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UTHM-KCP Smart Interactive Map: Enhancing Campus Navigation Through Augmented Reality-Based Building Visualization

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Abstract

Navigating a university campus can be challenging for new students, visitors, and staff unfamiliar with the campus environment. Conventional maps often provide limited contextual information, making it difficult to efficiently identify building locations and routes. This study presents the UTHM-KCP Smart Interactive Map, an augmented reality (AR)-based mobile application designed to enhance campus navigation through real-time building visualization and wayfinding assistance. The application overlays virtual building labels and navigation indicators onto the real-world environment, enabling users to locate campus facilities and navigate to their destinations more effectively. Developed using the Multimedia Development Life Cycle (MDLC) methodology, the system integrates Flutter, Unity, ARCore, computer vision-based environmental tracking, and low-polygon 3D building models to provide an intuitive user experience. User evaluation results revealed positive perceptions of the application's navigation experience, usability, and user experiences, particularly in terms of ease of use, navigation accuracy, and overall usefulness. The AR-based building visualization also enhanced spatial awareness and reduced user confusion in unfamiliar campus areas. These findings demonstrate the potential of the UTHM-KCP Smart Interactive Map as an effective campus wayfinding solution that supports smart campus development and digital transformation in higher education institutions.

1. Introduction

The rapid advancement of digital technologies has transformed information delivery in higher education institutions, making intelligent navigation systems increasingly important in large and complex campus environments [1]. Universiti Tun Hussein Onn Malaysia Kampus Cawangan Pagoh (UTHM KCP) currently relies on conventional maps and fragmented online information sources that provide limited interactivity and contextual guidance. Consequently, students and visitors may experience difficulties locating buildings and facilities, resulting in confusion, delays, and reliance on manual assistance [2].

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To address these challenges, this study proposes the UTHM-KCP Smart Interactive Map (UP-SIM), an augmented reality (AR)-based mobile application designed to enhance campus navigation through building visualization. The system overlays virtual building labels and navigation indicators onto the real-world environment, enabling users to identify campus facilities and navigate more efficiently. Developed using Flutter, Unity, ARCore, and low-polygon 3D building models, UP-SIM provides an intuitive navigation experience while improving users' spatial awareness. The application also supports UTHM KCP's digital transformation initiatives by demonstrating the practical implementation of AR technology in a smart campus environment.

1.1 Background

Campus navigation remains a challenge in many higher education institutions, particularly for first-time visitors and newly enrolled students. Although digital maps and virtual tour applications are widely available, many rely on static representations that offer limited interaction and real-time guidance [3]. Such limitations reduce their effectiveness in helping users understand campus layouts and locate facilities efficiently.

At UTHM KCP, navigation is primarily supported by physical signage and online information sources distributed across multiple platforms. The lack of a centralized navigation solution limits users' access to location-specific information about academic, administrative, and support facilities. This situation highlights the need for a more interactive and context-aware navigation system.

Therefore, UP-SIM is proposed as an AR-based solution that combines building visualization and navigation assistance within a single mobile application. By providing real-time visual guidance and facility identification, the system aims to improve wayfinding efficiency, enhance user experience, and contribute to the development of a smarter campus ecosystem.

1.2 Problem Statement

Efficient navigation and spatial orientation are essential for ensuring a positive campus experience. However, UTHM KCP currently lacks a centralized navigation system that provides guidance and building identification to users unfamiliar with the campus environment. Existing navigation aids, such as physical maps, university signage, and general web-based mapping applications, may provide limited support for accurate campus wayfinding, particularly when indoor locations and detailed route information are unavailable [4].

The lack of interactive, context aware navigation support may lead to confusion, inefficient route planning, delays, and increased reliance on manual assistance. These challenges are particularly evident among new students, visitors, and external stakeholders who have limited knowledge of the campus layout. Furthermore, current navigation methods do not fully leverage emerging technologies that can enhance users' spatial understanding and navigation efficiency.

Therefore, there is a need for an augmented reality-based navigation solution that provides building visualization and intuitive wayfinding assistance. The proposed UTHM-KCP Smart Interactive Map addresses this need by integrating AR technology, 3D building labels, and mobile navigation features to improve campus accessibility, enhance user experience, and support the university's smart campus development goals.

1.3 Objectives

This project aims to identify the content, building information, and navigation features required for the development of the UTHM-KCP Smart Interactive Map (UP-SIM). The project also seeks to develop an AR-based mobile application that provides building visualization within the UTHM KCP campus. In addition, the project aims to evaluate the usability, functionality, and effectiveness of the proposed system in supporting campus navigation and enhancing users' spatial awareness.

1.4 Scope

The scope of the project is limited to the UTHM KCP campus environment and focuses solely on outdoor navigation. The application is developed for Android devices and enables users to identify campus buildings using AR-based visual. Virtual building labels, and campus information are displayed via the mobile device camera to help users locate facilities efficiently. Low-polygon 3D building models are incorporated to ensure smooth performance on mobile devices. The evaluation focuses on usability, functionality, and effectiveness of AR tracking performance within the campus environment. Indoor navigation and indoor positioning functionalities are not included in the scope of this project.

1.5 Project Significance

The UP-SIM offers significant benefits to both the university and its campus community. By providing augmented reality (AR)-based building visualization, the application enables students, staff, and visitors to locate campus facilities more efficiently, reducing navigation time and dependence on manual guidance. This is particularly beneficial for new students and first-time visitors who may be unfamiliar with the campus layout.

From a user perspective, the application enhances spatial awareness by overlaying virtual building labels onto the real-world environment, making it easier to identify and understand the surrounding campus area. The application's intuitive, interactive nature also provides a more engaging experience than conventional maps and static information sources. At the institutional level, the project supports UTHM KCP's digital transformation and smart campus initiatives by demonstrating the practical application of augmented reality technology in higher education.

1.6 Multimedia Applications in Smart Campus

Multimedia applications integrate various forms of digital content, including text, graphics, animation, audio, and interactivity, to present information in more engaging and understandable ways. In higher education institutions, multimedia technologies are increasingly incorporated into smart campus initiatives to enhance communication, learning, and campus services [5]. Common applications include digital information systems, virtual campus tours, interactive wayfinding platforms, and online campus information portals that improve user access to information and services [2].

Among these applications, campus navigation systems have attracted significant attention for their ability to help students, staff, and visitors locate buildings and facilities efficiently. Multimedia-enhanced navigation solutions provide visual representations of campus environments, enabling users to better understand routes and destinations compared to conventional maps and static signage [2]. Recent advancements in augmented reality (AR) technology have further improved campus navigation by overlaying virtual information onto the real world, enabling users to identify buildings and receive real-time navigation guidance.

As university campuses continue to expand in size and complexity, AR-based multimedia applications offer a promising approach to enhancing spatial awareness, improving navigation efficiency, and enhancing the overall user experience. These technologies support smart campus objectives by providing intuitive, interactive, and context-aware access to campus information while promoting digital innovation within higher education institutions [6].

1.7 Digital Maps and Interactive Navigation Systems

Digital mapping systems have become a widely adopted solution for navigation and wayfinding in urban, institutional, and educational environments. Compared to conventional printed maps, digital maps provide interactive features such as location searching, route visualization, and real-time information access, enabling users to navigate more efficiently and effectively [6]. Interactive navigation systems further enhance this capability by providing contextual information, visual guidance, and location-specific services that improve user experience and support informed decision-making during navigation.

Despite these advantages, many existing digital campus maps continue to rely on static layouts and limited user interaction, providing only basic location information and failing to support effective spatial understanding and wayfinding [7]. Such limitations may confuse users who are unfamiliar with campus environments, particularly new students and visitors. Consequently, there is a growing need for more advanced navigation solutions that integrate interactive features and real-time visual guidance to improve building identification, spatial awareness, and navigation efficiency.

Recent developments in augmented reality (AR) technology have introduced new opportunities to enhance digital navigation systems by overlaying virtual information onto the real world. Through AR-based building visualization and navigation guidance, users can more easily identify destinations and understand their surroundings, making campus navigation more intuitive and user-friendly.

1.8 Campus Navigation and Wayfinding Challenges

University campuses are often complex environments comprising multiple academic buildings, administrative offices, laboratories, and student facilities distributed across large geographical areas. As campuses continue to expand, navigating these environments becomes increasingly challenging, particularly for new students, visitors, and external stakeholders who are unfamiliar with the campus layout [6]. Difficulties in locating destinations may result in increased travel time, user frustration, missed appointments, and a greater dependence on manual assistance from staff or other campus users.

Effective wayfinding requires users to identify their current location and determine their destination. However, unfamiliar surroundings and limited navigation support can make this process difficult, reducing navigation efficiency and overall user satisfaction. These challenges are especially significant in higher education institutions, where users frequently move between multiple facilities within a short period. Emerging technologies such as augmented reality (AR) offer promising opportunities to address these challenges by delivering real-time visual guidance and location-specific information directly within the user's environment.

1.9 Multimedia and User Experience in Navigation Systems

User experience plays a crucial role in determining the effectiveness of navigation systems. Multimedia elements such as visual cues, animations, interactive markers, and three-dimensional (3D) visualizations can improve users' understanding of spatial information by presenting content clearly and engagingly [2]. These features help users identify locations more easily, interpret navigation instructions effectively, and develop a better understanding of their surroundings.

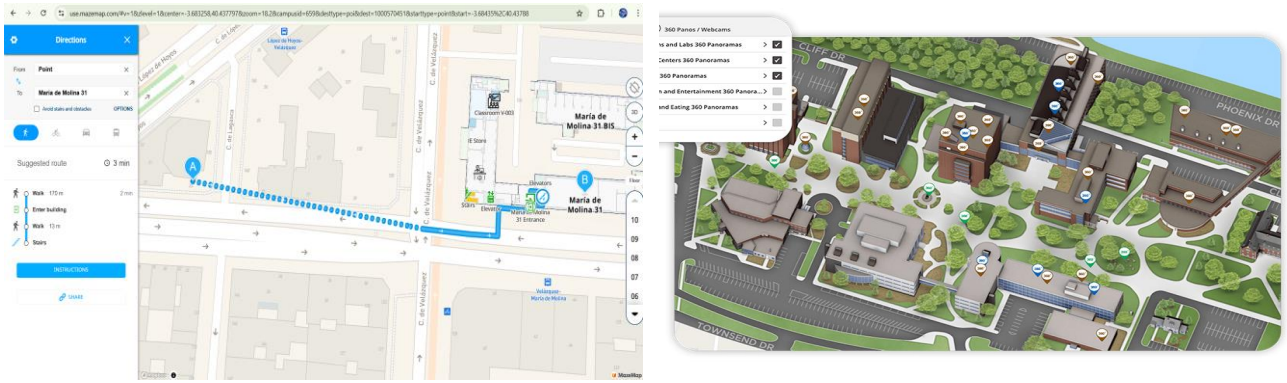
In navigation systems, intuitive interfaces and visual guidance can reduce cognitive load by simplifying complex spatial information and presenting it in a user-friendly format. This is particularly important in campus environments, where users often need to locate multiple buildings and facilities within a limited time. Effective navigation support enables users to make informed decisions, increasing confidence and reducing the likelihood of navigation errors [8].

Recent advancements in augmented reality (AR) technology have further enhanced the user experience by integrating digital information into the real world. Through AR-based building visualization and navigation guidance, users can receive contextual information directly within their field of view, improving spatial awareness and navigation efficiency. Therefore, integrating multimedia and AR technologies is essential for developing user-centered navigation solutions that enhance wayfinding performance, accessibility, and overall user satisfaction.

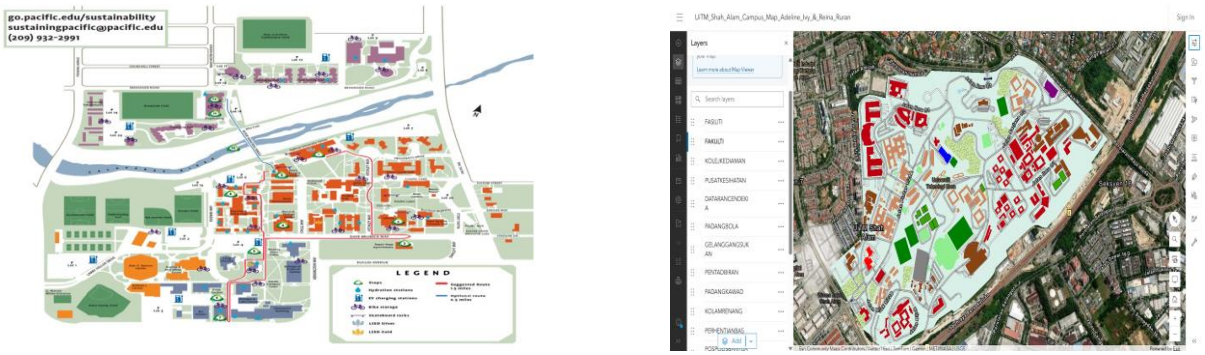
1.10 Related Works on Interactive Campus Mapping Systems

Various universities and organizations have implemented interactive campus mapping systems to improve navigation and accessibility within large campus environments. These systems incorporate different technologies and features, including interactive maps, virtual tours, location-based services, and wayfinding assistance, to help users locate facilities and navigate efficiently. Reviewing existing implementations is important for identifying current practices, strengths, and limitations that can inform the development of new campus navigation solutions.

Therefore, this section examines several existing campus mapping systems, namely MazeMap at the University of Queensland [9], Concept3D Interactive Campus Maps [10], the University of the Pacific Digital Campus Interface [11], and the UiTM Shah Alam Interactive Campus Map [12], as shown in Fig. 1. The review focuses on their key features, navigation capabilities, user experience, and technological approaches to identify research gaps and justify the development of the UTHM-KCP Smart Interactive Map (UP-SIM).



(a) **(b)**



(c) (d)

Fig. 1 *Several examples of interactive mapping systems (a) MazeMap University of Queensland; (b) Concept3D Interactive Campus Maps Interface; (c) University of the Pacific – Digital Campus Interface; (d) UiTM Shah Alam Interactive Campus Map*

1.10.1 MazeMap – University of Queensland

MazeMap is an interactive campus mapping platform implemented at the University of Queensland to support campus navigation and wayfinding [9]. The system provides both indoor and outdoor navigation, searchable points of interest, and accessibility-oriented routing features. By integrating spatial data with facility information, MazeMap enables users to locate buildings, rooms, and campus services efficiently. Its comprehensive navigation capabilities have made it a widely adopted solution in educational institutions and large organizational environments.

Despite its extensive functionality, MazeMap relies heavily on detailed spatial databases and third-party integration, which may increase implementation complexity and maintenance requirements. Furthermore, the system primarily focuses on route guidance and location services, offering limited support for augmented reality (AR)-based visualization that could further enhance users' spatial awareness and building identification. These limitations highlight opportunities for developing more interactive and visually engaging navigation solutions, such as the proposed UTHM-KCP Smart Interactive Map (UP-SIM).

1.10.2 Concept3D Interactive Campus Maps

Concept3D is a commercial interactive mapping platform adopted by numerous universities worldwide to support campus navigation and information delivery [10]. The system provides features such as turn-by-turn navigation, accessibility routing, and a content management system that enables administrators to efficiently maintain and update campus information. Its scalable architecture and user-friendly interface allow users to access location-based information and navigate campus environments effectively.

Despite its comprehensive functionality, Concept3D requires institutional licensing and substantial GIS integration, which may increase implementation costs and technical complexity. Furthermore, the platform primarily emphasizes web-based navigation and information management, offering limited support for augmented reality (AR)-based visualization and real-time building identification. These limitations present opportunities for developing more accessible and interactive navigation solutions that enhance spatial awareness through AR technology, such as the proposed UTHM-KCP Smart Interactive Map (UP-SIM).

1.10.3 University of the Pacific – Digital Campus Map

The University of the Pacific implemented a digital campus mapping system accessible through touchscreen kiosks and web-based platforms to support campus navigation and wayfinding [11]. The system allows users to search for locations, generate navigation routes, and transfer directions to mobile devices using QR codes. Its intuitive interface incorporates a top-down map view and visual legends that help users identify campus facilities and navigate more efficiently, thereby reducing reliance on manual assistance.

Despite its effectiveness in providing location-based information and route guidance, the system was primarily designed for large touchscreen displays and web access. As a result, its usability may be limited to mobile devices with smaller screens. Furthermore, the system relies on conventional map-based visualization and lacks augmented reality (AR) features that could enhance real-time building identification and spatial awareness. These limitations highlight the need for mobile-friendly navigation solutions that offer more interactive, context-aware guidance, such as the proposed UTHM-KCP Smart Interactive Map (UP-SIM).

1.10.4 UiTM Shah Alam Interactive Campus Map

An interactive campus map was developed at Universiti Teknologi MARA (UiTM) Shah Alam to improve the usability of conventional static maps and facilitate campus navigation [12]. The system incorporates interactive features that allow users to explore the campus layout and access location-specific information more effectively. The study reported improvements in user engagement and access to campus information, demonstrating the potential of interactive mapping systems to support wayfinding in university environments.

However, as an academic prototype, the system focused primarily on basic map interactivity and campus layout visualization. Its multimedia capabilities and evaluation scope were relatively limited, with less emphasis on advanced navigation technologies and real-time user guidance. Furthermore, the system did not incorporate augmented reality (AR)-based visualization to enhance building identification and spatial awareness. These limitations highlight opportunities to develop more interactive, context-aware navigation solutions, such as the proposed UTHM-KCP Smart Interactive Map (UP-SIM), which integrates AR technology to provide real-time visual guidance and building visualization.

1.11 Comparative Analysis of Existing Applications

A comparison of selected existing campus mapping systems was conducted to guide the design of the proposed UTHM-KCP Interactive Map.

Table 1 *Comparative analysis of existing applications*

Existing System	Platform	Multimedia	Accessibility	Interactivity	Contextual Info
MazeMap	Kiosk/Web	Low	Moderate	High (routing)	Moderate
Concept3D	Web/Mobile	Moderate	High	High	High
Univ. Of Pacific (Digital Map)	Web/Mobile	High	High	High	High
UiTM Interactive Map	Web	Low	Moderate	Moderate	Moderate

Table 1 highlights key aspects, including platform, multimedia capabilities, accessibility, interactivity, and the level of contextual information provided. Following the development of the map, this analysis helped identify features that could be further enhanced, integrated, or improved to better serve students, staff, and visitors.

The proposed system aims to combine high multimedia content, improved accessibility, interactive 3D navigation, and comprehensive contextual information to provide a more engaging and user-friendly campus experience.

2. Methodology

This section presents the research methodology adopted in the development of the UTHM-KCP Smart Interactive Map (UP-SIM), providing a structured and systematic approach to guide each stage of the development process from planning and design through to evaluation [13].

The Multimedia Development Life Cycle (MDLC) framework has been selected as the primary development methodology due to its structured and iterative approach, which is well-suited to the multimedia-intensive nature of the proposed system, consisting of six primary phases namely Concept, Design, Material Collection, Assembly, Testing, and Distribution as shown in Fig. 2, each of which will be described in detail in the following subsections.

2.1.1 Concept Phase

The concept phase established the objectives, scope, and functional requirements of the UTHM-KCP Smart Interactive Map (UP-SIM). This phase focuses on addressing navigation challenges faced by students, staff, and visitors when locating buildings and facilities within the campus environment. Requirements were gathered through discussions with the UTHM KCP Provost and other stakeholders to identify users' needs and determine the key features required for the system. The findings highlighted the need for an augmented reality (AR)-based navigation solution capable of providing real-time building visualization, navigation guidance, and campus facility information. In addition, suitable software tools and technologies were identified to support the development of the application. Blender was selected for creating low-polygon 3D building models, while Flutter was used for mobile application development. Unity and ARCore were integrated to provide AR functionality, enabling virtual building labels and navigation indicators to be displayed within the real-world environment. By

defining the system requirements, development tools, and expected outcomes, this phase established a clear foundation for the subsequent design and development stages.

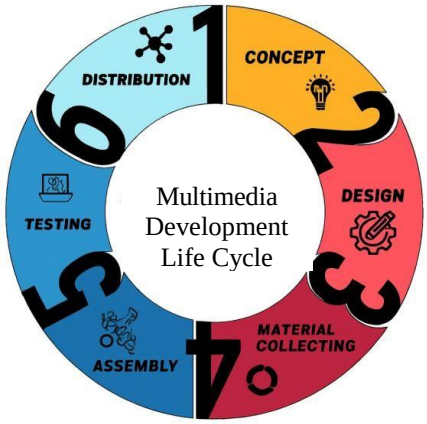


Fig. 2 *Methodology Development Life Cycle (MDLC) Model [13]*

2.1.2 Design Phase

The design phase focused on transforming the identified requirements into a structured blueprint for the UTHM-KCP Smart Interactive Map (UP-SIM). During this phase, the system architecture, user interface, navigation flow, and augmented reality (AR) visualization components were designed to deliver an intuitive, user-friendly experience. Wireframes and interface mock-ups were created to illustrate the application's main screens, including the home page, campus map, building information page, and AR navigation view. In addition, low-polygon 3D models of campus buildings were designed using Blender [14] to represent key facilities within the UTHM KCP environment. The AR navigation workflow was also planned, including the placement of virtual building labels and navigation indicators to help users identify destinations and navigate efficiently. The design outputs produced during this phase served as a reference for subsequent development and implementation, ensuring consistency between the project requirements and the final application.

2.1.3 Material Collection Phase

The material collection phase involved gathering all assets and information required for the development of the UTHM-KCP Smart Interactive Map (UP-SIM). This included collecting photographs of campus buildings, facility information, campus maps, and architectural references to support the creation of accurate three-dimensional (3D) building models and navigation content. Building photographs were captured on-site to document architectural structures, building appearances, and surrounding environments, while additional reference materials were obtained from official university sources where necessary.

Campus-related information, such as building names, facility descriptions, and location details, was also collected to ensure accurate representation within the application. Furthermore, official campus layouts and relevant spatial information were obtained through consultation with UTHM KCP personnel to support the development of navigation features and building visualization components. All collected materials were reviewed, organized, and optimized to ensure compatibility with the development tools and to maintain efficient application performance. The assets gathered during this phase served as the foundation for creating realistic building visualizations and providing reliable campus information within the AR-based navigation system.

2.1.4 Assembly Phase

The assembly phase involved integrating all multimedia assets, 3D models, and software components to develop the UTHM-KCP Smart Interactive Map (UP-SIM). During this phase, the low-polygon 3D building models created in Blender were imported into Unity and configured for use within the augmented reality (AR) environment. Building information, navigation data, and multimedia content were also integrated to ensure that users could access relevant facility information while navigating the campus.

The AR navigation functionality was implemented by integrating Unity with ARCore [15], enabling virtual building labels and navigation indicators to be displayed in the real world through the device's camera. Flutter was used to develop the mobile application interface and manage user interactions, including destination

selection and navigation requests. C# scripting was used to control AR visualization, building information display, and navigation.

Performance optimization was carried out throughout the development process to ensure smooth operation on mobile devices. This included optimizing 3D models, reducing asset sizes, and managing system resources to balance visual quality and application performance. At the end of this phase, the UP-SIM application was fully assembled and ready for functionality and usability testing. Fig. 3 illustrates the completed 3D building models of the UTHM-KCP campus, which were optimized and integrated into the AR-based mobile navigation application.

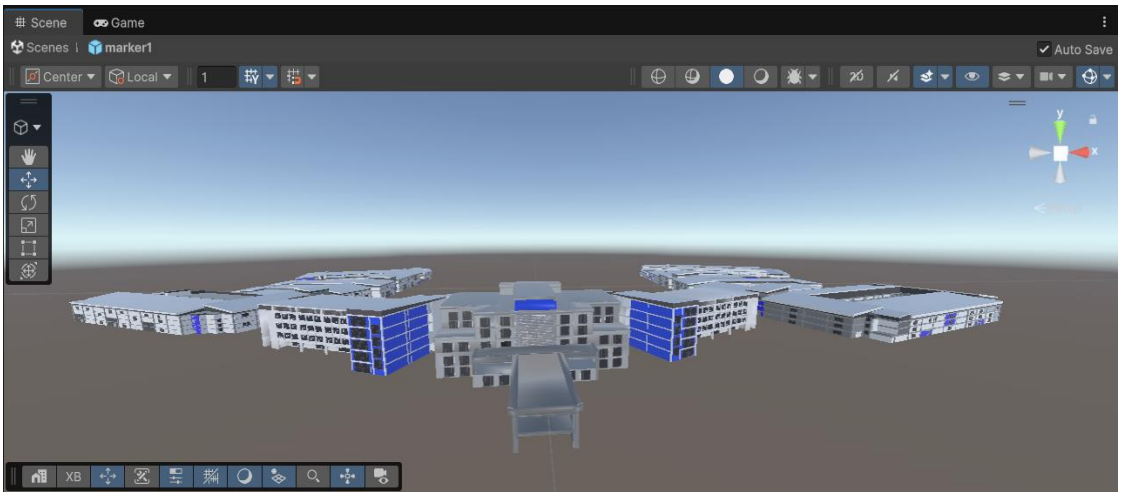
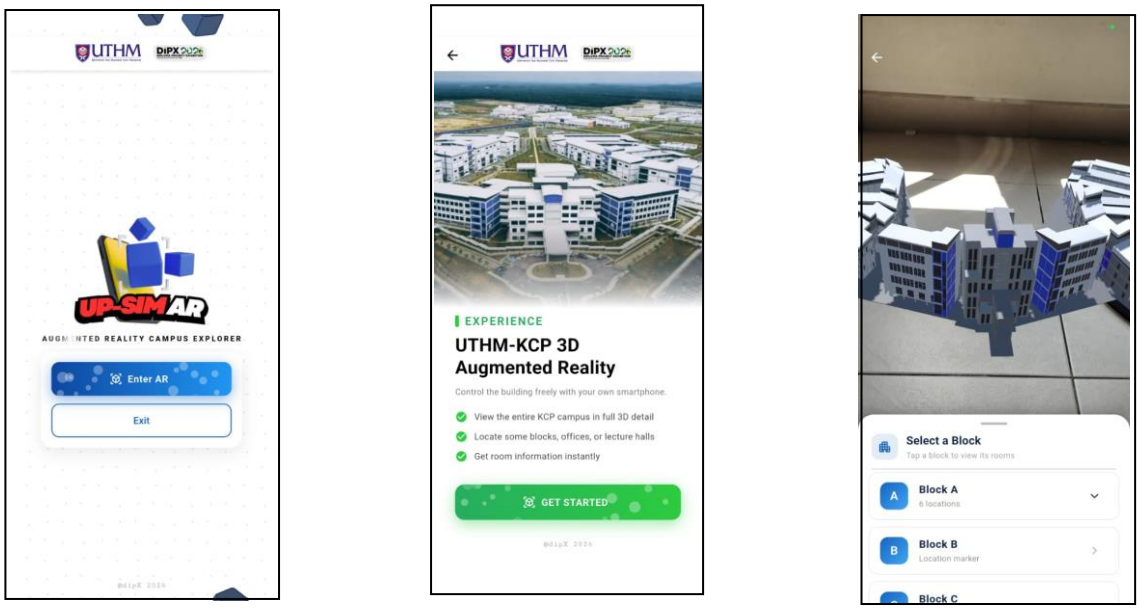


Fig. 3 *Visual representation of the digitalized UTHM-KCP campus structures*

Fig. 4 displays the interfaces of the app and the AR simulation. The 3D models, developed based on architectural layouts and reference materials gathered during the material collection phase, are adjusted to ensure accurate scaling, positioning, and orientation that closely reflects the actual campus layout, with on-site photographs and official floor plans used to maintain spatial and architectural accuracy throughout the construction process.



(a) **(b)** **(c)**

Fig. 4 *Some of the UP-SIM AR interfaces (a) UPSIM AR Home Screen; (b) UPSIM AR Landing screen; (c) UPSIM AR Interaction*

2.1.5 Testing Phase

The testing phase was conducted to evaluate the functionality, usability, and effectiveness of the UTHM-KCP Smart Interactive Map (UP-SIM). A group of students, staff, and visitors participated in the evaluation by performing navigation tasks, including locating campus buildings, and identifying facilities through augmented reality (AR) visualization within the UTHM KCP campus. These activities allowed the application to be assessed under realistic usage conditions.

A structured questionnaire was used to collect user feedback regarding the application's navigation experience, usability, and user experiences. In addition, functional testing was performed to verify the operation of key features, including building visualization, navigation guidance, information display, and AR tracking performance. The application was tested on compatible Android devices to evaluate system responsiveness, interface consistency, and the stability of AR elements in outdoor environments.

The collected feedback and test results were analyzed to identify potential improvements and ensure that the application met its intended objectives. Any issues related to usability, navigation accuracy, or AR visualization were addressed through refinements and optimizations before the system's final deployment.

2.1.6 Distribution Phase

The distribution phase involved preparing the UP-SIM for deployment and evaluation by its intended users. Prior to distribution, final system verification was conducted to ensure that all application features functioned correctly and that the system was stable for use on compatible Android devices. Supporting documentation, including installation instructions, user guidelines, and system requirements, was also prepared to facilitate user adoption.

As the project was developed primarily for academic and evaluation purposes, the application was distributed as an Android Package Kit (APK) rather than published on a public app store. To simplify access, a QR code was generated and included in the project documentation, allowing users to download the application from a designated cloud storage platform. This approach enables convenient installation and evaluation while eliminating the need for formal application store deployment.

The distribution phase also provided an opportunity to gather additional user feedback and identify potential enhancements for future development. Recommendations on navigation features, augmented reality visualization, and system performance were documented to support continued improvement and scalability of the UP-SIM application beyond the scope of this project.

3. Result and Discussion

In this section, surveys conducted during the testing phase were analyzed. Fig. 5 presents the average user ratings for three evaluation sections: Navigation Experience, Usability, and User Experience. Overall, most respondents selected Agree and Strongly Agree, indicating positive perceptions of the proposed UTHM-KCP Smart Interactive Map (UP-SIM).

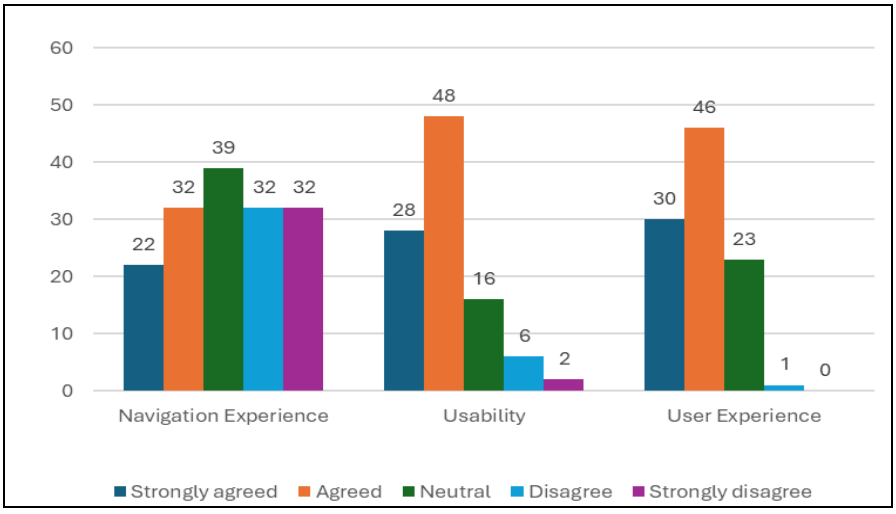


Fig. 5 *Distribution of user responses for navigation experience, usability, and user experience*

For the Navigation Experience section, the highest percentage of respondents selected Neutral (39%), followed by Agree (32%) and Strongly Agree (22%). This suggests that while respondents generally acknowledged the effectiveness of current campus navigation methods, many remained undecided regarding their overall satisfaction. The relatively low percentages of Disagree (5%) and Strongly Disagree (2%) indicate that only a small number of respondents experienced significant difficulties with existing navigation approaches.

In terms of Usability, respondents provided highly positive feedback: 48% agreed, and 28% strongly agreed that the system was easy to use and understand. Only 6% disagreed, and 2% strongly disagreed, while 16% remained neutral. These findings demonstrate that the application offers an intuitive interface and user-friendly interaction, enabling users to navigate the system effectively with minimal learning effort.

Similarly, the User Experience section recorded strong positive responses, with 46% agreeing and 30% strongly agreeing. Meanwhile, 23% selected Neutral, and only 1% disagreed, with no respondents strongly disagreeing. These results indicate that users were satisfied with the overall experience provided by the application, including its visual presentation, navigation assistance, and interactive features.

Overall, the findings show that users received the proposed UP-SIM application well. The high percentage of positive responses in the usability and user experience sections suggests that integrating augmented reality-based building visualization and navigation assistance successfully enhanced users' ability to locate campus facilities while providing an engaging, effective navigation experience. The low percentage of negative responses further indicates that the system met user expectations and achieved its intended objectives.

4. Conclusion

The UP-SIM was successfully developed as an AR-based mobile application to enhance campus navigation through real-time building visualization and wayfinding assistance. The system integrates Flutter, Unity, ARCore, and low-polygon 3D building models to provide users with an intuitive and interactive navigation experience. By displaying virtual building labels and navigation indicators in the real world, the application improves users' ability to identify campus facilities and navigate the UTHM Kampus Cawangan Pagoh (KCP) more efficiently.

The evaluation results demonstrated positive user perceptions of the application's usability, functionality, and overall user experience. Most respondents agreed that the system was easy to use, provided useful navigation assistance, and enhanced their understanding of the campus layout. These findings indicate that implementing AR technology can effectively improve spatial awareness and wayfinding performance while supporting the university's smart campus initiatives.

For future enhancement, the application can be extended to support indoor navigation, enabling users to locate specific rooms, laboratories, and offices within campus buildings. The accuracy and stability of AR navigation features can also be improved by integrating advanced positioning technologies and real-time location services. These improvements would further increase the usability, accessibility, and scalability of the UP-SIM application.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

Muhammad Ridzuan conceived and designed the study; Muhammad Ridzuan and Abdul Qayyum conducted the data collection and material gathering; Muhammad Ridzuan, Abdul Qayyum, and Daniel Arshad performed the system development, analysis, and interpretation of results; Rafizah was responsible for project supervision and manuscript editing.

Appendix A: Questionnaires

Section 1: Respondent's background
Q1: What is your current role at the university?
Q2: What is your primary purpose for visiting UTHM Pagoh Campus?
Q3: Gender
Q4: How often do you visit UTHM Pagoh Campus?
Q5: Are you familiar with using AR application before this survey?
Section 2: Current Navigation Experience
Q1: Do you sometimes have difficulty locating buildings or facilities on campus?
Q2: Are campus directional signs sufficient to help you navigate?
Q3: Do you feel confident navigating the campus without assistance?
Q4: Do you find printed campus map helpful when moving around?
Q5: Do visitors face difficulties finding locations within the campus?
Section 3: Usability
Q1: How easy was it to scan the QR code and launch the AR app?
Q2: How easy was it to learn the basic function of the AR app without prior training?
Q3: Did you feel confident using the AR app without needing extra help or instruction?
Q4: Did the AR help system correctly identify the designated location on campus?
Q5: How clear were the building labels?
Section 4: User Experience
Q1: Did the AR app help you reach your destination faster compared to traditional maps?
Q2: How engaging was the AR interface (visuals, interactivity)?
Q3: Would you recommend this AR app to new students or visitors?
Q4:Did you experience any lag, glitches, or tracking issues?
Q5: How satisfied are you with the accuracy of building placement in AR?
Section E: Open-Ended Feedback
Q1: What improvements would you suggest?
Q2: What features did you like most about the AR navigation?

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