The University of Hong Kong

Department of Computer Science

2023-2024
Interim Report

Sharing the Past with the Public: Augmented Reality User Experiences at Archaeological Sites

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Date of Submission: January 16, 2024

Abstract

With the advent of digital and virtual technologies in recent decades, there has been an emergence of archaeological projects integrating augmented reality. However, most current augmented reality to archaeology applications focuses on marker-based augmented reality in museums. Our team presents an application for iOS and Android phones or tablets that uses augmented reality (AR) as an alternative and portable way of viewing archaeological information from the Ararat Plain Southeast Archaeological Project led by Dr Cobb from the University of Hong Kong. This application will provide a unique experience of AR navigation through an archaeological site in Vedi, Armenia, and of exploring the artefacts unearthed. Using a map service API and ViroReact API, this application locates the ancient sites and artefacts by world coordination and projects a three-dimensional model of them onto the physical environment, AR such that the users can interact with them, including but not limited to triggering a popup information window that contains the details such as name and material description by touching a virtual point; viewing the surface details of models by physically moving the mobile device around or towards the target. This paper discusses the techniques applied and the current progress in the development. Soon, location-based AR with map services will be developed and tested. It is hoped that this application can act like a time machine, enabling the public to appreciate and interact with ancient sites and cultural artefacts anytime.

Acknowledgements

We would like to express our sincere gratitude to our supervisor, Dr. Choi Yi King for the guidance and suggestions throughout the project. Without her continuous guidance, dedicated involvement and support throughout the process, this project could not progress smoothly.

My team would also like to thank Dr. Cobb, Peter J. and his team for sharing necessary resources and archaeological expertise regarding their fieldwork in Armenia for this project.

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Abbreviations

API	Application Programming Interface
APSAP	Ararat Plain Southeast Archaeological Project
AR	Augmented Reality
GPS	Global Positional System
QTY	Quantity
SDK	Software Development Kit
TBD	To be determined
UI	User Interface
UX	User Experience

1 Introduction

This section provides the background and rationale, offers an overview and significance of our work toward the findings in Vedi, Armenia and sets out the goals of the project.

1.1 Background: Archaeology and Augmented Reality

Archaeology takes advantage of the use of augmented reality and 3D reconstructions, especially to present to the public a comprehensive and comprehensible view of the sites and artefacts suitable for different cultural levels. Augmented reality offers everyone a key to interpret the past or even a multi-sensory journey through time.

With the rise of digital and virtual technologies, various application opportunities from a cross-media perspective have been created [1]. By utilizing AR, a virtual ancient environment and culture could be simulated and integrated into physical surroundings seamlessly. Unlike other applications of augmented reality to archaeology, such as AVICOM et al. [2], which applies augmented reality to museums, our approach aims to not only show the outdoor archaeological site with the added information of where the artefacts were found but also guide the users to destinations.

1.2 Background: Vedi Fortress in Armenia

During the summer of 2019, a team of researchers and students led by Dr. Peter Cobb excavated ancient human material cultures in Vedi, Armenia, since they carried out the Ararat Plain Southeast Archaeological Project (APSAP) [3]. Vedi is located at the southeast edge of the Ararat Plain. For centuries, this region has been a meeting point for Turkey, Iran (formerly Persia), and Russia. It has always played a significant role in transportation, particularly on the historical Silk Road. Today, Armenia is one of the nations participating in the Belt and Road initiative [3].

Enormous, ruined fortification walls up to four meters high, with a central rectangular defensive tower, are preserved at the Vedi Fortress archaeological site [3]. The APSAP team is currently working on reconstructing these walls. However, physical reconstruction is an incremental process in which each excavation can only unearth a thin ground layer, as a result, it is difficult to present the whole buildings or artefacts. This is where augmented reality takes advantage – viewing the ancient site in its full glory and even its transition by utilizing technology. To achieve this goal, this project aims to implement AR in the form of a mobile application.

1.3 Project Objectives

This project aims to develop a cross-platform mobile application that can:

i. Promote and enhance public understanding and appreciation of cultural heritage in Armenia through public education and engagement, including tourism.
ii. Facilitate public education in archaeology and cultural heritage.
iii. Reconstruct and visualize heritages in Vedi Fortress digitally.
iv. Encourage the public to explore the Vedi Fortress by tracking down various inspiring virtual cultural heritages and artefacts.
v. Promote sustainable tourism development in the Armenian Araxes River Valley.

The project is being completed in two phases:

Phase 1: Research and development.
Phase 2: Integration of real data sets to the application, performance tuning and debugging.

1.4 Project Contributions

It is hoped that the final deliverable will be able to create an immersive experience for tourists, schoolchildren, and other members of the public to witness the transition from the late Bronze Age to the Iron Age and the Medieval period in Vedi.

1.5 Outline of the Report

This report proceeds as follows. Section 2 describes the methodology involved in this project. Development tools and techniques that are applied will be discussed. Section 3 demonstrates the interim outcomes or tasks achieved in the project, including the current situation and problems encountered, followed by the plan and project schedule. Section 4 summarizes this report by providing a conclusion that restates the objectives, highlights outcomes and presents the progress of this project.

2 Methodology

This section focuses on the techniques and development tools used during app creation, discusses the reasons for using these tools by analyzing their advantages or comparing their players in the same industry and states the equipment and materials that need aid from the APSAP team.

2.1 Knowledge and Techniques Involved

2.1.1 Markless Augmented Reality

Early AR technologies were based on markers, an interactive experience activated by a specific image or graphic signal. This process is known as image tracking and recognition and the technique is called marker-based AR [4]. Markless AR, on the other hand, does not rely on physical markers like a QR code or image and offers a more immersive experience through real-time scanning of the world environment and simulation of AR objects [4]. In this project, two types of markless augmented reality were applied – projection-based AR and location-based AR.

2.1.1.1 Projection-based AR

Projection-based AR relies on the projectors to display digital content onto a flat two-dimensional surface, such as a wall, floor or paper. It requires *plan detection* which finds horizontal or vertical flat surfaces in the physical surroundings by accessing and using the device's camera for detection [5]. After plan detection, a mesh is projected on the planes and the three-dimensional AR object is placed on the virtual point on the mesh touched by the users. This procedure is called *object placement.* To increase the realism of the digital content, *light estimation* can be involved to detect real-world lighting by the camera in the devices. The object can then be lit by directional light in the environment. It is noted that the light detections are dependent on the device's hardware, meaning not all the devices are available with this function. The program should be able to track and recognize hand gestures because most interactive functions such as object scaling, collection and placement rely on hand gestures such as pinching with two fingers and touching by pointing the index finger.

2.1.1.2 Location-based AR

Location-based AR uses geographical data retrieved by GPS in mobile devices [4]. The program then detects and tracks the user's environment and delivers virtual content at specific locations given the data. Location-based AR relies on real-time GPS tracking to collect geographical data, or geolocation, for users, while data for digital objects is stored in a database. Geolocation consists of latitude, longitude and altitude. In real-time syncing, the user's location also contains a compass direction with magnetic and true headings. The algorithm takes latitude, longitude and the true heading as inputs.

The procedure can be divided into two phases: Mercator projection which converts the spherical Earth with latitude and longitude into cylinder coordinates, and the compass heading matching. The Mercator projection algorithm follows, where the project coordinate system uses a right-hand arrangement as it does in ViroReact in which the x-axis is lateral sway, the y-axis is vertical heave (gravitational up), and the z-axis is longitudinal surge [6]. Let rad denote the formula of converting degree to radian as seen in (1), R be the constant radius of Earth in meters, x be the latitude and y be the longitude. Equations (2) and (3) show the Mercator projection of latitude and longitude respectively. Let (x_1, z_1) and (x_2, z_2) be the user's coordinate and the AR object's coordinate in the xz plane in which their coordinates are computed by equations (2) and (3). By subtracting the two projected coordinates in the form of a vector, the coordinate system is adjusted to be user-centred, that is transforming the global coordinates into local coordinates (AR space).

$$rad(\theta) = \frac{\theta}{180} \times \pi \tag{1}$$

$$f(x) = rad(x) \cdot R \tag{2}$$

$$f(y) = \log\left(\frac{sin\big(rad(y)\big) + 1}{cos(rad(y))}\right) \cdot R \tag{3}$$

2.1.2 Map Services

This project attempts to conduct tests outdoors and develop an app that will guide tourists around archaeological sites. To achieve this objective, the above-mentioned location-based AR was used. Geographical data required by location-based AR greatly relies on the sensors and camera in devices, and hence the operation devices should have spatial awareness, such as GPS or the ability to scan their surroundings. Data is collected from these sensors and is processed by map service API for retrieving the user's current position and calculating the distance between users and targets [7].

2.2 System Architecture Design

Figure 2.1 illustrates the components and flow of communication between components in the program. This application collects data from device sensors including GPS and camera and user inputs such as text inputs and hand gestures (Fig.2.1A). The data is then sent to the mobile application interface (Fig.2.1B) for different types of services, involving storage service (Fig.2.1C), map service (Fig.2.1D) and AR service (Fig.2.1E).

This application serves local and cloud storage. When launching the application, users related data, including their personal information, bookmarks, and collected findings during exploration, is fetched from the cloud storage. A copy is then saved in local storage for the use of authentication and offline. Other information such as the findings studied by the APSAP team and exploration routes are fetched but not saved locally when the users enter corresponding pages. This design ensures the application does not consume excessive storage space; however, it requires a constant network connection to function properly.

Since the app is used outdoors, a cellular network is used for communication with the cloud-hosted server and map services (Google Maps in Android and Apple Maps in iOS). A device must be online to obtain map and route data.

Location Tracking API and Compass Heading Tracking API are used, which are involved in AR object placement, navigation and matching of AR space and real space. Map Anchor Customization API and Geofencing API are implemented in 2D map viewing.

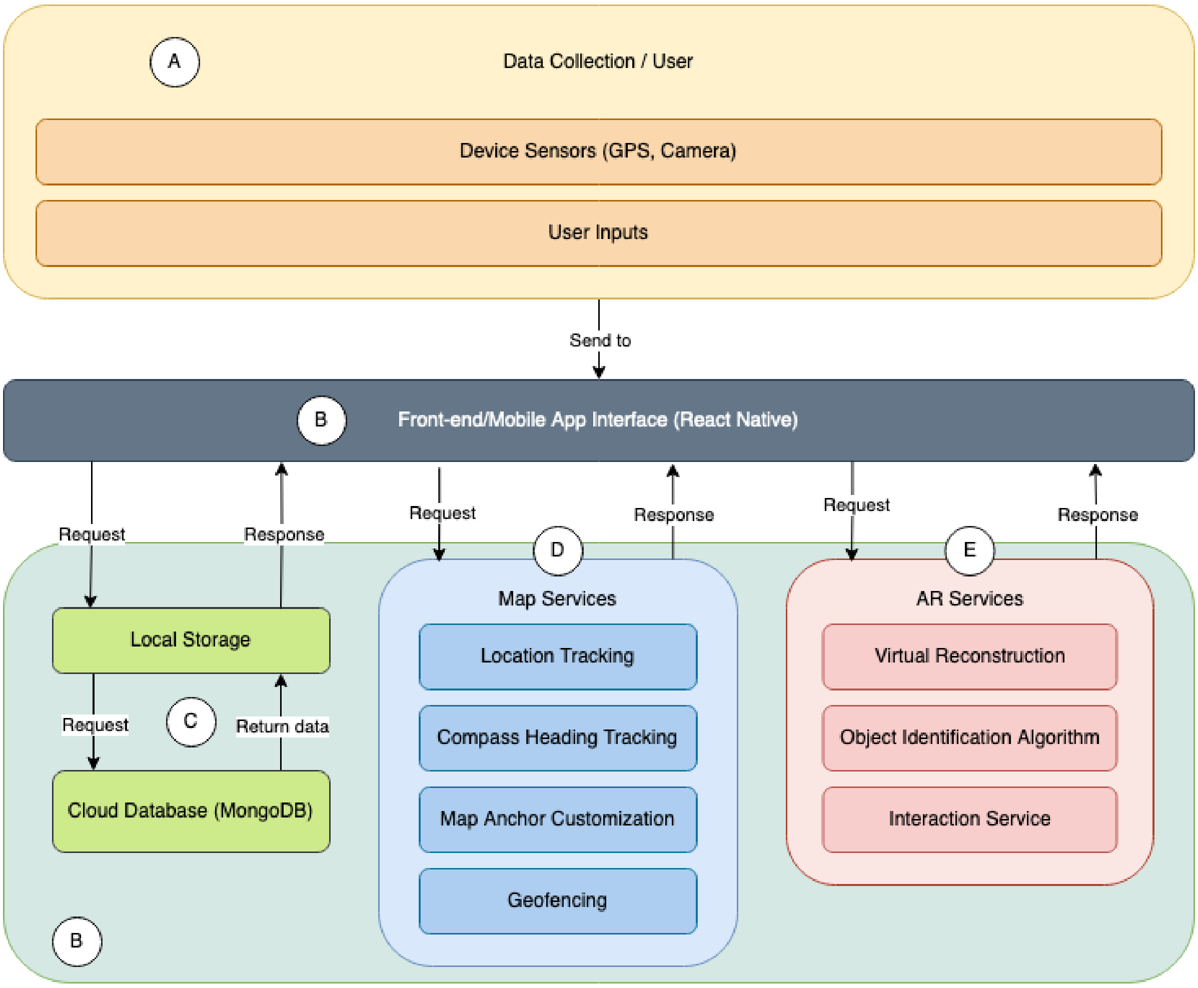

Fig. 2.1 The system architecture diagram. (A) Data collection, (B) Client-end. (C) Data storage. (D) Map services. (E) AR services

2.2.1 Front-end and Mobile Framework

To ensure consistency in design and streamline the development process, React Native as a cross-platform tool has been used for mobile development environments, including Android and iOS. To simplify the connection between iOS and Android SDKs, Expo, a bundle of tools and services specifically designed for React Native, was also utilized [8]. This approach creates one application without additional setups in different development environments, ultimately saving development time and allowing us to reach a broader audience. Expo also allows app release without deployment, which helps in delivering testing prototypes to the internal team members, hence facilitating communication. In addition, React Native has a significant advantage in outcompeting other frameworks or native codes (e.g., iOS using Swift and Android using Kotlin) -- it is well-supported by Three.js for displaying 3D models and ViroReact for rapidly building AR experience. ViroReact is crucial to AR development because it avoids the need for separate AR development in Apple's ARKit and Google's ARCore [9], which ultimately speeds up the development process.

2.2.2 Database Management System and Backend

Considering the enormous data including but not limited to 3D models, 2D images and pieces of literature on archaeological items being stored in a database, MongoDB, a NoSQL database, was used rather than Firebase. According to the nature of this application, it heavily depends on querying a database, instead of data calculation and analysis. Real-time calculations, such as the geolocation of object placement made by the user and the distance between the user and targets during the navigation, will not be stored in the database, as a result, customized API endpoints should not be difficult, and the backend is lightweight.

This project should prioritize data storage. MongoDB outweighs Firebase for its high performance in manipulating massive data [11 - 13]. In addition, MongoDB as a NoSQL database offers data in JSON format that helps in faster data interchange and web service results. When it comes to storing and retrieving 2D images and 3D models, MongoDB offers GridFS. This system enables the storage and retrieval of large documents in BSON format, which is a binary representation of JSON [10]. This format is lightweight and traversable and can handle additional data types such as Decimal128 for converting images and models.

2.3 Equipment and Material Setup

This part outlines the necessary project materials, which require professional and accurate information on archaeological aspects. Therefore, the APSAP team was suggested to be responsible for these materials.

As seen in Tables 2.1 and 2.2, the first main difference in material preparation between the development and implementation stages, which is highlighted in blue colour, is the world coordinates of cultural heritages and historical buildings. Limitations in terms of capital, time and geography make it difficult for the development team to go to Vedi and conduct experiments on the accuracy of geolocation of AR objects there. Therefore, in the early stage of the development, this project attempts to conduct outdoor tests locally, and hence position with latitude, longitude and altitude is not required.

The second difference highlighted in green colour is the required quality of cultural heritage. There will be numerous findings studied by the APSAP team that will be displayed on this application. Before all data is implemented on the app, only several of them are put into the application to keep the minimum fetching time of data during the development stage.

Table 2.1-- Equipment and Material Required in the Development Stage

Items	Sub-items	QTY.
Cultural heritage	Textual description	≥ 3
	3D models	
Historic buildings	Textual description	≥1
	3D models	
NPCs	Characteristics, background, features, role, etc.	≥1
	Voice acting	
Story	Game script: Text parsing and menu-driven NPC conversations	1
	Storyline and background	
	Player's missions	
User test cases		TBD

Table 2.2--Equipment and Material Required in the Implementation Stage

Items	Sub-items	QTY.
Cultural heritage	Textual description	≥ 10
	3D models	
	Latitude, longitude, and altitude	
Historic buildings	Textual description	≥1
	3D models	
	Latitude, longitude, and altitude	
NPCs	Characteristics, background, features, role, etc	≥1
	Voice acting	
Story	Game script: Text parsing and menu-driven NPC conversations	1
	Storyline and background	
	Player's missions	

3 Results and Discussion

This section focuses on the current situation of the project (Section 3.1) and the problems encountered (Section 3.2), future planning (Section 3.3) and project schedules (Section 3.4).

3.1 Current Status

This project has two phases – research and development, and implementation. To date, the project has gone through the planning, analysis, and design stages included in the research, and has stepped into the development stage. Agile practice that breaks development work into small increments and iterations was adopted. Each iteration that lasts from two weeks involves planning what features will be implemented, coding, unit testing and/or acceptance testing. At the end of an iteration, working software is demonstrated to the internal parties involving the supervisor and the APSAP team members.

The application consists of two main pages: the Home page (Fig.3.1) and the Explore page (Fig.3.2). On the Home page (Fig. 3.1a), users can access various artefact categories through category search. A search bar is conveniently placed at the top of the scene, allowing users to search for specific artefacts using keywords. Users can now access additional information about each artefact on its dedicated Detail page (Fig. 3.1b). An audio narration is also available on this page, providing guidance and information along the route. All artefacts that have a 3D model can be projected onto nearby surfaces using the AR capabilities of ViroReact. Users can access different routes through the Explore page, which is displayed on a 2D map. The map service used depends on the user's mobile operating system - Android devices use Google Maps, while iOS devices use Apple Maps. In addition, users can view additional details, such as pictures along the route, by tapping on the list icon shown at the bottom right corner in Fig.3.2a. After a route is selected by the user, the system accesses GPS to track the user's geolocation. The user's current location and the nearest destination coordinate on the route are then computed as a navigation path, which is presented as a green semi-transparent path shown in Fig.3.2b. The navigation path is displayed below the user and points to a sparkle indicating the location anchor, as shown in Fig. 3.2b.

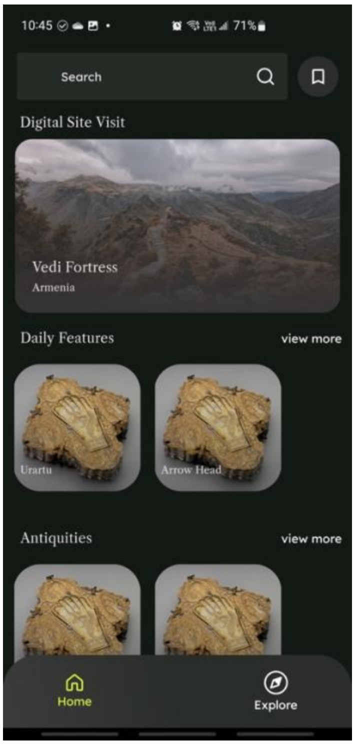

Fig. 3.1(a) Home page

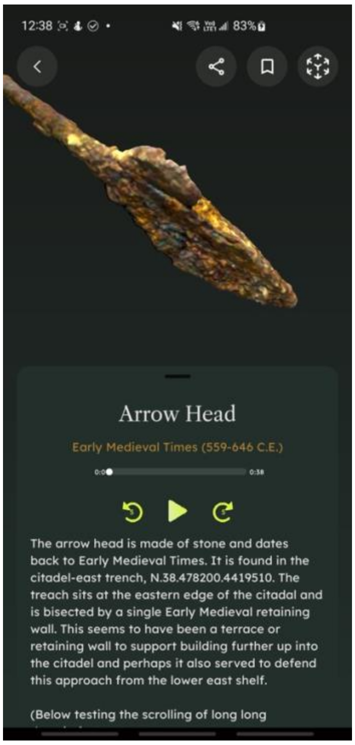

Fig. 3.1(b) Detail page

Fig. 3.1 Home page and detail page

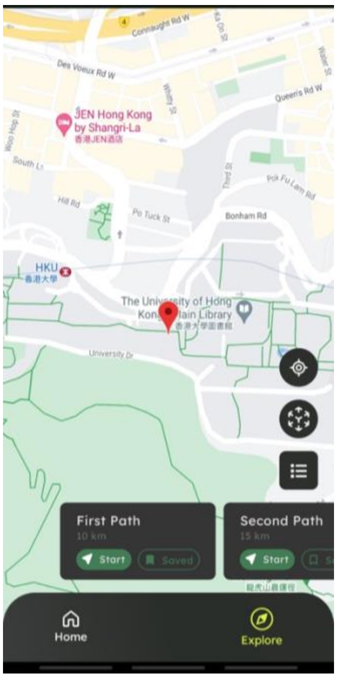

Fig. 3.2(a) 2D map Page

Fig. 3.2(b) AR Explore Page with navigation path (green route) and location anchor (sparkle)

Fig. 3.2 Two-dimensional map page and AR exploration page

Currently, the location-based AR exploration is almost completed. Parts of it are waiting to be reviewed by the APSAP team. The completed tasks in Phase 1 are listed below:

Sep 9: The APSAP team member shares their ideas. Proposed a proposal and redesigned the UI based on their thoughts.

Sep 28: React Native setup completed. UI except for AR exploration completed. 3D model demonstration and interaction using Three.js began.

Oct 2: MongoDB setup completed. Success in retrieving and querying information from MongoDB.

Oct 4: Met with Dr Peter Cobb. Reviewed the app according to his suggestions, finalized the UI design and removed Microsoft HoloLens 2 from the development environment.

Oct 17: Bookmark of articles and 3D models demonstration and interaction completed. Projection-based AR using ViroReact completed.

Nov 12: Map services of Android and iOS setup completed. Registered iOS development certification and profile for the test flights of the application.

Dec 23: AR exploration setup completed. Began algorithm of converting geolocation into local coordinates in AR space.

Jan 5: AR navigation setup completed. Began the accuracy adjustment of mapping the real world and AR space.

3.2 Difficulties

To date, there are several problems encountered, but some of them are expected. Most of them are related to the restrictions of development tools and devices.

3.2.1 Inconsistent Mobile GPS Accuracy

Mobile GPS accuracy has been assessed during development, mainly in open spaces at HKU. The results indicated that in each initialization of AR exploration, the initial user's geolocation returned slightly inconsistent longitude and latitude, even though the tester remained stationary and at the same place. Consequently, this inconsistency affects the accuracy of the AR navigation guide and the rendered position of AR artefacts. This could potentially result in placing artefacts in areas that are inaccessible to users. A threshold for accuracy value returned in the map service is set up to address this issue. It is to filter improper geographical data so that overall accuracy and usability of AR placement and navigation are maintained.

3.2.2 Device Incompatibility

Two different approaches are used for using GPS and compass data on iOS and Android devices due to their distinct hardware. During testing, it was discovered that the AR space provided by ViroReact does not always start facing true North, which means that the orientation of AR objects depends on the device's compass. To ensure a consistent heading experience across both platforms, a method is being sought to align the compass readings.

It has been challenging to achieve accurate alignment between the real-world compass and AR space's heading value due to the possibly unclear and unreliable compass heading value returned by ViroReact. A solution is actively being found to ensure a seamless and synchronized AR experience for users on both iOS and Android devices.

3.2.3 UX Design Revamp

After the second round of testing, Dr Peter Cobb provided feedback that revealed additional requirements and expectations for the application going beyond its current capabilities. Dr Cobb expressed his interest in incorporating nearby attractions and possibly helping with hotel bookings, neither of which are currently available in the application nor were they originally included in the design.

After receiving this feedback, it has become necessary to revamp the user experience design, including the user interface, to meet these new requirements. It is crucial to communicate with the APSAP team to redefine the project's scope, specify the required inputs, identify the target users, and outline the necessary outputs that can be feasibly produced.

3.3 Future Plan

The immediate priority is to complete the location-based AR development given it is the central focus of this project. Finalizing the UX design revamp is the next important task at the same time. The identified issues mentioned above are to be resolved simultaneously.

3.4 Schedule and Milestones

Table 3.1 shows the project schedule. The team has completed setting up the mobile development framework and database, digital demonstration and interaction of cultural heritage, retrieving and querying data from the database, and marker-less AR. Currently, the team is improving accuracy in matching real space and AR.

Table 3. 1--Project Schedule

Date	Activities/Milestones	Status
Sep 2023	Meet with the project supervisors	Completed
	Set up a project proposal	Completed
	Draft UI designs	Completed
	Project web page	Completed
Oct	Finalized system architecture design	Completed
	Finalize UI designs	Completed
	Set up database schema	Completed
	Complete basic front-end	Completed
Nov	Prepare static assets including audio and 3D models	Completed
	Implementation of location-based AR	Completed
Dec	Complete basic app features	Completed
Jan 2024	First-stage deliverables and presentation	Completed
	Interim report	In Progress
Feb	Complete all app features	In Progress
	Revamp UX and UI designs	In Progress
	Complete revamped front-end	Pending
Mar	Final User Acceptance Testing	Pending
	Debug and Fine-tune of app	Pending
Apr	Finalized project web page	Pending
	Final report	Pending
	Final presentation	Pending

4 Conclusion

Various cross-media application opportunities have emerged with the advent of digital and virtual technologies. By utilizing AR, the ancient sites can be viewed in their full glory and transition, seamlessly integrated into the physical surroundings. The focus of this project is to develop a cross-platform mobile application that offers a comprehensive experience by not only presenting the outdoor archaeological site with detailed information on the location of the artefacts but also guiding the users to those spots. Through this application, the user can better understand and appreciate the cultural heritages in Armenia with an immersive experience.

This paper provided an overview of this project and discussed the techniques applied and the current progress in the development. Since this project is a collaboration project with the APSAP team led by Dr Peter Cobb from the Faculty of Arts at the University of Hong Kong, the focus can be directed to the development of the mobile application, while massive and significant data gathered from the ancient site is provided by Dr Peter Cobb and his team. The data includes information about the history of the site, the artefacts found and their respective locations, and the cultural significance of the site. We have been working closely with Dr Cobb's team to ensure that data is accurate and up to date.

Up to now, although this project has encountered several difficulties and limitations, it can proceed as scheduled. There are still some areas of improvement to be implemented in the future, but the immediate step is to complete the UI and set up the map services. Meanwhile, the team will explore more development tools and algorithms to achieve better performance.

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