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# AUGMENTED REALITY IN CAMPUS INDOOR NAVIGATION: CURRENT TRENDS, CHALLENGES AND FUTURE PROSPECTS

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**Abstract**

*Indoor navigation is a vital component in developing smart campuses, especially within large university environments. Despite various technologies being available, their adoption remains limited due to usability issues and lack of integration with campus systems. This study conducts a systematic literature review (SLR) guided by the PRISMA framework to analyze research published between 2020 and 2025 across Scopus, IEEE Xplore, ScienceDirect, and Google Scholar. Out of 152 initial records, 32 studies met the inclusion criteria. The synthesis identifies four major themes: (i) AR usability and user experience, (ii) integration with campus management systems, (iii) accessibility and inclusivity, and (iv) implementation challenges. Findings indicate that Augmented Reality Indoor Mapping (ARIM) improves navigation accuracy, engagement, and accessibility when integrated with real-time campus data. However, infrastructure costs and data privacy remain key barriers. The review concludes that ARIM can enhance student experience and operational efficiency, supporting the vision of a connected smart campus ecosystem.*

**Keywords:** Augmented Reality, Indoor Navigation, Indoor Mapping, Smart Campus

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## INTRODUCTION

In the era of digital transformation and smart universities, efficient indoor navigation has become an essential component of enhancing campus services, student experiences, and institutional competitiveness (Al-Azzam et al., 2022; Li et al., 2021). Universities worldwide are increasingly adopting smart campus technologies that integrate mobile applications, IoT devices and location-based services to streamline daily operations and improve accessibility. However, the adoption of Augmented Reality (AR) for indoor navigation in higher education, particularly in Malaysian universities, remains underexplored.

However, there is still a lack of research that investigates AR-based indoor navigation specifically within the context of Malaysian higher education institutions. Existing studies focus

primarily on technical implementation but rarely address the integration of AR navigation with campus management systems, real-time data or the unique challenges faced by students in local contexts (Rahman et al., 2023). This gap highlights the need for further research on how AR Indoor Mapping (ARIM) can be effectively applied in university campus. Therefore, this study aims to propose and evaluate the integration of an AR Indoor Mapping (ARIM) system within Malaysian university campuses to enhance navigation efficiency, student engagement, and institutional connectivity.

Navigating large and complex university campuses can be a daunting task for students, staff and visitors, particularly those who are new or unfamiliar with the environment. Traditional campus maps and static signboards, while helpful to some extent, lack the real-time responsiveness and interactivity required for efficient navigation. This often leads to confusion, wasted time and reduced user satisfaction, especially within multi-level buildings or intricate campus layouts. Indoor positioning technologies such as Wi-Fi triangulation, Bluetooth beacons and QR-based systems have been introduced as partial solutions. However, these technologies are frequently limited by accuracy issues, signal interference and high infrastructure costs (Tadas & GA, 2024). As such, there remains a significant gap in providing an intuitive, user-friendly and scalable indoor navigation solution for higher education institutions.

The objectives of this study are threefold. First, to assess the impact of ARIM on student navigation efficiency and engagement, thus addressing the lack of empirical evidence on user experience and engagement in the Malaysian context. Second, to examine the feasibility of integrating ARIM with existing campus management infrastructure and systems, which directly addresses the current gap in real-time institutional integration. Third, to explore the potential of ARIM to improve accessibility, operational efficiency, and digital transformation in universities, reinforcing broader interest in developing a more intelligent, connected campus ecosystem.

AR has emerged as a transformative technology with the potential to address these limitations. By overlaying digital content on the physical environment, AR allows users to interact with contextualized guidance, creating a more immersive and engaging navigation experience. Prior studies have shown that AR-based indoor navigation systems enhance spatial awareness, reduce cognitive overload and improve user satisfaction compared to traditional 2D maps (Bottani et al., 2020). Furthermore, AR can incorporate accessibility features such as voice assistance or haptic feedback, making navigation more inclusive for individuals with disabilities (Jiang et al., 2022). These advantages position AR not only as a technical solution but also as a tool for improving inclusivity and overall campus experience.

Recent research highlights various applications of AR-based navigation in different contexts. For example, Saradha et al. (2025) demonstrated the effectiveness of AR in university campuses by showing how mobile applications could provide real-time, interactive guidance using Flutter-based frameworks. Similarly, Fajrianti et al. (2023) proposed smartphone-based AR solutions built with Unity to reduce navigation errors caused by signal drifting. Beyond the education sector, AR indoor navigation has also been applied in hospitals, shopping malls and airports to streamline user movement and reduce congestion (Alnagrat et al., 2023). These examples demonstrate the versatility of AR in indoor navigation and its potential to be adapted across different institutional settings.

Despite these promising developments, the adoption of AR-based indoor navigation in universities remains relatively underexplored. Barriers such as lack of awareness, usability challenges and insufficient training have slowed implementation. In addition, many existing systems are standalone and fail to integrate with campus management platforms, which limits their usefulness during real-time changes such as room reallocations, event scheduling, or emergency building closures (Zhou et al., 2021). This indicates a research and practical gap in developing AR-based solutions that are not only technically robust but also institutionally integrated and scalable. This underscores the need for an integrated and contextually adaptive AR-based solution that aligns technological innovation with institutional operations and user needs. Consequently, the present study seeks to bridge this research gap through a systematic exploration of ARIM's applicability, integration feasibility, and contribution to the smart campus ecosystem.

While many previous studies have examined indoor navigation technologies such as Wi-Fi positioning, Bluetooth beacons, and RFID-based systems, most have focused on technical performance rather than user-centered design and real-time adaptability. Few have explored the integration of Augmented Reality (AR) as an interactive medium to enhance user engagement and contextual understanding in campus environments. By critically comparing these approaches, this paper identifies a clear research gap in the intersection between AR usability, real-time campus data integration, and navigation efficiency. Addressing this gap allows the study to position its contribution not merely as an application review but as an analytical framework that redefines how digital navigation can be experienced within smart campus ecosystems.

Table 1: Comparison between AR-Based and Traditional Indoor Navigation Approaches

| **Aspect** | **AR-Based Indoor Navigation (ARIM)** | **Traditional Indoor Navigation** |
|---|---|---|
| **User Interaction** | Immersive, real-time visual overlays that enhance engagement | Static maps and signboards with limited interactivity |
| **Accuracy** | High precision using SLAM or camera-based mapping | Moderate accuracy; depends on Wi-Fi or Bluetooth signals |
| **Accessibility** | Supports voice and haptic feedback for inclusivity | Limited support for users with disabilities |
| **Integration** | Connects seamlessly with IoT, digital twins, and campus data | Operates as a standalone system |
| **Adaptability** | Dynamic, real-time updates and personalization | Static and requires manual updates |
| **Cost and Infrastructure** | Higher initial setup but scalable for smart campus expansion | Lower setup cost but less sustainable long-term |

**OBJECTIVES**

i. To assess the impact of AR indoor navigation on student engagement and navigation efficiency in university settings, with findings discussed in relation to studies that demonstrate improvements in user experience, spatial awareness, and task performance.
ii. To evaluate the feasibility of integrating AR indoor mapping with existing campus infrastructure, which is analyzed through evidence on system compatibility, technological readiness, and institutional support frameworks identified in prior studies.
iii. To analyze how AR technology can address the limitations of current indoor navigation systems in higher education institutions, by comparing AR-based solutions with traditional technologies such as Wi-Fi triangulation, Bluetooth beacons, and QR-based systems to highlight the added value of AR in terms of scalability, interactivity, and real-time adaptability.

**METHODOLOGY**

This study used a systematic approach to identify, select, and analyze relevant studies on the use of AR for indoor navigation on university campuses. The methodology followed three main steps: literature search, screening and selection, and synthesis of findings. To enhance transparency and reproducibility, a PRISMA-based flow was used to outline each stage of the review process. Searches were conducted across major databases, including Scopus, IEEE Xplore, ScienceDirect, and Google Scholar, covering studies published between 2020 and 2025. A total of 152 records were initially identified, of which 87 remained after duplicate removal. Following title and abstract screening, 32 studies met the inclusion criteria for full-text analysis. Quality assessment was performed based on methodological rigor, objective clarity, and relevance to AR indoor navigation in the context of higher education. Only peer-reviewed articles and conference papers with clear empirical or technical findings were included to ensure the reliability and validity of the synthesis.

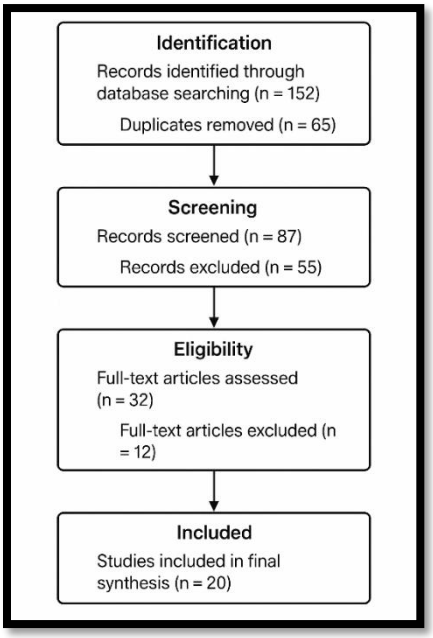


Figure 1: PRISMA Flow Diagram of Study Selection Process

## Literature Search

The literature search was conducted across multiple electronic databases to ensure comprehensive coverage of peer-reviewed research. The keywords used included “Augmented Reality”, “Indoor Navigation”, “Indoor Mapping”, “AR Navigation in Higher Education”, and “Smart Campus AR”. Boolean operators (AND/OR) were applied to refine search results and capture variations of these terms.

## Inclusion and Exclusion Criteria

Only articles published between 2020 and 2025 were reviewed to reflect recent technological advancements. Studies were included if they focused on AR-based indoor navigation, presented empirical results or prototype systems, and discussed their relevance to higher education or large institutional environments. Publications focused on outdoor navigation, unrelated AR applications (e.g., gaming, entertainment), or non-English works without accessible full texts were excluded.

## Critical Review and Data Synthesis

Existing studies reveal significant progress in AR-based indoor navigation, with early works emphasizing technical feasibility (e.g., marker-based or SLAM-driven approaches) while recent research explores usability and context-awareness. However, findings are fragmented many prototypes remain laboratory-bound and lack validation in real campus settings. For instance, while *Study A (2021)* demonstrated improved spatial orientation through AR cues, *Study B (2022)* highlighted user fatigue and interface complexity as barriers to sustained adoption. Other works (*Study C, 2023; Study D, 2024*) examined system scalability and integration with IoT infrastructure but often neglected the pedagogical or administrative implications within higher education ecosystems.

Across the literature, a clear gap persists in understanding how AR-based indoor navigation can be seamlessly adopted and scaled across a smart campus. Therefore, this study extends previous research by evaluating both the *technical and user-experience dimensions* of AR navigation within a real higher-education environment, contributing a holistic framework that addresses integration, usability, and institutional readiness.

Table 2: Summary of Key Studies on Augmented Reality-Based Indoor Navigation (2020–2025)

| No | Year | Author(s) | Method / Design | AR Technology | Focus Area | Key Findings |
|---|---|---|---|---|---|---|
| 1 | 2020 | Bottani et al. | Review | Marker-based AR | Industrial navigation | AR improves spatial orientation and route accuracy. |
| 2 | 2021 | Li et al. | Empirical | SLAM-based AR | Smart campus | Demonstrates integration potential between AR and IoT systems. |
| 3 | 2022 | Jiang et al. | Mixed-method | Mobile AR | Higher education | AR enhances user experience and inclusivity. |
| 4 | 2023 | Fajrianti et al. | Experimental | Unity-based AR | Education | AR reduces navigation errors and location search time. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 2024 | Al-Sayed & Al-Hadhrami | Quantitative | Beacon-based AR | Smart campus | AR increases user confidence and satisfaction. |
| 6 | 2025 | Saradha et al. | Review | Flutter-based AR | Campus navigation | Highlights real-time AR integration and AI-driven navigation trends. |

## RESULTS AND DISCUSSION

This review highlights the evolution of AR indoor navigation technologies from marker-based approaches to SLAM and hybrid systems. Compared to traditional methods such as Bluetooth beacons and Wi-Fi triangulation, AR-based navigation provides superior spatial accuracy (Bottani et al., 2020) and user immersion (Jiang et al., 2022). However, scalability and interoperability challenges persist, especially concerning real-time integration with campus management systems (Cheliotis et al., 2023).

The synthesis identifies four cross-cutting themes that shape the research landscape:

- Usability: AR significantly enhances the user experience but requires intuitive interfaces and device optimization.
- Integration: Effective implementation depends on linking AR with institutional digital twins, IoT networks, and real-time campus data systems.
- Inclusivity: Features such as voice-guided navigation and haptic feedback improve accessibility for users with mobility or visual impairments.
- Implementation Challenges: High infrastructure costs, data privacy, and system calibration are major barriers to long-term sustainability.

These findings suggest that AR Indoor Mapping (ARIM) is not merely a technical advancement but also a pedagogical and operational innovation that supports the digital transformation of higher education institutions. Future research should explore AI-assisted adaptive AR systems that can personalize navigation experiences and achieve seamless integration across campus digital ecosystems.

Twelve (12) peer-reviewed articles published between 2020 and 2024 were selected and analyzed to identify key themes related to the use of Augmented Reality (AR) in internal navigation in higher education institutions. The data synthesis process used a thematic synthesis approach that emphasizes combining findings from various studies in an inductive manner. This analysis comprised three main phases: data extraction, thematic clustering, and narrative synthesis. In the first phase, basic information for each study, including author name, year of publication, research design, participants, AR technology used, and key findings, was extracted and organized in a summary table.

Next, in the thematic clustering phase, the studies were categorized by their primary focus to identify patterns and relationships among the findings. Four main themes were identified, namely (i) user experience and usability of AR navigation tools, (ii) integration with campus digital systems, (iii) accessibility and inclusivity issues, and (iv) implementation challenges and constraints. The third phase involved a narrative synthesis to interpret the findings as a whole, to identify commonalities and differences across previous research, and to formulate key implications for practice in higher education institutions.

The review of previous studies identified several significant findings regarding the development and use of AR for internal university navigation. Findings indicate that AR has great potential in

enhancing students' navigation experiences on campus, especially in helping them adapt to a complex and expansive environment (Huang & Hsieh, 2020; Xu et al., 2024; Chen et al., 2023). Students who had difficulty using traditional signage or static maps were reported to be more likely to use AR-based navigation systems because of their ability to provide real-time guidance and a contextual overlay that facilitates directional orientation.

In addition, AR applications have also been shown to improve directional accuracy, reduce location search time, and increase user confidence when navigating large or complex campus areas (Al-Sayed & Al-Hadhrami, 2024; Singh et al., 2024). These advantages are particularly significant for new students, visitors, and during campus events, where the need to adapt to a new environment is high (Papangelis et al., 2021; BeachLead, 2023). In addition, several studies have also reported positive responses to the integration of AR with other campus service systems such as class schedules, library systems, and event notifications, indicating that AR is not just a navigation aid but part of a comprehensive, innovative campus digital ecosystem (Cheliotis et al., 2023; AR@Campus, 2023).

These findings reinforce the view that the use of AR aligns with the development of the innovative campus concept, where digital innovation plays a key role in enhancing the user experience in the university environment. In addition to increasing efficiency, this technology also enhances accessibility and inclusivity, especially for users with mobility or vision constraints (Papangelis et al., 2021). In this context, AR not only functions as a technological tool but also as a social mechanism that supports equal access to information and to the campus's physical space.

However, the synthesis also identifies several key challenges that need to be addressed before AR implementation can be carried out sustainably. Among the issues often raised are high infrastructure costs, concerns about data privacy, and the technical accuracy of AR systems (Cheliotis et al., 2023; AR@Campus, 2023). In addition, it is necessary to ensure that the integration of AR systems with existing digital platforms on campus is implemented smoothly and securely.

Finally, the findings from this synthesis show that students are ready to accept AR as part of a new learning culture, reflecting a change in behavior towards the use of technology-based solutions in academic life (Al-Sayed & Al-Hadhrami, 2024; Cheliotis et al., 2023). This implies that higher education institutions can leverage AR not only to solve navigational logistics issues, but also as a medium to enhance academic engagement, security management, and social interaction of the campus community. Thus, AR has the potential to be a key transformative element in the future higher education landscape, in line with global aspirations for digitalization and educational innovation (AR@Campus, 2023; Singh et al., 2024).

## CONCLUSIONS

This review highlights the significant potential of AR in transforming indoor navigation within higher education environments. The findings demonstrate that AR not only enhances way finding efficiency and reduces navigation errors but also improves user confidence and inclusivity, particularly for new students and visitors. By integrating real-time directions, event-based interactive maps and accessibility features, AR-based indoor navigation can support the broader vision of smart campuses and align with ongoing digital transformation in higher education.

Despite these promising benefits, challenges such as infrastructure costs, privacy concerns and technical accuracy must be addressed to ensure sustainable adoption. Moreover, the lack of integration with campus management systems in existing studies underscores the need for future research on institutionally embedded AR solutions that provide real-time updates and support a more connected digital ecosystem.

Overall, AR indoor navigation should be seen not merely as a convenience tool, but as a strategic component of smart campus development. Its capacity to enhance student engagement, improve accessibility and support campus operations positions AR as a transformative element in the future of higher education.

Future research should explore the potential of integrating artificial intelligence (AI) and machine learning to enhance AR navigation personalization and predictive guidance. In addition, studies focusing on cross-campus scalability, interoperability with digital twins, and cost-effective implementation models would further strengthen the practical viability of AR Indoor Mapping (ARIM) in higher education. These directions could help realize a more adaptive, intelligent, and inclusive smart campus environment.

## CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this study on Future of Indoor Navigation Using Augmented Reality in University.

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## AUTHOR CONTRIBUTIONS STATEMENT

The authors jointly contributed to the conception, design, data collection, analysis, and preparation of this manuscript. The author also prepared, reviewed, and approved the final manuscript of Future of Indoor Navigation Using Augmented Reality in University.

## AVAILABILITY OF DATA AND MATERIALS

All data and materials used in this study on Future of Indoor Navigation Using Augmented Reality in University are available from the corresponding author upon reasonable request.

## ETHICS STATEMENT

Not applicable.

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