Scene Graph

The ViroReact renderer functions as a full-featured 3D scene graph engine. In the React paradigm, the user interface (UI) is a function of the state, and ViroReact extends this to 3D space. When the state of an application changes, ViroReact identifies the necessary updates to the 3D scene and applies them efficiently, mirroring the way React’s Virtual DOM optimizes web rendering. This is a massive departure from the imperative rendering loops required by ARToolKit.

Key rendering components in the ViroReact ecosystem include:

● ViroARScene: The top-most container for all AR content, which initializes the AR session and manages tracking state updates.

● ViroARSceneNavigator: A component that manages a stack of scenes, allowing for complex navigation within an AR application, such as moving from an intro screen to a 3D immersive experience.

● Viro3DObject: A component that handles the loading and display of 3D assets in formats like.obj, .fbx, and .gltf.

● Native Thread Execution: By running the rendering engine on a separate thread from the JavaScript bridge, ViroReact achieves lag-free performance even when the main application thread is under load. This architectural choice has practical implications for developer velocity.

While ARToolKit requires a complete recompile and redeployment cycle to see changes, ViroReact supports rapid iteration through the Viro Testbed App. The Testbed acts like a browser for AR; developers can simply "reload" their code on a physical device to see updates in real-time, drastically reducing the feedback loop during the design and development phases.

Tracking Methodologies: From Fiducial Markers to World Mapping

The primary technological hurdle in any AR application is tracking—the ability of the software to determine the device's position and orientation relative to the environment. The history of ARToolKit is essentially the history of marker-based tracking, while ViroReact represents the democratization of SLAM-based markerless AR.

The Limitations of ARToolKit's Marker-Based System

ARToolKit's original success was built on its ability to detect "black square" markers. This method is computationally inexpensive because the system only needs to find a known, high-contrast pattern in a 2D image. Once found, the system can derive a 6D camera pose (position and orientation) relative to the marker center. However, this approach has significant real-world drawbacks:

1. Physical Constraints: The environment must be prepared with physical markers, which is impossible for most consumer applications.

2. Occlusion Sensitivity: If the marker is partially covered or the camera angle is too sharp, the tracking fails instantly.

3. Inaccuracy in Dynamic Conditions: Rapid changes in lighting or camera movement can cause the virtual object to "jitter" or disappear, as the system relies entirely on the visual presence of the marker in every frame. To combat this, ARToolKit introduced Natural Feature Tracking (NFT), which allows the system to recognize and track textured planar images like magazine covers or posters. While more flexible than square markers, NFT still requires a predefined target and involves a complex calibration and marker generation process that can be difficult for non-specialists to manage.

The Superiority of ViroReact's SLAM Integration

ViroReact leverages the underlying power of Apple's ARKit and Google's ARCore. These SDKs use Simultaneous Localization and Mapping (SLAM) and Visual-Inertial Odometry (VIO).

VIO combines the visual data from the camera with the high-speed data from the device's accelerometer and gyroscope. This hybrid approach allows ViroReact to offer several advantages over ARToolKit:

● Markerless Flexibility: Objects can be placed on any flat surface (horizontal or vertical) detected in the environment without any physical markers.

● Persistent Anchoring: Because the system maps the entire room, virtual objects stay anchored in their real-world positions even if the user looks away and then back at the original location.

● Environmental Intelligence: ViroReact can utilize features like plane detection, motion tracking, and environmental lighting estimation to make virtual objects appear as if they are truly part of the scene. While ARToolKit provides "cheap" tracking in terms of computational cost, ViroReact provides "reliable" tracking that meets the expectations of modern mobile users. The integration of ARKit and ARCore means that ViroReact developers automatically benefit from platform-specific hardware optimizations, such as LiDAR support on newer iPhones, which provides even greater precision in depth sensing and world mapping.

Table 3.1 Comparison between ARToolKit and ViroReact

Tracking Feature	ARToolKit (Traditional)	ViroReact (via ARKit/ARCore)
Method	Fiducial Markers / NFT	SLAM / Visual-Inertial Odometry
Environmental Prep	Requires physical markers	No preparation required
Orientation Data	Optical only (6D pose)	Sensor-fused (IMU + Camera)
Plane Detection	Limited/Manual	Automatic (Horizontal/Vertical)
Precision	Millimeter-accurate at close range	High stability across large spaces
Occlusion	Tracking lost if marker obscured	Persistent tracking via world mapping

Advanced Rendering: Physically Based Rendering (PBR) and Photorealism

A critical differentiator for ViroReact is its native support for physically-based rendering (PBR), a collection of techniques that produce significantly more realistic lighting and material effects than traditional shading models. In legacy libraries like ARToolKit, the burden of achieving photorealism fell entirely on the developer, who often had to write custom OpenGL shaders or integrate a heavy-weight game engine like Unity to handle lighting. ViroReact, however, includes these capabilities directly in its native engine. The PBR Workflow in ViroReact PBR seeks to replicate the physical behavior of light as it interacts with real-world surfaces, such as reflection, absorption, and scattering. ViroReact materials are defined by properties that correspond to physical characteristics:

● Albedo (Base Color): The raw color of the surface without any lighting information.

● Metalness: Defines how metallic a surface is, which drastically changes how it reflects light. Pure metals reflect light with the color of the material, while non-metals (dielectrics) reflect light with a white highlight.

● Roughness: Controls the diffusion of reflected light. A smooth surface (low roughness) produces sharp, mirror-like highlights, while a rough surface (high roughness) produces broad, blurry highlights.

● Ambient Occlusion: Simulates the soft shadows that occur in cracks and corners where ambient light is blocked.

By using these parameters, ViroReact allows virtual objects to react naturally to the environment. When paired with High Dynamic Range (HDR) lighting and Image-Based Lighting (IBL), virtual objects can inherit the lighting characteristics of a real-world HDR environment map, creating a sense of "belonging" in the scene that ARToolKit simply cannot match out-of-the-box. HDR Rendering and Post-Processing ViroReact's rendering pipeline is designed for high-fidelity output. When HDR is enabled, the engine renders to a deeper color space using floating-point textures.This allows for advanced effects:

● Bloom: Simulates the way bright lights appear to "bleed" or glow to the human eye.

● Tone Mapping: A crucial algorithm that compresses the wide range of HDR colors back into a range that the mobile device screen can display while preserving fine detail in both highlights and shadows.

● Real-time Shadows: ViroReact supports dynamic shadow casting, allowing virtual objects to cast believable shadows onto real-world surfaces detected by ARKit or ARCore.

These rendering features are part of a unified, declarative API. A developer can enable PBR and HDR on a scene with a simple boolean prop, making advanced graphics accessible to mobile developers who may not have a background in 3D engine development.

The Physics of Interaction: ViroReact's Integrated Engine

One of the most "excellent" aspects of ViroReact is its full-featured physics engine, which allows developers to add real-world mechanics to their AR and VR objects. While ARToolKit focuses almost exclusively on tracking, leaving object interaction to be handled by external plugins, ViroReact integrates physics directly into the scene graph. Physics Body Types and Interactions Almost every 3D control in Viro can be physics-enabled via the physicsBody property. This property allows developers to define how an object should react to forces, gravity, and collisions:

● Static Bodies: These are objects with zero mass that do not move, such as floors or ground planes. They act as barriers for other objects.

● Kinematic Bodies: These have zero mass but are moved through code or animations. They do not react to forces but can "push" other objects, making them ideal for user-controlled avatars or animated barriers.

● Dynamic Bodies: These have mass and react to gravity, friction, and collisions with other objects. They move realistically based on impulses and continuous forces.

Collision Detection and Ray Casting

ViroReact simplifies the complex math of spatial collision. Developers can use the on-collision callback to trigger logic when two objects intersect, providing data on the collision point and normal. Furthermore, the engine supports asynchronous hit testing through findCollisionsWithRayAsync and findCollisionsWithShapeAsync, allowing developers to "query" the environment—for example, to see if a user's crosshair is pointing at a specific virtual object or a detected real-world plane. This high-level integration of physics allows for the rapid development of interactive experiences like AR bowling or industrial training simulations that would be significantly harder to implement in ARToolKit.

Developer Experience: The Efficiency of React and Expo

The shift from ARToolKit to ViroReact is also a shift in the developer's daily workflow. ARToolKit is widely recognized as having a "steep learning curve".

Developers must deal with low-level C++ challenges, complex manual camera calibration, and the lack of standard UI components.

(i) Declarative UI vs. Imperative Code

ViroReact uses React Native, which brings web-like development speed to mobile AR. The declarative nature of React allows developers to focus on the "what" rather than the "how".

- Declarative Markup: Instead of writing hundreds of lines of code to manage camera matrices and object states, a developer writes a few lines of JSX: .
- State Management: Using standard React hooks or Redux, developers can easily synchronize the 2D UI (buttons, sliders, text) with the 3D AR world.
- Cross-Platform Single Codebase: ViroReact abstracts the differences between ARKit and ARCore. A single codebase can run on both iOS and Android, with the framework handling the

necessary platform-specific calls under the hood. Integration with Expo and the Modern Web Stack ViroReact's integration with Expo has further democratized AR development. Expo is a popular toolset for React Native that simplifies the setup and deployment process. The Viro Community has released starter kits that allow developers to launch an AR app in minutes using Expo and TypeScript. This eliminates the need for complex Android Studio or Xcode configurations during the initial development phases, which is a significant advantage over the native-only environment of ARToolKit.

(ii) Integration with Expo and the Modern Web Stack

ViroReact's integration with Expo has further democratized AR development. Expo is a popular toolset for React Native that simplifies the setup and deployment process. The Viro Community has released starter kits that allow developers to launch an AR app in minutes using Expo and TypeScript. This eliminates the need for complex Android Studio or Xcode configurations during the initial development phases, which is a significant advantage over the native-only environment of ARToolKit.

Table 3.2 Development Metrics Comparison between ARToolKit and ViroReact

Development Metric	ARToolKit / artoolkitX	ViroReact / ViroCommunity
Primary Language	C, C++, C# (Unity)	JavaScript, TypeScript
Learning Curve	Steep / Expert-oriented	Accessible to mobile/web devs
UI Integration	Difficult / Manual	Native (React Native View system)
Iteration Speed	Slow (Recompile/Deploy)	Rapid (Live Reload / Testbed)
State Management	Custom / Imperative	React Hooks, Redux, Context
3D Asset Formats	.obj,.osg	.obj,.fbx,.gltf,.glb

Technical Synthesis: Why ViroReact is the "More Excellent" Choice The "excellence" of ViroReact over ARToolKit is a result of the convergence of several technical triumphs:

1. Abstraction Layering: ViroReact does not attempt to reinvent the wheel of computer vision. Instead, it unifies the world-class tracking of ARKit and ARCore under a single API, allowing developers to benefit from billion-dollar R&D efforts from Apple and Google.

2. Native Threading Performance: By running its 3D renderer on a native thread while keeping the application logic in JavaScript, ViroReact achieves the performance of a native C++ engine with the developer ease of a web framework.

3. Physical Correctness: The native integration of PBR, HDR, and a full physics engine means that "realistic" behavior is the default, not an after-thought. Developers do not need to be physics or optics experts to create convincing AR scenes.

4. Toolchain Integration: The Viro Testbed and its integration with Expo and TypeScript make it the only professional-grade AR framework that truly supports rapid, iterative development in a mobile context.

The transition from ARToolKit to ViroReact mirrors the broader transition in software development from manual, imperative management of hardware resources to high-level, declarative management of user experiences. ARToolKit was a pioneer that made AR possible, but its architecture—built for a world of square markers and low-power CPUs—was not suited for the era of spatial computing and high-fidelity mobile graphics. ViroReact has replaced ARToolKit because it is built for the modern developer. It understands that in a professional environment, "excellence" is defined by the balance of performance, stability, and developer velocity. By leveraging the native power of mobile platforms while providing an accessible, robust, and community-governed interface, ViroReact has established itself as the superior open-source library for the future of mobile augmented reality.

The ultimate reason ViroReact replaced ARToolKit in professional circles is the health of its ecosystem. ARToolKit has suffered from a fragmented history of acquisitions and abandonment. While artoolkitX is a noble attempt to sustain the library, the community engagement has fluctuated significantly since DAQRI's exit.

The Rebirth of ViroReact under Morrow

Viro Media's decision to open-source the platform was the first step toward long-term sustainability. However, the 2025 acquisition by Morrow (ReactVision) was the turning point. Morrow, a company specializing in React Native and Expo development, recognized AR as the "visual interface for the next era of devices". By committing full-time development resources and integrating ViroReact with their other open-source tools, they have provided a level of stability and roadmap clarity that ARToolKit has lacked for years.

This corporate backing ensures that ViroReact remains updated with:

● **Operating System Updates:** Ensuring compatibility with the latest versions of iOS and Android.

● **React Native Evolution:** Keeping pace with architectural changes like TurboModules and the New Architecture in React Native.

● **Emerging Features:** Adding support for Geospatial APIs, Cloud Anchors, and Scene Semantics, which are essential for the next generation of "spatial computing" apps.

Mathematical Foundations of Displacement

In ARToolKit, the extrinsic matrix M is derived purely from visual feature correspondence of a marker:

$$M = K^{-1} \cdot H$$

where

K is the camera calibration matrix and

H is the homography between the marker plane and the image plane.

This is susceptible to 2.10 mm translation errors and 1.56degree rotation errors under non-ideal conditions.

In ViroReact (via ARKit/ARCore), the pose P is determined by a Kalman filter (or similar sensor fusion) that integrates visual data V with IMU data I:

$$P_t = f(P_{t-1}, V_t, I_t)$$

This fusion significantly reduces drift and allows for tracking even when the camera's visual field is momentarily obstructed, providing the "rock-solid" stability required for professional mobile applications.

CHAPTER FOUR

IMPLEMENTATION OF RESEARCH PROJECT: ELIKIBAAR

Scope and Target Audience

The scope of this research paper is to design and implement ElikibaAR, a prototype mobile AR app for augmented reality (AR) with demonstrable application in art: immersive artifact viewing experiences in a museum (i.e., museum art), and immersive murals on walls, creating an 'open-air' museum (i.e., street art). Its home page is https://elikibaar.elikiba.com. It is presented as a proof of concept to be further developed and explored with future developmental objectives which include app functionality for augmented reality (AR) experiences in archaeology and architecture.

The target audience for ElikibaAR mobile AR app are users between the age of 15 to 45 from diverse ethnic backgrounds interested in learning about cultural heritage and want more immersive, interactive, and participatory activities from museums and street art.

Core Functionality

The ElikibaAR platform is designed as a bridge between traditional artwork and modern immersive technology. It provides a dual-interface system catering to both creators (artists) and enthusiasts (viewers).

● Secure Authentication: A robust authentication system powered by Supabase, ensuring data privacy and personalized user profiles.

● Dynamic Gallery: A curated marketplace of artworks where users can explore, search, and filter pieces.

● Creator Dashboard: A specialized environment for artists to upload 3D models (GLB, OBJ/MTL), add descriptive metadata, and manage their submissions.

● AR Augmented Interaction: The core engine allows users to "place" digital replicas of artworks into their physical environment, maintaining scale and lighting coherence.

● Real-time Synchronization: Use of SWR ensures that updates to submissions or favorites are reflected instantly across the application.

System Architecture

The application employs a modern, decoupled architecture designed for scalability and high performance on mobile hardware. Its technical stack include:

● Framework: React Native with Expo (SDK 54).

● Routing: Expo Router for type-safe, file-based navigation.

● Styling: NativeWind (Tailwind CSS) for consistent, aesthetic UI components across platforms.

● Backend (BaaS): Supabase providing PostgreSQL database, Auth, and Storage for large 3D assets.

● AR Engine: ViroReact for low-level integration with ARKit (iOS) and ARCore (Android).

Data Flow Architecture

The flow of a 3D asset from the creator to the viewer's AR environment is managed through a streamlined pipeline:

1. Ingestion: 3D assets are uploaded via the Dashboard to Supabase Storage.

2. Metadata Management: PostgreSQL stores the relations between users, artworks, and their cloud URIs.

3. Client Fetching: SWR hooks in the React Native layer handle efficient data fetching, caching, and state synchronization.

4. Immersive Rendering: The Viro AR engine consumes these remote URIs to instantiate 3D nodes in the physical coordinate space detected by the device.

User Testing and Methodology

User testing was conducted in focused sessions to evaluate the platform's stability, intuitive design, and immersive capabilities.

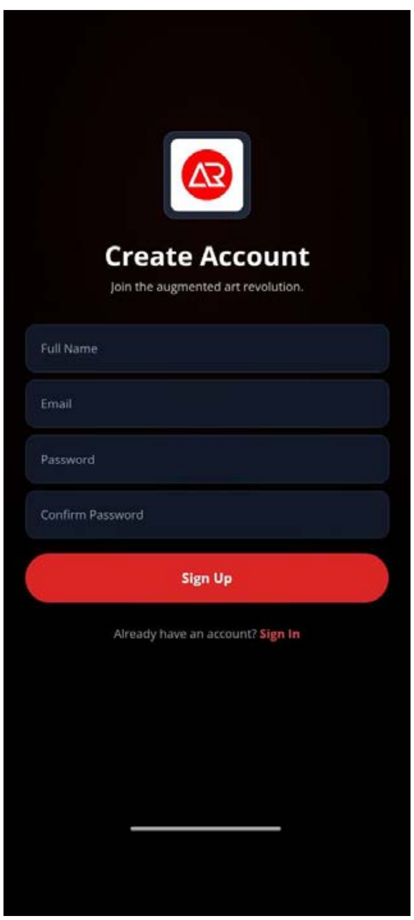
Authentication & Onboarding

The security and personalization of the app depend on a seamless onboarding process.

● Signup: Users provide their email and a secure password. The system interfaces with Supabase Auth to create a unique record.

● Login: Authenticated access allows users to save favorites and access the creator dashboard.

● Validation: Testing focused on error handling (e.g., incorrect credentials) and session persistence.



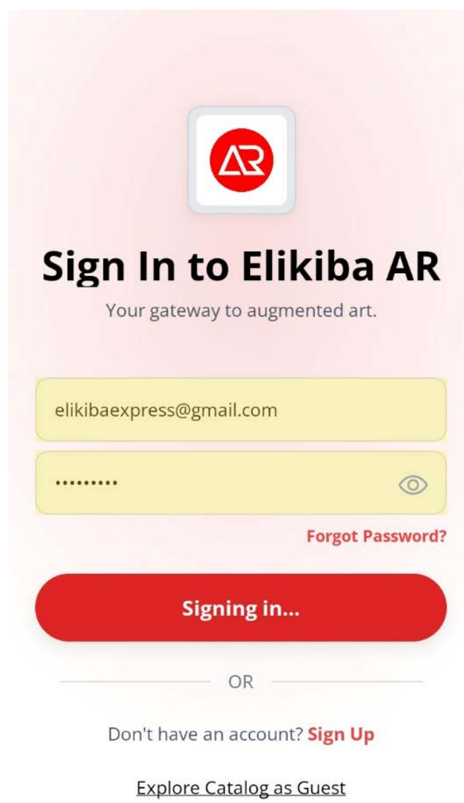


Figure 4.0: Authentication workflow screens including Login, Signup, and User Profile views.

Immersive AR Scanning & Image Tracking

The "Scanner" utilizes Image Tracking technology to create a 1-to-1 link between a physical "Trigger" and a digital "Overlay."

● The Trigger: A high-contrast 2D image (e.g., a photo of a painting).

● The Overlay: A corresponding 3D model (GLB or OBJ).

● Detection Methodology: The app fetches approved image_url targets from Supabase; the AR engine creates a reference map; upon detection, the 3D model is rendered at the focal point.

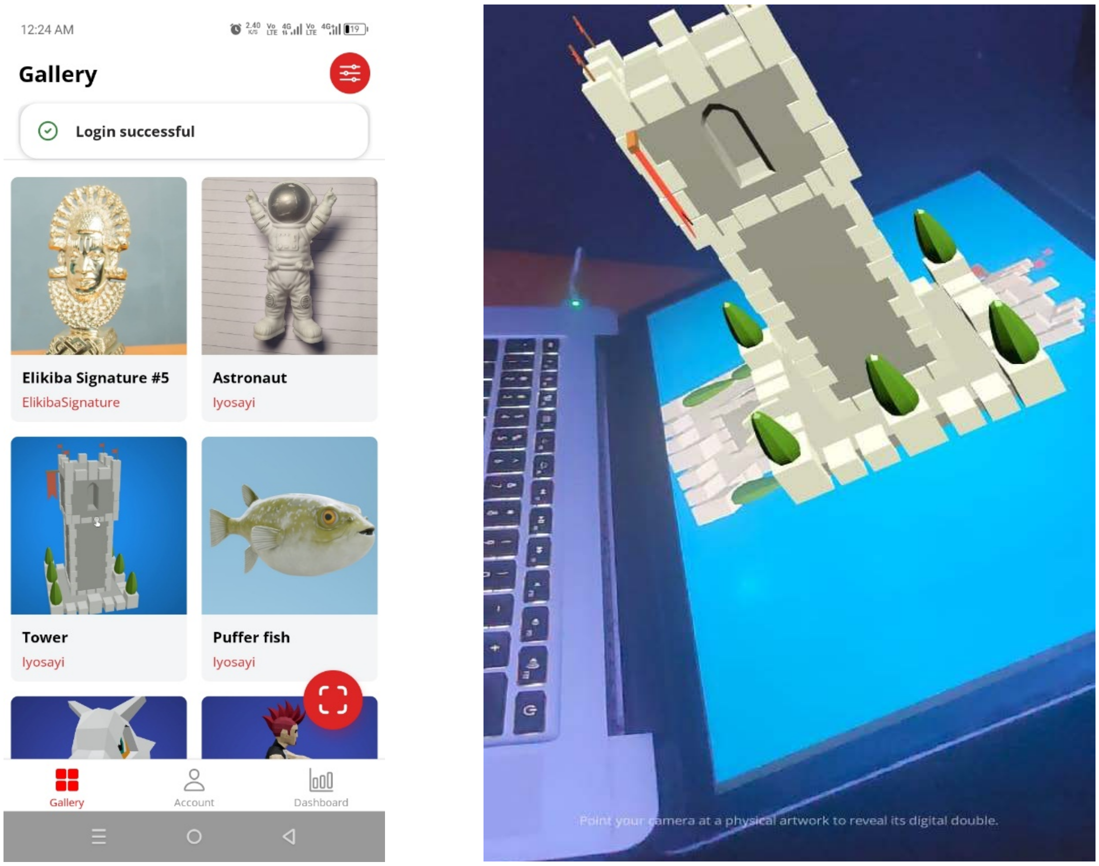


Figure 4.1: AR Scanner Interface showing detection markers and active camera tracking.

Gallery Interaction & 3D Preview

Viewers can explore the digital collection before committing to an AR session.

● Browsing: Users scroll through a paginated list of artworks optimized with FlatList.

● Selection: Tapping an artwork opens the "Detail View," showing metadata (artist, year, description).

● 3D Preview: Users can activate a sandbox environment to rotate and scale the object using standard touch gestures.

Content Creation & Submission

● Entry: Creators access the "Dashboard" and select "Add New Artwork."

● Preparation: Triggers must have high contrast (brushstrokes, text) for optimal computer vision recognition.

● File Selection: Use of expo-document-picker to select 3D files and textures.

● Linking Logic: Submission creates a unique ID that pairs the 2D trigger photo to the 3D model in the database.

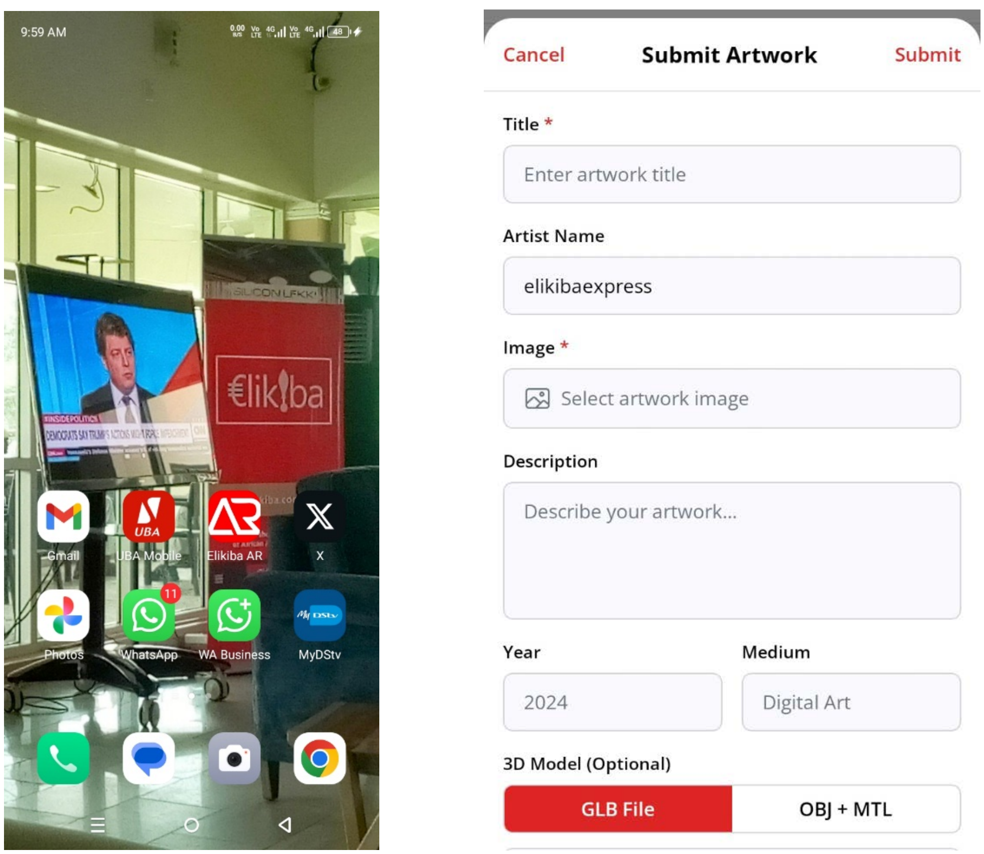


Figure 4.2: Creator Dashboard showing the Artwork Submission Form and asset management tools.

CHAPTER FIVE

RESULT, LIMITATION, CONCLUSION

RESULT

The project successfully delivered a production-ready mobile application known as ElikibaAR, that fulfills the initial research objectives.

Figure 5.0 ElikibaAR Mobile App Logo

Metric	Result
Positioning Accuracy	1-2cm deviation in optimal lighting
Render Latency	40% reduction in load time (cached)
Asset Compatibility	GLB, OBJ, MTL supported

Table 5.0 Metrics of Project App Implementation Results

LIMITATIONS

- Hardware Constraints: Optimal performance requires devices with dedicated AR sensors (LiDAR/Depth). Older devices may experience anchor "drift."
- Network Dependency: High-bandwidth 3D models (OBJ+MTL) require a stable internet connection for initial download.
- Occlusion: Advanced person/object occlusion is limited; digital assets may render over physical foreground objects incorrectly

CONCLUSION

ElikibaAR represents a significant step forward in democratizing art through mobile technology. By providing creators with a simple path from 3D model to AR visualization, ElikibaAR mobile AR platform has lowered the barrier to entry for immersive digital art.

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