

HAWKAR-T: ENHANCING THE UNIVERSITY TOUR EXPERIENCE WITH  
AUGMENTED REALITY

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## ABSTRACT

HawkAR-T: Enhancing the University Tour Experience with Augmented Reality.  
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Augmented reality technology is increasingly being used in tour applications to enhance the travel experience for tourists. These applications have been deployed for systems used in museums, navigation, and university campus tours. Making an augmented reality application available to university campus visitors can provide a beneficial tool to attract and recruit new students. Over the past two decades augmented reality applications have been deployed for use at World Heritage sites, museums, and hiking trails, and commonly use either location-based or marker-based methods to present users with descriptive information of points of interest. Hawk AR-T is a cross-platform application to improve the current virtual campus tour, provided by the University of North Carolina at Wilmington, and provide an immersive and memorable experience using augmented reality while delivering information on the university's culture, programs offered, and amenities to its users. This proposed system uses a modified model-view-controller design pattern, developed in the Unity gaming engine, and implements both location-based and marker-based methods for content delivery. Upon completion of development, 36 participants used two applications and provided feedback on their experience. Results of the user testing were used for the comparison of the current virtual tour and the proposed system. User testing resulted in a markable difference between the two applications, with more consistent scores for Hawk AR-T among the participants. Based on this evidence, Hawk AR-T is considered as an appropriate replacement for the current virtual tour.

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## CHAPTER 1: INTRODUCTION

Augmented reality (AR) and virtual reality (VR) has crept into the daily lives of individuals who use technology over the last few decades. Chances are smartphone owners have an AR application at their disposal, either through an app store or already installed on the device. Information applications like SkyView Lite, an application that identifies orbiting objects, constellations, and planets, or entertainment applications like PokémonGo are some examples of what a smartphone owner might use. With the Coronavirus (COVID-19) pandemic disrupting lives in 2019, the demand for access to applications using AR and VR increased. The need for society to pivot and use new tools was evident with the shutdowns that affected activities like working in an office or taking a vacation. The purchase of these technologies increased by 50% in 2020 compared to 2019 (Vardomatski, 2021), and because of this demand, new frameworks were introduced to better develop and meet these needs.

This is not to say that AR is applicable to solving all the problems associated with the aftermath of COVID-19 as the world continues to return to some semblance of normal. Like Fred Brooks' (1987) message of "no silver bullet" regarding software development, it is necessary to understand that AR is a potential solution for a subset of these problems and ensure it is a suitable fit based on the use cases it looks to address. For example, AR has provided an exceptional solution in tourism and mobile gaming. It has been deployed for systems used in museums (Charr, 2021; Smithsonian Institution, n.d.) and navigation (Changing the way we navigate through augmented reality, 2017). AR has also been deployed in systems for university campus tours such as the augmented reality library tour at Appalachian State University and as discussed by Andri's research from 2018, which is the primary focus of this research.

## *Background*

A good AR experience includes three characteristics: it is interesting; it is engaging; it provides an immersive experience. Studies have shown a connection between delivering a strong first impression and the prospective students' interest. Bejou and Bejou (2012) claim that higher education institutions must use aggressive tactics to attract interest and recruit new students. This tactic begins with using a modified customer relationship management (CRM) model when looking at the recruitment, enrollment, and retention of prospective students. According to Bejou and Bejou (2012, p. 253), the objective of the recruitment phase of the CRM model is, "to build desirable recruits' satisfaction to a high enough level that they apply for admission." Having an experience that touches on the three key points of AR may provide a beneficial tool to use in the business relationship between a university and its prospective student body.

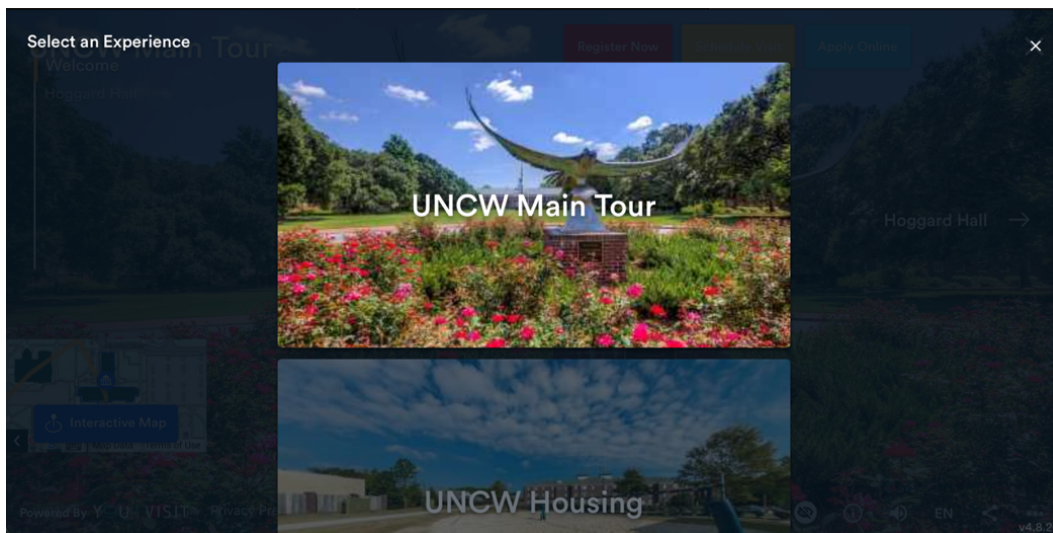


Figure 1. YouVisit Desktop Application Welcome Screen.

The University of North Carolina at Wilmington (UNCW) currently has both web and mobile applications, developed by YouVisit, designed to give users information about what the campus has to offer, shown in Figure 1 and Figure 2. These applications provide a "good enough" solution to delivering information to prospective students and

their families, specifically in situations where an in-person visit to the campus is not possible. However, the mobile application could improve the user experience, functionality, and ease of use.

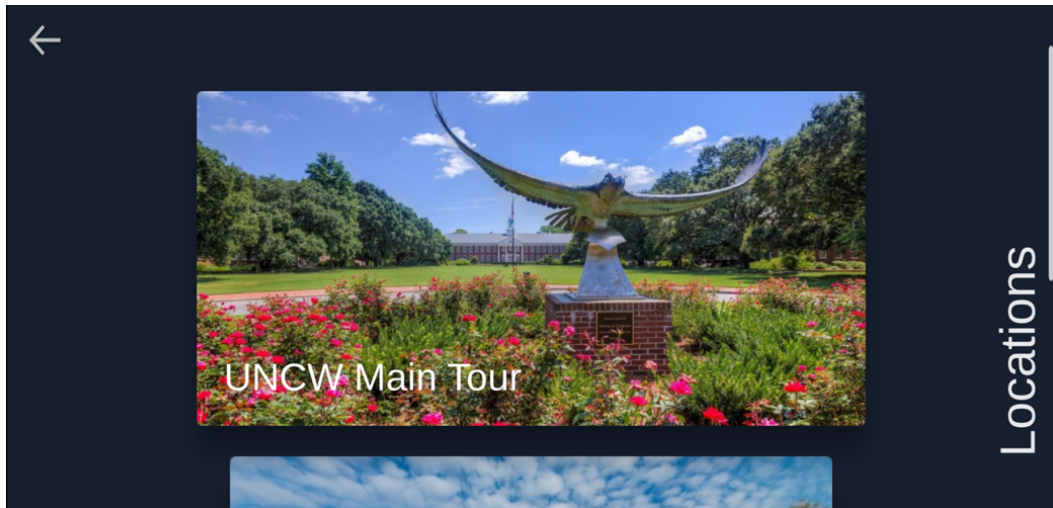


Figure 2. YouVisit Mobile Application Welcome Screen.

The YouVisit application attempts to meet these key points but misses the mark. Of 87 ratings for the application, most are single-star reviews addressing the usability of the application indicating that the application does not work, in some cases. Only two reviews state successful use of the application and its helpfulness in the user's search for information about the college of interest.

The application provides 360° imagery of campus buildings, shown in Figure 3, not allowing the user to fully experience every point of interest (POI) in the building and is the same experience that is found in the web application. Pressing the "i" icon in the top menu allows the user to see information about the location they are visiting in the application, shown in Figure 4, and provides more detail than the web application. Figure 5 shows a map of waypoints identifying buildings for a self-guided tour on the campus; however, the waypoints do not identify all the campus buildings or allow a user to search for and create a new destination on the map. Moving from the map view back to the main

application is not an option, requiring the user to fully close and reopen the application, which could account for the single-star reviews.

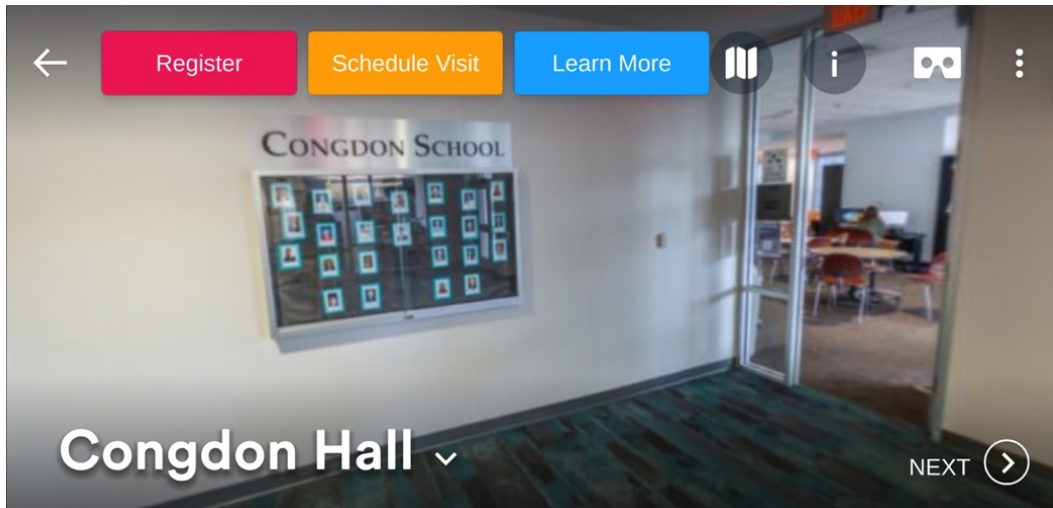


Figure 3. YouVisit Building View. UNCW Congdon Hall.

UNCW also affords visitors the opportunity to also take in-person tours of the campus. These tours require visitors to register for a tour and are only offered Monday-Friday. During times of inclement weather, the virtual tour is the only option. UNCW could maximize tour availability if a new AR application were available, focused on the three key points of AR, which could generate more interest in the university. More interest can generate a ripple effect that would lead to higher admission rates, new faculty hires, and a more diverse educational experience for the student body.

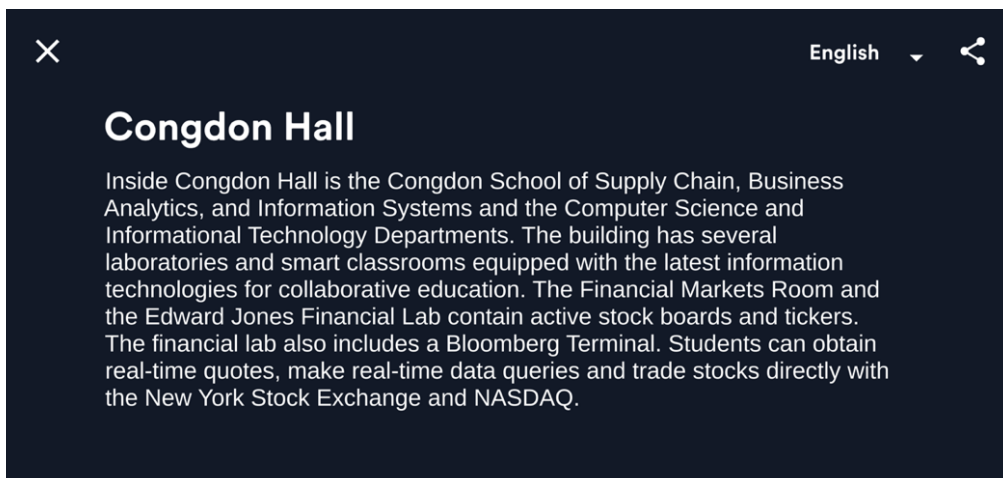


Figure 4. YouVisit Information Screen.

## Objective

The goal of this research is to develop an augmented reality application that provides an interesting and engaging user experience. HawkAR-T is a system intended to solve the identified shortcomings of and improve on the current implementation of YouVisit's virtual campus tour application. The design of the new system will provide the user with an engaging experience during an in-person tour of the UNCW campus. The intended users for this application will focus on potential students and their parents but could also provide benefits for first-day navigation of the campus for newly admitted students, new faculty, or any other visitor to the campus.

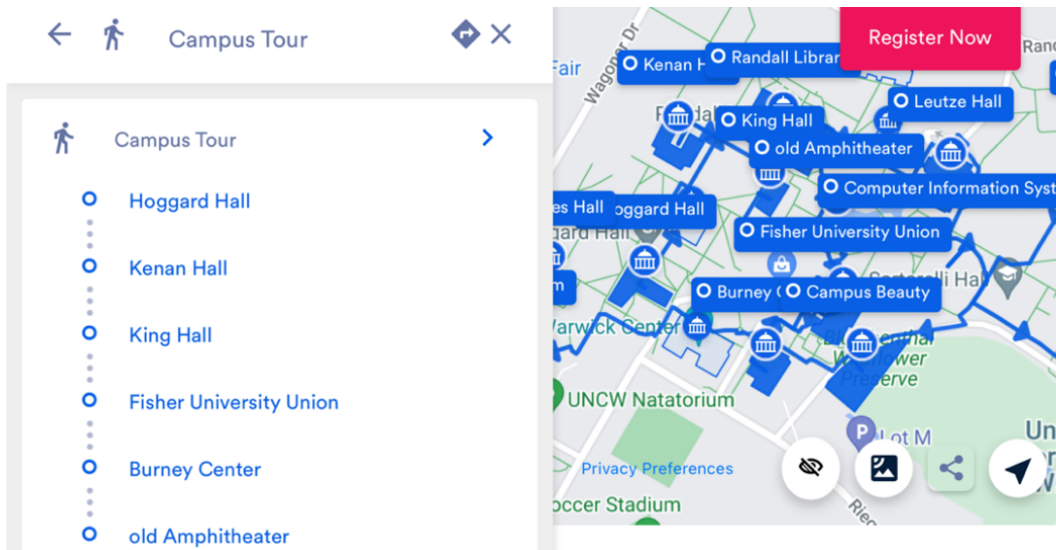


Figure 5. YouVisit Map View.

This paper is organized to introduce the proposed new system, provide a review of the existing literature on AR, discuss the design and implementation of the system, document testing, and provide recommendations for future investigation. Chapter 2 provides a review of the literature on augmented reality and its application in tourism, to include analysis of these works. Chapter 3 discusses the design and implementation methods of the HawkAR-T system. Chapter 4 documents the performance and testing of

HawkAR-T. Chapter 5 discusses recommendations for future work and conclusions of this research.

## CHAPTER 2: REVIEW OF LITERATURE REVIEW AND ANALYSIS

AR technology is increasingly being used in tour applications to enhance the travel experience for tourists. Virtual tours, navigation, and interactive guides are a few applications of AR that provide users with an immersive experience. As augmented reality has grown in popularity, so too have its methods. Location-based, marker-based, and marker-less AR are frequently used application technologies, aiding in the presentation of information to the user.

### *Mobile AR and Tourism*

Kim and Park (2011) present a mobile augmented reality tour application to provide an intuitive interface for the tourist. The use of context-awareness allows the user to access a “smart” guide to provide information on points of interest in a tour of the National Palace Museum of Korea using iPhone device sensors. The focus of their research was centered on three key steps of context-awareness: context recommendation, using automatic detection from device sensor data, context exploration and additional resources, using manual inputs from the user. The use of manual user input presents a solution to overcoming device sensor limitations and enhancement of the tour experience.

Fino et al. (2013) introduces the design and implementation of a tourist guide using the combination of AR, video, and QR code recognition for visiting two significant routes in a walking tour of a World Heritage city, San Cristobal de La Laguna. In the design of this walking tour, the user obtains a city map from the Tourist Information Office with an embedded QR code and two proposed routes. Animation videos for each route follow the route path where 3D views of the preset POIs appear with the name and route number. Buildings along the routes also have a QR code, allowing tourists to scan and receive on-site information for the POI. They conclude that the use of augmented

reality is a viable tool for the dissemination of POI information and enhancement of the user experience, which could lead to more frequent visits to the location.

Andri et al. (2018) present a survey of 15 mobile campus tour applications using augmented reality at various universities, as well as the features of each application like information about points of interest, location search, navigation, 3D campus building, campus events, ecological environment, virtual tour, and outdoor games. Of the applications surveyed, there was a split between using marker-less and marker-based tracking implemented in the system. When comparing the applications, most incorporate POI information and navigation. Two recurring themes found in the comparison of the applications, highlighted use of a third-party map application for use in the navigation feature and lack of filtering capabilities when searching for a POI. Their follow-on work (2019) discusses the development of a mobile augmented reality and virtual tour application for Management and Science University (MSU) in Malaysia. The application was designed to address limitations found in the previous study and provide users with the capability to use augmented reality in on-campus tours and virtual reality for those who are not able to travel. The goal of their work was to highlight the effectiveness and how memorable the tour experience is for visitors when using AR to supplement the traditional campus tours provided by institution personnel. Their 2019 contribution received favorable marks from users during acceptance testing and performed to meet this goal.

Blanco-Pons et al. (2019) present an AR application developed for the identification, recreation, and descriptive information of prehistoric rock art paintings found in the Cova dels Cavalls rock-shelter to improve current guided tour user experiences. The intended audience for this application was non-expert visitors who may

want to improve their rock art knowledge and awareness of a fragile archeological site. With a user-friendly design, the application only requires the user to point their phone's camera at the rock art scene. Using marker-based methods, a virtual overlay of the current scene, highlighting the artwork, is presented to the user with selections to view the current state, possible original state, and descriptive information. Users of the application responded positively when surveyed after use. Blanco-Pons et al. (2019) conclude their application is a useful tool that is most beneficial for inexperienced visitors.

Koo et al. (2019) study the development of an application for a cultural heritage site in South Korea discussing the design, development, and evaluation of augmented reality-based mobile application for a tour guide. The application was designed to address the traditional site tour reservation restriction requirements of four or more people and allow visitors to navigate on their own in a self-guided visit. The application offered users a choice of themes to visit POIs, a navigation module to direct them to the next POI, and an optional tutorial video at the start of the tour and for each POI. Furthermore, it made it possible for interactive augmented reality content to load when a user's device scans a POI target, and interactive games were implemented to enhance knowledge about each POI. Theme selection allowed a user to choose between historical, cultural, and architectural themes to provide a unique visit based on the user's desires.

Kondlo et al. (2020) propose using augmented reality to create a self-guided virtual tour of the Cape Flat Nature reserve in South Africa to get around constraints brought on by a shortage of qualified and available tour guides. Their solution was to present the user with historical and ecological information about the reserve and plant identification while on a tour. The application focuses on implementing marker-based

and location-based methods to provide information within the application based on the user's location identification in respect to a POI. Information output is retrieved from a database to overlay on the device screen once a marker is scanned or a POI is identified.

#### *AR Methods, Technologies, and Frameworks*

Bauer et al. (2001) propose a component-based framework to develop an augmented reality application on a wearable device. They highlight that this type of framework provides advantages for project managers, end users, and developers through code reuse, system configuration, and the ability to abstractly view the system. A component-based framework architecture is advantageous in that it allows for more rapid development and testing times, flexibility to change an application behavior, and functionality through the adding or changing of components without major disruptions to the system. As proof of concept, they developed an indoor and outdoor campus navigation system using this type of framework.

Mulloni et al. (2011) study the user experience with augmented reality aided navigation on a handheld device. They developed a navigation system that implemented a *forward-up map* with virtual directional arrows and audio instructions, with new instruction notifications that vibrate the phone. The navigation system also triggers a map view if the user tilts the phone down. The study asked participants to navigate a one-mile route while tracking their usage of the system. Results from the study showed average system usage was 21.2% of the total task time with an approximate 70/30 split between map and AR respectively. Both map and AR usage increased when users approached decision points and intersections. Consideration, based on these findings, should be taken when deciding on whether to implement a navigation feature in a campus tour application.

Geiger et al. (2014) study the design and implementation of a location-based mobile augmented reality application, comparing the implementation on iOS and Android mobile operating systems. The goal for their core system, Augmented Reality Engine Application (AREA), was to display POIs in the field of view based on the angle and position of the device. The application featured a component-based design using the *Model View Controller* design pattern that was built on top of the AREA kernel. In this software design pattern, the *Model* contains the pure application data, the *View* presents the data to the user, and the *Controller* acts as the connection between the other two, listening and reacting to events from the view and calling methods, retrieving data, on the model. To improve efficiency for the display and redrawing of POIs and battery power, native implementation of the kernel was used to communicate with the operating system through built-in Application Programming Interfaces (APIs).

Kourouthanassis et al. (2015) identify and evaluate mobile augmented reality (MAR) application design choices based on a field study of 33 tourists. They provide five recommendations that should be followed during the creation of MAR applications to ensure a high-quality user experience. Their five recommendations are:

1. Using context-awareness to provide content.
2. Deliver only relevant content to the user to eliminate “noise”.
3. Inform the user about user data collection privacy.
4. Provide feedback about the infrastructure’s behavior like in cases of weak network signal.
5. Support the user’s procedural and semantic memory through familiar and consistent icons.

Applying these design recommendations in a mobile augmented reality travel

application for the field study revealed potential to enhance usability and the overall user experience. Similarly, Irshad and Awang (2016) also identify key considerations that developers should consider while designing a mobile augmented reality application. They suggest focusing on the presentation of the product, information content, service functionality, user interaction, control of augmentation by the user, and mobility to enhance the user experience. These considerations are aligned with the suggestions from Kourouthanassis et al. (2015) and add to the necessity to apply these principles to a mobile augmented reality application.

Pryss et al. (2017) continue their work, see Geiger et al. (2014), of the AREA framework for location-based mobile augmented reality applications. In this work, version 2 of the AREA was developed and tested. Three new features were introduced in AREAv2; allowing the user to interact with a single POI among a cluster, point-to-point connection with a visual line, and key area highlighting. Other significant improvements in AREAv2 updated the POI algorithm, POI coordinate system, data sources for position changes, and the use on built-in operating system functions for iOS and Windows sensor management. Testing of the kernel showed satisfactory performance compared to competitive location-based applications.

Vakaliuk and Pochtoviuk (2021) analyze different cross-platform engines and software development kits (SDKs) for the development of augmented reality applications. This analysis is intended to aid beginner AR developers in choosing the most appropriate development tool for their project. Of the seven cross-platform development engines, Unity was the one most discussed. Vakaliuk and Pochtoviuk (2021) boasted of the usability, platform support, to include HTML5 applications, and performance of Unity for the development of 2D and 3D projects. Other advantages of

Unity include a large support community, asset store with a wide selection of development assets. Disadvantages pose learning curve issues for novice developers, but with the size of the community, this can be a minimal problem. SDKs provide a way to speed up and simplify the development process, however, the most popular ones come with a large cost for full functionality.

Over the past two decades, augmented reality has proved to be a useful tool to improve the tour experience. Common themes from literature show the use of marker-based and location-based methods for the implementation, a large focus on the end user's experience during use, and the viability of AR being used in the tourism industry. The intent of this work is the development of a tour application, using augmented reality, that will provide a visitor with an interesting and engaging experience and complement the traditional campus tour provided by university personnel for the University of North Carolina at Wilmington.

### *Definition of Terms*

This section provides the definition of technical terminology used in this paper that may not be common knowledge for an average reader. These terms are technical jargon commonly used in areas of software engineering and Augmented Reality applications.

*Architecture.* Architecture, in software engineering, is the overall design of a computing system and the logical and physical interrelationships between its components. The architecture specifies the hardware, software, access methods and protocols used throughout the system (Gartner glossary, n.d.).

*Augmented Reality.* Augmented reality is the real-time use of information in the form of text, graphics, audio, and other virtual enhancements integrated with real-world

objects (Gartner glossary, n.d.).

*Context-Awareness.* Context-awareness is the ability of a system or system component to gather information about its environment at any given time and adapt behaviors accordingly (Computer glossary, n.d.). Web browsers, cameras, microphones and GPS receivers and sensors are all potential sources of data for this type of computing.

*End User.* The definition of end user in this paper comes from oed.com. An end user is the person who is the ultimate recipient or user of a product; the typical or intended customer or consumer (Quick search results, n.d.).

*Kernel.* A kernel is the essential foundation of a computer's operating system (OS). It is the core that provides basic services for all other parts of the OS. It is the main layer between the OS and underlying computer hardware (Computer glossary, n.d.).

*Marker-based AR.* Marker-based, in augmented reality, is the process of introducing virtual elements into the scene view using a recognizable image from the real world. For activation, the user's phone's camera needs to properly identify the "marker" among its surroundings. For example, a marker might come in the form of a QR code, which the phone's camera can identify as a point of interest for the application (The ultimate augmented reality glossary, n.d.).

*Marker-less AR.* In contrast to Marker-based augmented reality, Marker-less AR is the process of introducing virtual elements into the scene view without a marker. Activation is accomplished through the scanning of a flat surface and the digital element is incorporated into the scene (The ultimate augmented reality glossary, n.d.).

*Location-based AR.* Location-based, or Geo augmented reality, places virtual elements into the user's real-world environment through the user's phone's GPS readings data. Activation is determined when the user is within range of a selected point of interest

(The ultimate augmented reality glossary, n.d.).

*Use Case.* Use case, in software engineering, is a methodology used in system analysis to identify, clarify, and organize system requirements (Computer glossary, n.d.). It is made up of a set of sequences of interactions between systems and users in a particular environment and related to a particular goal.

*Virtual Reality.* Virtual Reality provides a computer-generated 3D environment (including both computer graphics and 360-degree video) that surrounds a user and responds to an individual's actions in a natural way, usually through immersive head-mounted displays (Gartner glossary, n.d.).

*Waypoint.* Waypoint, in computer science and navigation, is the co-ordinates of a specific location as defined by a GPS (Waypoint, n.d.).

## CHAPTER 3: METHODOLOGY

The university campus tour offers visitors information on the institution's culture, programs offered, and amenities. HawkAR-T is an application that will improve the university campus tour and provide an immersive and memorable experience using augmented reality while providing UNCW visitors with this information. This chapter discusses the HawkAR-T system implementation, design and information gathering methods that will be used, project timeline, and the expected limitations of these methods. HawkAR-T aims to address the need to improve the existing YouVisit virtual tour of the University of North Carolina at Wilmington campus and meet the informational needs of application users.

### *Research Design*

*System Implementation.* Unity is a game development engine used to build 2D, 3D, virtual reality and augmented reality games and applications. It boasts a large support community, a wide selection of development assets, and is a common framework for creating Android, PC, and iOS applications. Due to its convenience and its availability of technologies for use in location-based augmented reality, HawkAR-T was developed using the Unity engine.

*System Design.* Design patterns in software engineering afford developers generalized solutions to software design problems. There are many design patterns to choose from and making the right choice for a software is beneficial throughout all phases of the software development life cycle. The behavior of an augmented reality tour application, such as HawkAR-T, uses a modified version of the Model, View, Controller (MVC) design pattern. Users view information provided by the model, where the data resides, accessed through a controller. In HawkAR-T, the view is the user's device, and

the model is the point object. As the device arrives at a waypoint location, the controller requests the data from the model to pass to the view for display, shown in Figure 6.

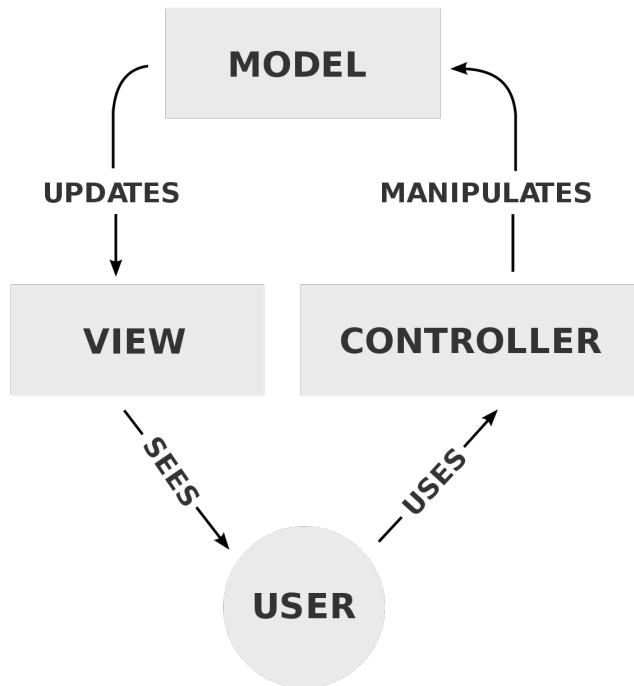


Figure 6. Model, View, Controller Pattern (RegisFrey, 2010).

*System Requirements.* HawkAR-T is a tour system that addresses the key areas of information dissemination and navigation while providing a user with a friendly interface. To meet these requirements, consideration of the application's user must be a central theme in identifying system requirements through user stories. The application needs to read the current location of the device in relation to tour points of interest. This will require location-based methods for exterior points. Due to unreliable GPS signals while indoors, the application also needs to implement marker-based methods. Once the device location is within range or captures a marker at a point of interest, the application needs to display the POI information to the user. Identified user stories for HawkAR-T are as follows:

1. As a user, I want to see most of UNCW's campus, so I may have a general familiarization of the institution.
2. As a user, I would like to view a map of my location, so I may see and orient myself with surrounding points of interest.
3. As a user, I want to freely explore the campus, so I may experience UNCW without using the preset tour points.
4. As a user, I want to see the point of interest I am looking at, so I may better familiarize myself with that point of interest.
5. As a user, I want to choose point description delivery, so I may listen to or mute descriptions.
6. As a user, I want to be notified when I am at a point of interest, so I may see the information for the point.

*System Prototyping.* Figures 7 through 11 show prototypes of what the user will encounter while using HawkAR-T. Navigation between screens is accomplished through touch screen buttons, typically found at the bottom of the screen, to reduce view clutter.



Figure 7. HawkAR-T Welcome Screen Prototype.

*Development Timeline.* HawkAR-T was developed in three iterative phases over a three-month period. Phase 1 concentrated on the development of marker-based technologies and the delivery of interior point of interest information. Phase 2 concentrated on the development of location-based technologies and the delivery of exterior point of interest information. Phase 3 concentrated on the development of navigation aids while on a tour and the implementation of audio functionality to the system. Each phase focused on its respective feature development and testing. After the completion of development, user acceptance testing, and data collection was conducted. To capture a true comparison between the current system and the proposed system, a quantitative data collection method was performed.

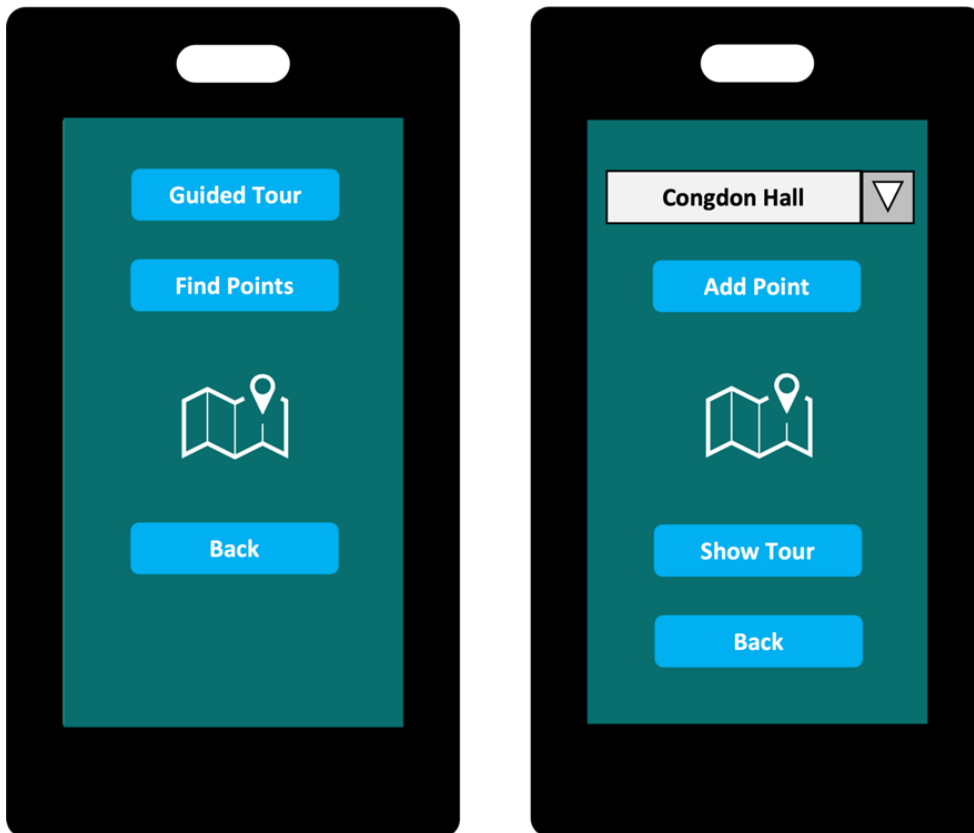


Figure 8. HawkAR-T Main Navigation Screen Prototypes.

*Data Collection.* The use of surveys provided a measure to determine if the development of HawkAR-T was successful and insight on whether the project met the intent to provide an immersive and memorable experience to the user. Three surveys were given to participants (Appendix A). An application survey was taken twice by each participant, for the use of the YouVisit application and Hawk AR-T and is modeled from John Brooke's (1995) System Usability Scale (SUS). The application survey consists of an application identifying question, to determine which application was evaluated, followed by ten usability questions measured on a five-point Likert scale. Survey responses were collected from 36 participants who used both applications and the calculated SUS scores are used to compare the two applications. Participants were given 50 minutes total to use each application and anonymously answer the survey questions after each use.

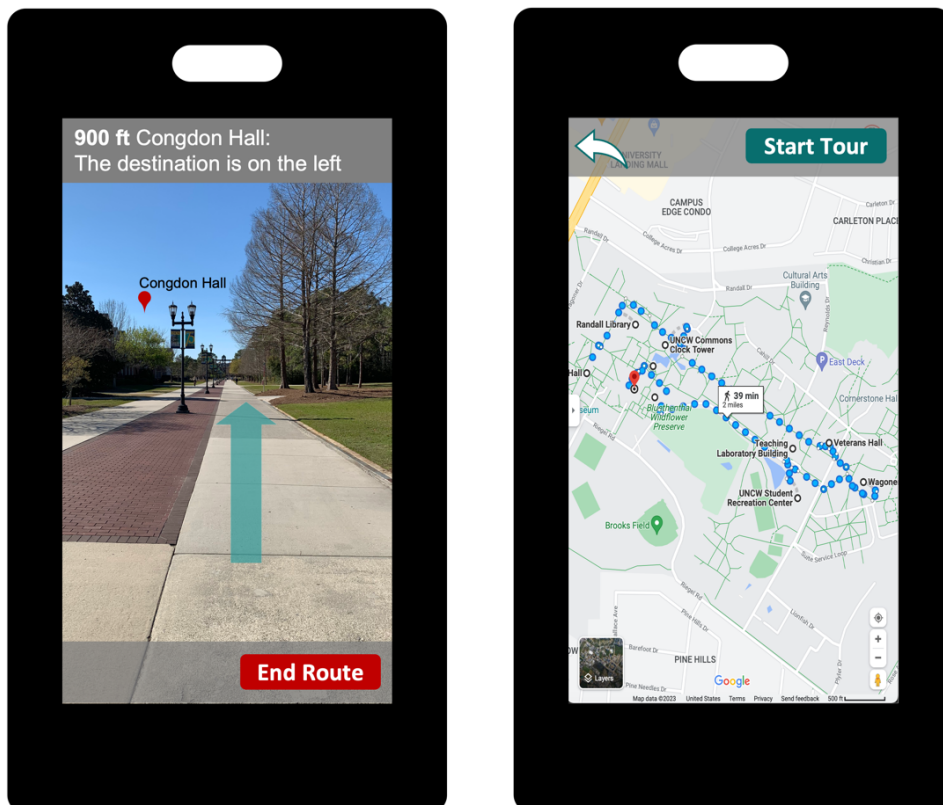


Figure 9. HawkAR-T Navigation Screen Prototypes.

### *Limitations*

Because Hawk AR-T is a small-scale application, development costs due to the use of APIs provided by Google, for use in all location-based needs of Hawk AR-T was the first expected limitation. To mitigate monetary costs that could be accrued, some features, like the static map, were limited to single Application Programming Interface (API) requests when the map feature was accessed in the application.



Figure 10. HawkAR-T Outdoor Location Prototype.

In a perfect world, HawkAR-T would be developed with every point of interest at UNCW made available in the application through navigation guidance. The lack of development time to implement every desired feature was the second expected limitation. This required prioritization of features that can be developed and still provide a usable product. To mitigate this time constraint, Hawk AR-T focused on implementing self-guided tour lines within the Commons area surrounding the center of campus near Congdon Hall. This allowed the showcasing of requirements and created a baseline for future work.

Survey participation was another concern. To mitigate any lack of participation, a three-week period for user testing and feedback was scheduled to ensure sufficient time to obtain enough responses for the evaluation of HawkAR-T.



Figure 11. HawkAR-T Indoor Location Prototype.

### *Summary*

HawkAR-T's goal is to improve the current mobile virtual tour of the University of North Carolina at Wilmington campus to offer an immersive and memorable user experience. To be developed using Unity, this application leveraged both location-based and marker-based augmented reality technologies. As a proof of concept, this system was applied with all available features to the area surrounding the Campus Commons, allowing for later expansion to other locations.

## CHAPTER 4: OUTLINE OF COMPLETED PROJECT

Hawk AR-T is a cross-platform application developed to address the need to improve the current YouVisit virtual tour of the UNCW campus while augmenting the in-person tour and meeting informational needs of application users. This chapter outlines the implementation of the Hawk AR-T application and examines the data collected from user participants. This includes the presentation of documentation from user requirements and the activities for the application's development. Next, a review of the user testing model and testing plan is examined. Finally, the results of the usability survey and evaluation are discussed.

### *Development Activities*

Implementation of Hawk AR-T follows the development processes outlined in the Software Development Life Cycle (SDLC) and standard practices of Agile development. This is beneficial in that it provides developers flexibility and capacity to adjust to changing requirements during development. Detailed discussion of the activities in the project's development follows.

*Requirement Gathering and Analysis.* Requirements for Hawk AR-T were identified through information obtained from Admissions, additional point information gathering from the UNCW website, and analysis of the YouVisit virtual tour. Admissions personnel provided insight on what building information would be useful to deliver to users, the current guided tour route, and what buildings should be included in Hawk AR-T. The UNCW website provided additional information not covered in materials obtained from Admissions. Finally, the YouVisit application provided vital information on areas of improvement to implement in Hawk AR-T.

*System Design.* The design of the Hawk AR-T system uses a modified model, view, controller design pattern (Appendix B). The activity flow diagram, detailing what functional routes the user can take (Appendix C).

Location-based activities are accomplished through the Geospatial Manager, responsible for starting location services on the device and tracking the device's current location, and the Location Manager, which is responsible for tracking the closest exterior point of interest and calculating true distance from the device to that point. Device location is reported to the Location Manager and once the device meets a threshold distance of 10 meters from the POI, the View component is notified via the Controller to provide a vibration notification and display a POI marker and header with the point name to the user. Interacting with a POI marker allows the user to view a description of this active point retrieved from the Model.

Marker-based activities are accomplished through the Tracked Image Manager, which is responsible for displaying a POI marker when a tracked image from the image reference library is scanned by the device camera. Marker images used were created using an online AR marker generator (Augmented reality marker generator-Brovision), an example is found in Appendix D.

*Implementation and Coding.* Once requirements were identified and the system design was formalized, implementation of Hawk AR-T was developed over three phases comprised of seven iterations. Each phase consisted of two to three iterations while each iteration lasted between one and two weeks and focused on the development of a feature and system testing. The details of each iteration are discussed in the following.

Iteration 1 was the development of interior points of interest and 3D clickable objects. Images for AR markers were generated for six interior points that described

programs offered by the UNCW Computer Science department and Cameron School of Business and added to the image reference library. Reference images were named by point identification used for point database queries to access point description information, shown in Figure 12.



Figure 12. HawkAR-T Indoor Location.

Iteration 2 added rotation animation to the 3D clickable objects, user interface components for standardizing the point description view for both iOS and Android

platforms, and compilation flags to check image tracking states for Android builds.

Additionally, for resource management, the device camera was turned off when accessing POI descriptions.

Iteration 3 began the development of application device location services use. A list of latitude and longitude reference points was created to identify the nearest point to the device location. This allowed for easier access to information when the POI was within the specified 10-meter threshold. This threshold is used by the application to identify when the user is notified and activate the 3D clickable object at the appropriate world position, shown in Figure 13.



Figure 13. HawkAR-T Outdoor Location.

Iteration 4 added third-party dependencies for ARCore Extensions and the map tiles API from Google and Cesium for applying geospatial anchors in the application and rendering of map tiles in Unity. Geospatial anchors are used to set points of interest at their specified latitude and longitude locations.

Iteration 5 added additional POI anchors, tour route waypoints, animated Sammy models, and wayfinding line rendering for guided and self-guided tours, shown in Figure

14. On-site tests were conducted to ensure correct scale and placement of Sammy models, additional POIs, and proper rendering of tour lines.



Figure 14. HawkAR-T Route Guidance and Map.

Iteration 6 added audio files for reading of POI descriptions and the application welcome message. Audio files were created using an online text to speech software (Free text to speech online) that compiled audio into mp3 files to download. The welcome, shown in Figure 15, and information screens were added and connected functionality to screen buttons to navigate between screens and start of the tour. Additionally, a static map was added for viewing during a tour, shown in Figure 14. The static map displays the user's location signified by the blue dot at the map center, adds map markers for POI

locations, and functionality to rotate the map to help orient the user with the nearby surrounding points.

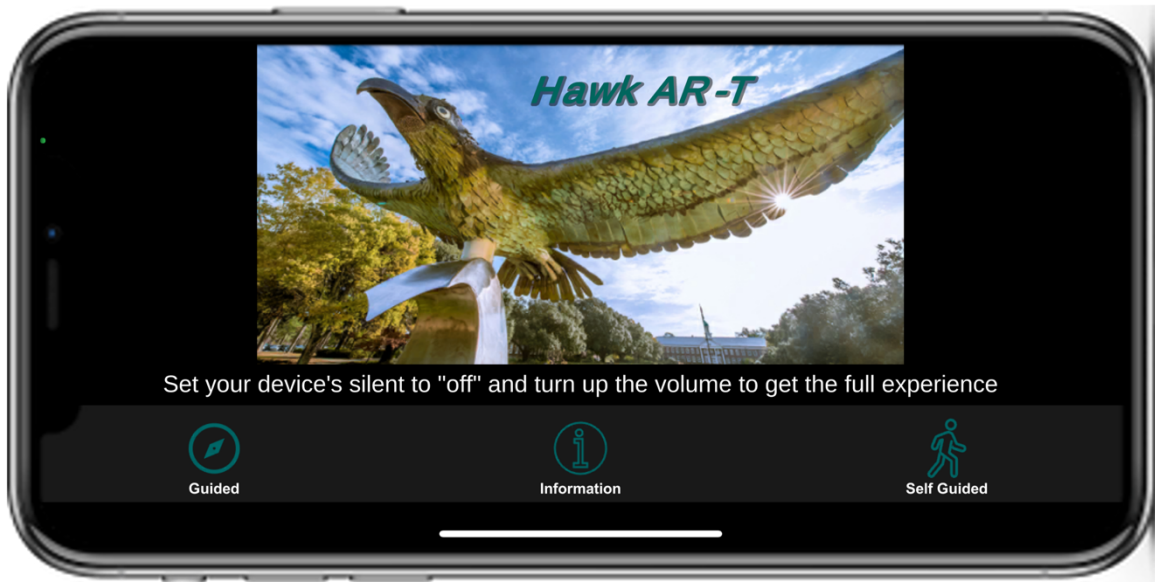


Figure 15. HawkAR-T Welcome Screen.

Iteration 7 introduced the application to the committee members to conduct initial user tests and receive feedback for any updates prior to data collection. To emulate a typical cellular configuration for Android, a SIM card was installed to provide cell service and allow for network connectivity outside of Wi-Fi network signals. Updates requested by committee members: adding instructions to the information screen to locate point markers; adding instruction to users for the location of the first interior point for Congdon Hall; adding functionality to return to the main screen and select a different tour type; adding descriptive text for point markers and buttons were also implemented to improve the usability of the application.

*Testing.* Testing of application features was conducted throughout the development process in each iteration. User Acceptance Testing was conducted between September 11 and September 29, 2023. What follows is a discussion of the details of the user testing model and testing plan.

## User Testing

The System Usability Scale is a quick evaluation of the usability of a software system using a five-point Likert scale, where a score of one equates to strongly disagree and a score of five equates to strongly agree. System users are asked a series of ten questions after the use of the application being tested, see Table 1. SUS scores are then calculated by the sum of one less than the raw score from the odd questions and five minus the raw score from the even questions, multiplied by a factor of 2.5. This score, ranging from 0-100, is then used as a metric to determine the usability of the software system, where scores above 60 are considered successful.

Table 1. System Usability Scale Questions

System Usability Scale						
		Strongly Disagree			Strongly Agree	
Question 1	I think that I would like to use this system frequently.	1	2	3	4	5
Question 2	I found the system unnecessarily complex.	1	2	3	4	5
Question 3	I thought the system was easy to use.	1	2	3	4	5
Question 4	I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
Question 5	I found the various functions in this system were well integrated.	1	2	3	4	5
Question 6	I thought there was too much inconsistency in this system.	1	2	3	4	5
Question 7	I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
Question 8	I found the system very cumbersome to use.	1	2	3	4	5
Question 9	I felt very confident using the system.	1	2	3	4	5
Question 10	I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

From *SUS: A quick and dirty usability scale*, by J. Brooke, 1995, [https://www.researchgate.net/publication/228593520\\_SUS\\_A\\_quick\\_and\\_dirty\\_usability\\_scale](https://www.researchgate.net/publication/228593520_SUS_A_quick_and_dirty_usability_scale), p. 189-194.

Because Hawk AR-T is a cross-platform application, development and testing was performed on an iPhone XS, for iOS, and a Moto G-Power 22, for Android. Users were given one of these devices to perform test activities during their session, with 50% of participants using the iOS device and 50% using the Android device. Testing was accomplished as follows:

1. Users answered an initial survey (Appendix A) identifying the type of device used during the test, population group they belong to, and if they had any prior experience using an augmented reality application.
2. Users alternated between using the YouVisit virtual tour application or Hawk AR-T first, followed by the application survey, then using the other application, followed by another application survey (Appendix A).
  - a. Testing activities for YouVisit required users to become familiar with the available features in the application. They were asked to retrieve information and view imagery from Congdon Hall, access the map feature, and view at least two of any other point of interest they choose.
  - b. Testing activities for Hawk AR-T began at the northwest corner of Congdon Hall. Users were asked to view the information screen, select a guided tour, and follow route guidance to access two nearby exterior points at Leutze Hall and Morton Hall. Once at Morton Hall, users were asked to access the self-guided tour and follow route guidance past the Millennium Clock Tower and back to Congdon Hall. Finally, users entered Congdon Hall to access a minimum of two interior points.

- Users ended their session through completion of the final survey (Appendix A), answering if they were able to complete all activities on the same device, if they would recommend Hawk AR-T to others, and provide feedback on their experience.

*Usability Survey and Evaluation Results*

Of the 36 participants, 86.11% were current UNCW students, 8.33% were Admissions personnel, and the remaining 5.56% were defined as other, shown in Figure 16. 52.78% of participants said they have prior experience with augmented reality applications, while 47.22% said they did not, shown in Figure 17.

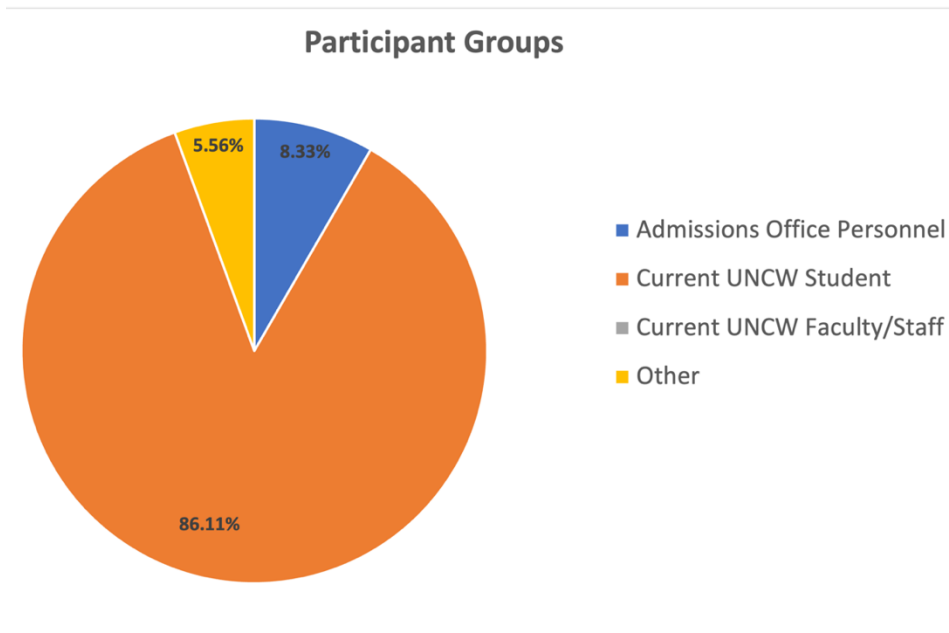


Figure 16. Participant Groups.

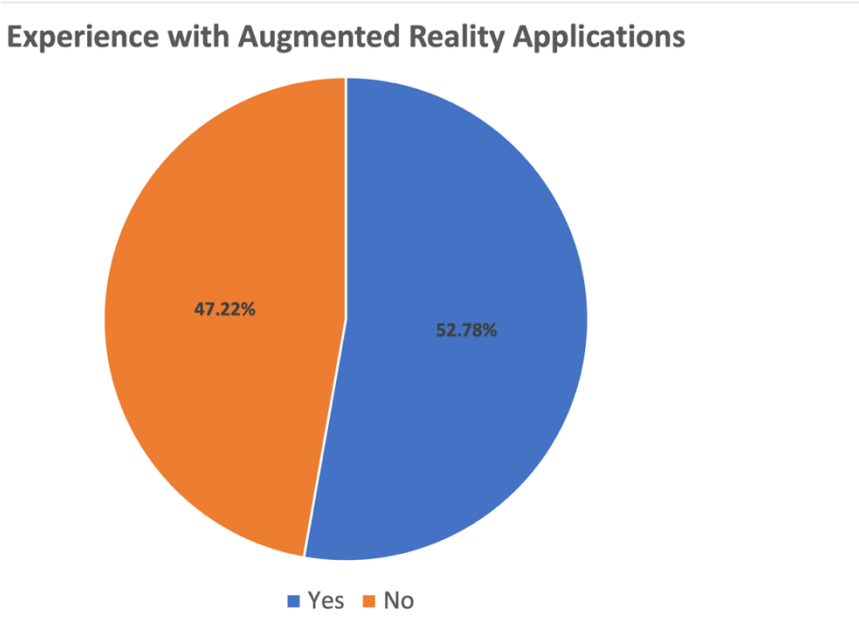


Figure 17. Experience with Augmented Reality Applications.

Calculating the SUS scores and the Wilcoxon signed-ranks test was used to evaluate and compare YouVisit to Hawk AR-T. The Wilcoxon signed-ranks test is used to compare two matched samples to assess whether their population mean ranks differ. Calculation of the test statistic, as seen in equation (1), is compared to the defined critical value based on the sample size of all non-zero differences of the matched pairs.

$$W = \sum_{i=1}^{N_r} [\text{sgn}(x_{2,i} - x_{1,i}) \cdot R_i] \quad (1)$$

From the formula, the variables  $W$  is the test statistic,  $N_r$  is the sample size, excluding pairs where  $x_1 = x_2$ ,  $\text{sgn}$  is the sign function,  $x_{1,i}$  and  $x_{2,i}$  are the corresponding ranked pairs, and  $R_i$  is the rank of  $i$ . The parameter  $\alpha = 0.05$  is the desired level of significance used in this test for the calculated sample size  $n = 34$ . The null hypothesis,  $H_0$ , and alternative hypothesis,  $H_A$ , are defined as the SUS scores are equal between YouVisit and Hawk AR-T and the SUS scores are not equal, respectively. Rejection of or failure to reject  $H_0$  is determined on how the test statistic compares to the identified critical value, shown in Table 2 and boxed in red.

Table 2. Wilcoxon Sign-Ranks Table

n	alpha values						
	0.001	0.005	0.01	0.025	0.05	0.10	0.20
32	94	116	128	144	159	175	194
33	102	126	138	155	170	187	207
34	111	136	148	167	182	200	221
35	120	146	159	178	195	213	235
36	130	157	171	191	208	227	250

From *Real Statistics Resources*, <https://real-statistics.com/statistics-tables/wilcoxon-signed-ranks-table/>.

Comparison was made for the critical value of 182 and  $W = 103.5$ . Since the test statistic is less than the critical value,  $H_0$  is rejected. This provides sufficient evidence that the SUS scores are not equal and are statistically significant, at a 95% confidence level. Furthermore, this is seen when plotting the comparison of the two applications, shown in Figure 18.

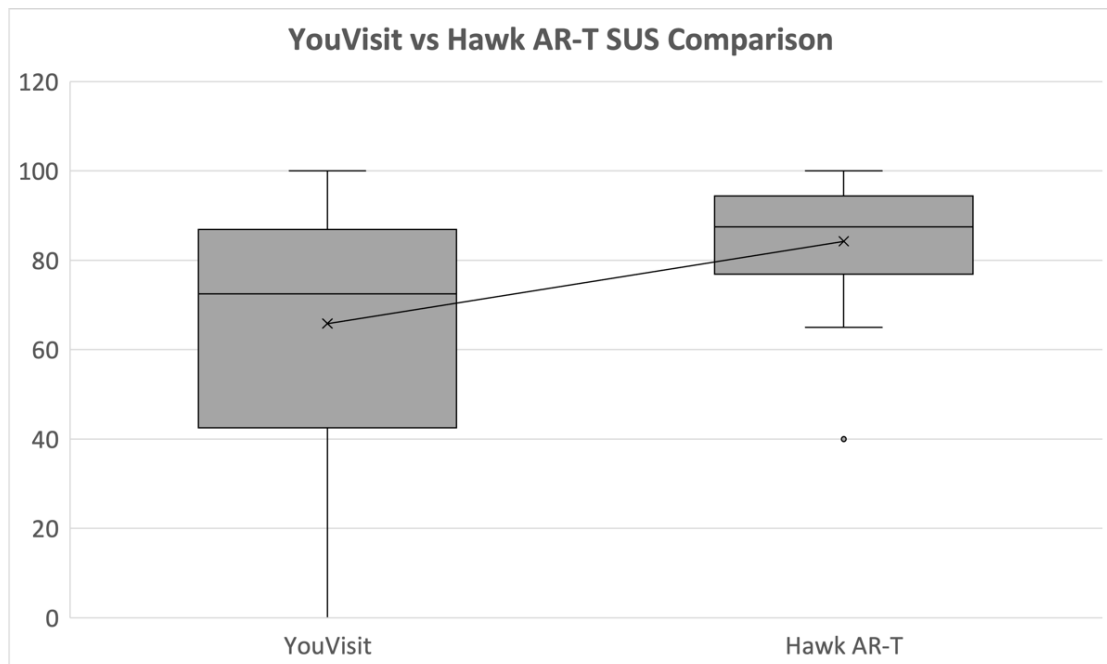


Figure 18. YouVisit vs Hawk AR-T SUS Comparison.

It is important to investigate how Hawk AR-T ranked between experienced and inexperienced augmented reality users, shown in Figure 19. Augmented reality experience among users appears that it is a determining factor when evaluating the usability of the application. Users with augmented reality experience have an overall agreement among their scores, shown by the more compressed plot, while inexperienced users have a wider spread amongst their scores. This can be indicative to Hawk AR-T's implementation is consistent to other AR applications that are available in the market.

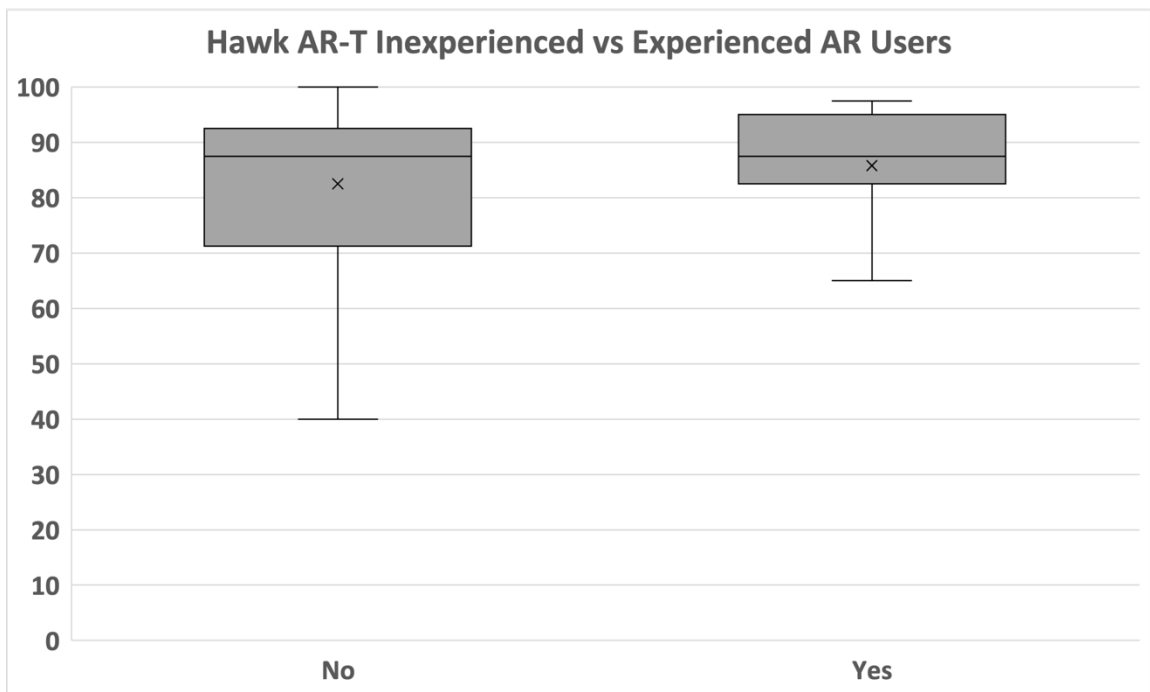


Figure 19. Hawk AR-T Inexperienced vs Experienced AR Users.

Additionally, it is important to see how Hawk AR-T ranked between iOS and Android users, shown in Figure 20. SUS scores for Android were more consistent when compared to iOS, though most scores for iOS have a smaller range.

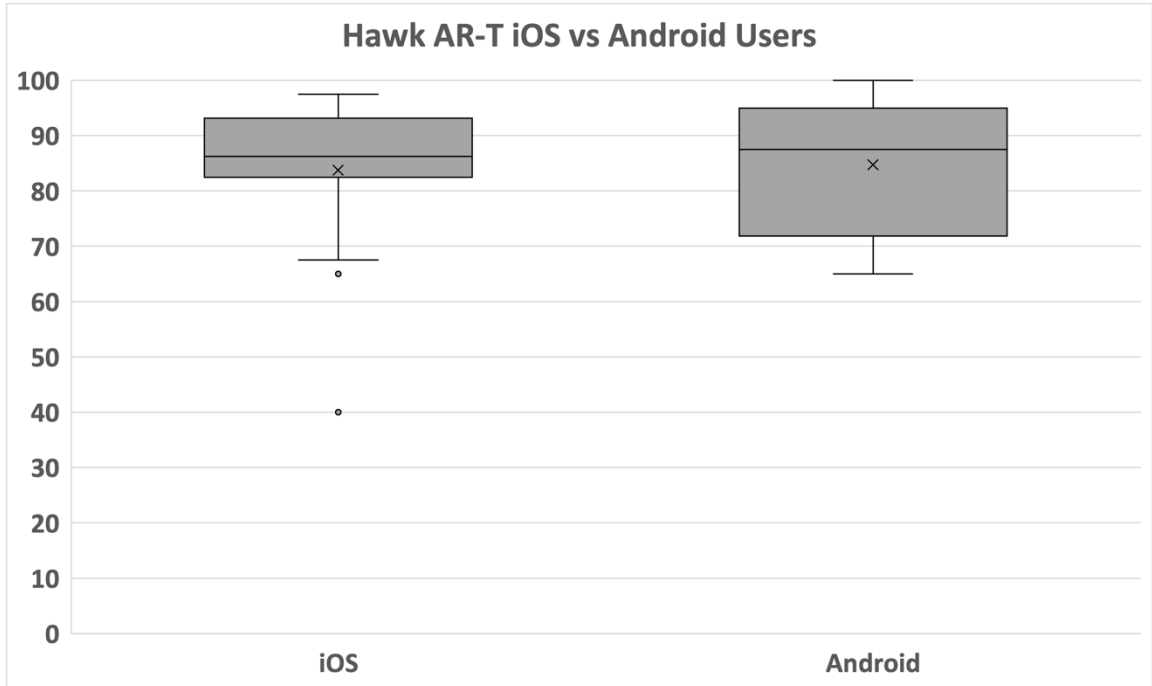


Figure 20. Hawk AR-T iOS vs Android Users.

When asked if Hawk AR-T would be recommended to others, 61.11% strongly agreed, 33.33% agreed, and 5.56% remained neutral, shown in Figure 21. Based on this evidence, it is determined that Hawk AR-T performed better than YouVisit and would be a viable replacement of the current system.

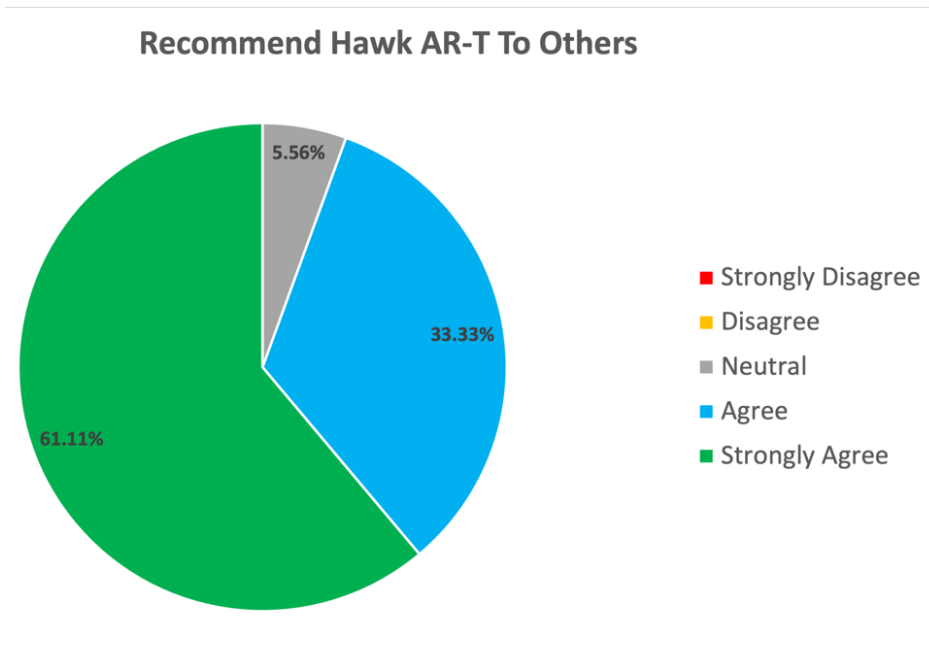


Figure 21. Recommend Hawk AR-T To Others.

## CHAPTER 5: CONCLUSIONS AND FUTURE WORK

This research aimed to develop a cross-platform mobile augmented reality application to improve the current virtual tour available to the public and provide users with an interesting and engaging experience while visiting the UNCW campus. Visitors would have the freedom to explore the campus without being confined to scheduled, in-person tours if they used this application. This maximizes tour availability and is advantageous to visitors if in-person tours are canceled or take place outside of regularly scheduled tour hours, such as on weekends or holidays. The institution would also profit from any increases in interest from prospective students, which might result in greater acceptance rates, the hiring of more faculty, and the provision of more course alternatives for the students.

The successful development of this project, in part, was due to making suitable design choices early in the process, from the development environment to the software design pattern. Unity's ability to use, and communicate with, third-party software APIs made the process of bringing real world content into the application world and development an easier process. Additionally, Unity's development environment afforded the rapid creation and reuse of prefabricated assets. This was advantageous in placement of the virtual objects on the marker images and in the intended geographic locations to present to the user. Due to the nature of how information was needed to be presented to users the modified MVC pattern was an adequate fit for the creation, storage, and delivery of content. This allowed more time to concentrate on feature development and the user experience. The benefits of these choices enabled the shorter development timeline of this application to happen and the addition of more points of interest than previously planned.

## *Future Work*

Though the development of Hawk AR-T can be considered an overall success, developer observations made during its development and feedback obtained from users during data collection gives insight on future improvements to the application. To better understand the implications of these results, future studies should address the following.

*Interactions.* Though the UNCW mascot was a popular feature along the tour, adding a way to interact with the Sammy model would help improve the user experience. Additional animations for the model and making it a clickable object could facilitate the implementation of this feature.

*Interior Experience.* Not all interior points of interest are in full public view or on the same level in Congdon Hall. Providing the user to view a building floorplan or implementing indoor navigation can improve access to more hidden markers. If not these features, implementing a way to see number of interior points visited out of total points available could be just as helpful. This may require geofencing, adding a virtual perimeter around campus buildings that have interior POIs to identify when a user enters or exits the building.

*Location Services.* Accuracy of the GPS signal is something that can quickly hinder the user experience for applications that use these sensors. Although Unity provides a way to request a desired accuracy when starting location services, it is dependent on the device operating system to calculate and report to the application. This is not a guarantee that true accuracy will be what is requested or better. Inaccurate GPS fixes will cause applications such as Hawk AR-T to have unintended behaviors, like rendering lines off the intended path or cause exterior POIs to not appear when expected.

Further understanding is needed on how Android and iOS devices calculate device location and how it applies to Unity's method for starting location services.

*Map Improvements.* As mentioned, due to the small scale of this application, mitigating costs of API requests was necessary and it limited the map feature of Hawk AR-T. It was a goal to provide useful content to the user and the static map allows the user to orient themselves with surrounding points. However, a moving map that updates while the user is walking would be a remarkable improvement. This was not attainable while keeping monetary costs low but is strongly suggested.

*Navigation.* Allowing users to customize their own tour, by selecting a group of points, and navigating point-to-point would provide users with a campus tour that is more aligned with their interests. Though it was originally planned when identifying requirements for Hawk AR-T, it was deemed outside of the scope for this project. However, this improvement would further meet the goals of providing the user with an interesting and engaging experience and meet their informational needs more efficiently than the current design.

### *Conclusions*

Based on quantitative analysis of the system usability between the YouVisit virtual tour and Hawk AR-T, it can be concluded that Hawk AR-T is an improvement over the current system. The results indicate application users preferred, and are more likely to suggest, Hawk AR-T over the YouVisit virtual tour. Hawk AR-T performed well on both the iOS and Android device and would be an appropriate replacement for the YouVisit virtual tour.

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## APPENDIX A

### Evaluation of Hawk AR-T Application

These surveys will be used by MSCSIS graduate student Andrew Davison to evaluate the design and use of Hawk AR-T.

Please be honest in your assessment of this cross-platform application as the survey results will be used for further refinement of the software.

Thank you for your participation in this research and completing these surveys.

*\* Indicates required question*

---

What is your preferred device? \*

- Android
- iOS

To what group do you belong? \*

- Admissions Office Personnel
- Current UNCW Student
- Current UNCW Faculty/Staff
- Other

Have you ever used an Augmented Reality application before? \*

- Yes
- No

# Application Survey

Please record your immediate response to the following questions for the application you just used. If you cannot respond to a particular item, you should mark the center point of the scale.

\* Indicates required question

---

What application are you evaluating? \*

- YouVisit virtual tour
- Hawk AR-T

I think I would use this application frequently. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I found the application unnecessarily complex. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I thought the application was easy to use. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I think that I would need the support of a technical person to be able to use this application. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I found the various functions in this application were well integrated. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I thought there was too much inconsistency in the application. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I would imagine that most people would learn to use this application very quickly. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I found this application cumbersome to use. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I felt very confident using the application. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

I needed to learn a lot of things before I could get going with this application. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

## Final Survey

\* Indicates required question

---

Did you complete the activity on the same device you started with? \*

- Yes
- No

I would recommend Hawk AR-T to others. \*

	1	2	3	4	5	
Strongly disagree	0	0	0	0	0	Strongly agree

Please describe any problems you encountered and any changes or improvements you would recommend for Hawk AR-T.

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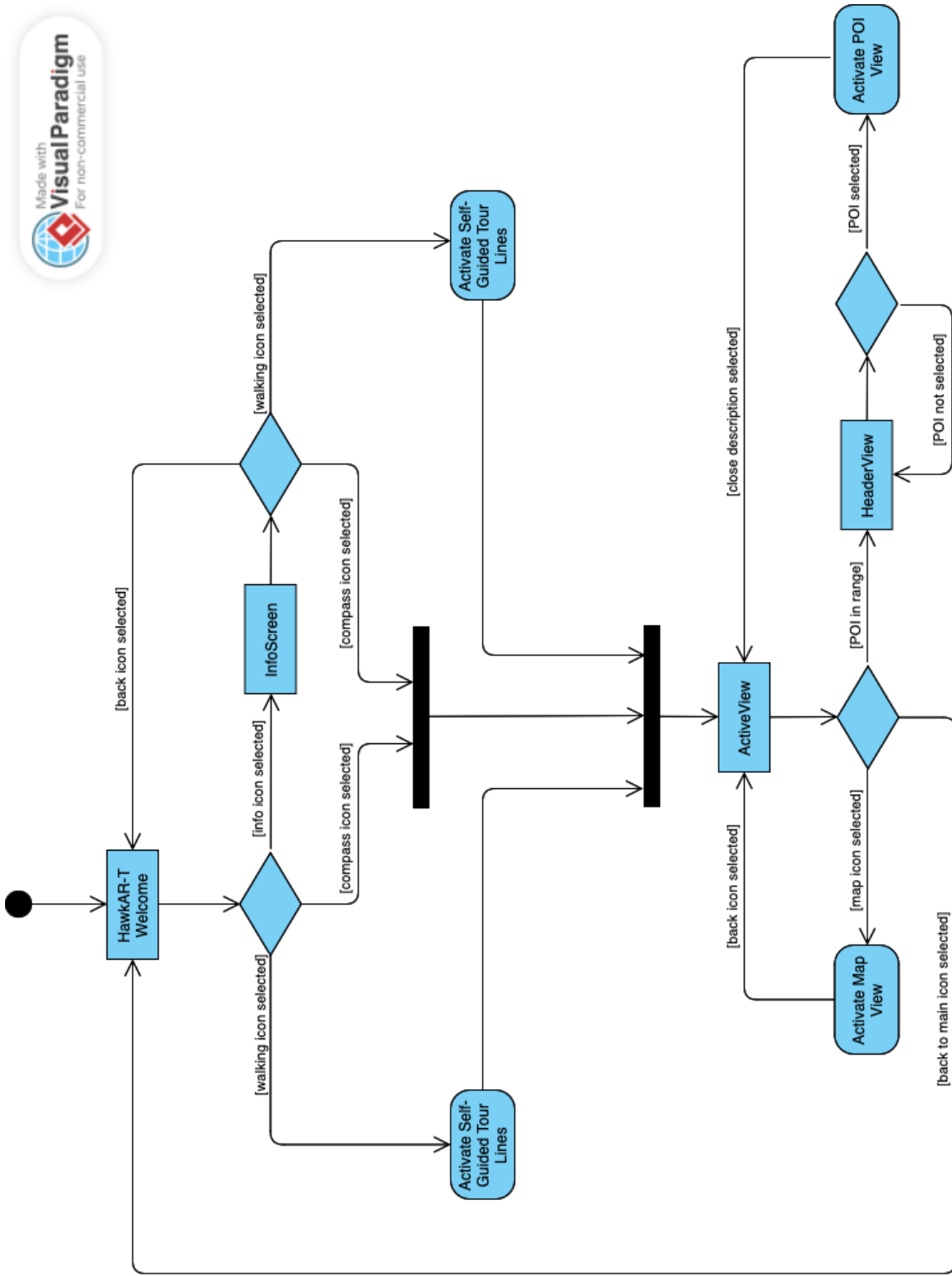
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# APPENDIX C

## Hawk AR-T Activity Flow Diagram



## APPENDIX D

Example augmented reality marker image.

