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A SMART 3D CAMPUS NAVIGATION SYSTEM WITH AR INTEGRATION AND SECURE ACCESS

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Abstract

It can be difficult for new students, visitors, and event-goers to get around big college campuses. Conventional GPS-based systems do not help much, as they do not support indoor navigation, offline mapping, and secure access. This paper suggests NavMate, a Smart 3D Campus Navigation System that incorporates Augmented Reality (AR), 3D mapping, and QR-based secure authentication. The platform supports secure log- in via Student, Teacher ID QR codes or temporary visitor access, maintaining data privacy and usage control. In real time, directional arrows and markers are superimposed over the physical world through AR technology, offering interactive indoor and outdoor guidance. A graph-based path algorithm optimizes route planning between destinations, and interactive 3D campus map facilitates visualization of locations with zoom and rotation functions. NavMate is also offline-capable and has an event and exam hall finder to help with scheduling academic activities. Through the integration of accessibility, interactivity, and security, the system improves the experience

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of its users and helps in realizing a contemporary, smart campus setup.

Keywords: Augmented Reality (AR), Smart Campus, 3D Navigation System, QR-based Authentication, Pathfinding Algorithm, Secure Access Control, Indoor Navigation, Outdoor Wayfinding, ARCore, Unity 3D, Location-Based Services (LBS), Graph-based Routing, Event Locator.

I. Introduction

Universities in today's digital age are transforming into smart campuses places where technology integration unifies people, information, and infrastructure. Even in these advanced settings, however, one of the most typical issues is comm basic: getting to the right place at the right time. For new students, visitors, or event attendees, to navigate a big and complicated campus is very often a stressful and time- consuming experience. Confusion regarding building plans, unfamiliar corridors, and unavailability of good directions can impact not only effectiveness but also the overall experience of being a part of an academic organization.

Classic navigation aids such as Google Maps or generic GPS- enabled apps serve outdoor purposes but fail when inside. They do not supply indoor navigation and even lack offline

Functionality, and they altogether do not have secure access controls a primary consideration when working within an institutional perimeter. Within an education environment where privacy, security, and limited access are paramount, these shortcomings render such traditional systems unsuitable.

To counter these practical challenges, this paper proposes NavMate, a Smart 3D Campus Navigation System with AR Integration and Secure Access. NavMate uses Augmented Reality (AR) to superimpose real-time visual directions on the physical environment, rendering an engaging and intuitive experience. Using 3D mapping, users are able to navigate the entire campus in a collaborative fashion, visualizing pathways, buildings, and indoor layouts in a natural and engaging manner. A secure login system based on QR guarantees that students and visitors use the platform via authenticated credentials ensuring both convenience and confidentiality.

In contrast to traditional apps, NavMate can run even without an internet connection, utilizing locally stored data for offline navigation. It uses graph-based pathfinding algorithms to calculate the shortest and most efficient paths, enabling swift and precise movement from one point to another. Additionally, event and exam hall locators make its use extend beyond navigation, making it a digital guide for various day-to-day activities on campus.

With accessibility, intelligence, and human-centered design, NavMate redefines how individuals connect with their environments. It takes static campus maps and turns them into dynamic, living systems that react to the user's context and requirements. In the process, it contributes to

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the larger vision of designing smarter, safer, and more connected learning environments where technology helps people, but not just guides them, really improving their experience within the campus framework.

II. Literature Review:

Over the past decade, researchers have increasingly explored the integration of Augmented Reality (AR), 3D mapping, and QR-assisted navigation for improving indoor and outdoor positioning within campus environments. A review of existing literature highlights significant advancements, while also pointing out the limitations that motivate the development of a more secure, scalable, and offline-capable navigation system like NavMate.

Armenakis and Sohn [1] developed iCampus, a 3D digital campus model for York University using aerial imagery and LiDAR. This project demonstrated the potential of creating highly accurate campus-scale digital twins and immersive 3D visualizations. However, the system was primarily visualization-oriented and did not provide interactive real- time navigation or indoor positioning capabilities, limiting its use for practical wayfinding.

Rajagopal et al. [2] proposed an AR-based navigation system using Unity and ARCore, which displayed arrows and markers in real-time on mobile devices. Although effective outdoors, their system encountered challenges indoors, such as drift errors due to limited ARCore tracking and the absence of multi-floor routing support.

Liu and Zhang [3] presented a QR code–based indoor navigation approach, where QR markers were distributed across buildings to guide users. This method was cost- effective and simple to deploy, but its heavy reliance on frequent scanning reduced usability in large campuses where continuous navigation without interruptions is expected.

Fajrianti et al. [4] introduced INSUS, a hybrid indoor navigation system combining AR-based guidance with strategically placed QR checkpoints. Their solution effectively reduced AR drift errors by recalibrating user positions at checkpoints. However, the requirement of, repeated rescanning made the system less seamless and reduced user experience quality.

Putra et al. [5] designed an adaptive AR navigation system that integrated ARCore, NavMesh, and the A* pathfinding algorithm to improve route optimization. While the solution demonstrated strong usability and accuracy, its reliance on high computational resources made it unsuitable for deployment on low-end smartphones, thereby limiting scalability in real-world educational institutions.

Oyeman et al. [6] developed an interactive kiosk with 3D mapping and campus directories. This system offered excellent visualization and information access but lacked mobility and portability, since kiosks are fixed installations that do not assist users once they leave the kiosk location.

Nikoohemat [7] explored the creation of smart campus digital twins by integrating

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OpenStreetMap with CAD floor plans. This work showed how comprehensive 3D campus environments could be built to support mapping applications. However, it did not incorporate AR visualization, indoor navigation, or secure user access mechanisms, making it primarily a mapping solution rather than a navigation system.

Nordin et al. [9] proposed a web-based mobile AR navigation system for Universiti Utara Malaysia using ARToolKit. Their solution supported AR overlays for lecture halls, labs, and offices that were not covered by Google Maps. While users successfully interacted with the system, it lacked strong security features and suffered from limited adaptability to large-scale deployments.

Das et al. [10] worked on Indoor Campus Navigation Using AR, developed using Unity, ARCore, and AR Foundation. Their approach introduced drop-down destination selectors, mini-maps, and AR markers, enhancing usability. However, the system lacked offline support and secure authentication, which are critical for controlled environments like universities.

Oyeman et al. [6] (kiosk study) and Bendre et al. [11] (AR- VR campus navigation) both emphasized the potential of immersive visualization, but scalability remained a challenge, as these systems were often limited to specific devices or static setups.

Zhang et al. [8] investigated security flaws in QR-based login systems, showing vulnerabilities such as malicious QR codes, phishing attacks, and session hijacking. Their findings underline the importance of designing secure QR-based authentication mechanisms in any navigation system intended for sensitive environments like educational campuses.

Finally, Nikoohemat [7] and Oyeman et al. [6] highlighted the role of digital twins and 3D kiosks in smart campus initiatives, but their solutions were more infrastructure-dependent than mobile-oriented.

Year	Author(s)	Method/ Contribution	Limitation
2009	Armenakis & Sohn [1]	Developed iCampus, a 3D campus model using aerial imagery and LiDAR	Focused only on visualization; no real-time or interactive navigation.
2021	Rajagopal et al. [2]	AR-based navigation using **Unity + ARCore** with real-time arrows and markers.	Indoor drift errors; lacked multi-floor routing.
2022	Liu & Zhang [3]	QR code–based indoor navigation for cost-effective deployment.	Required frequent scanning; poor usability in large campuses
2023	Fajrianti et al. [4]	**INSUS**: Hybrid AR navigation with QR checkpoints to reduce drift.	Needed repeated QR scans; limited validation at large

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			scale.
2023	Putra et al. [5]	Adaptive AR navigation using **NavMesh + A*** algorithm for optimized routing	High computational load; poor performance on low-end smartphones
2023	Das et al. [10]	Indoor campus navigation using **Unity, ARCore, ARFoundation, and NavMesh**.	Lacked offline support; no secure authentication for controlled access.
2021	Nordin et al. [9]	Web-based AR campus navigation.	Limited scalability; weak security features.
2024	Oyeman et al. [6]	**ARToolKit** for lecture halls & labs; interactive 3D kiosk system with stationary maps and directories for campuses.	Kiosk-based system; not portable; no real-time mobile navigation.
2024	Bendre et al. [11]	AR/VR-based immersive campus navigation application at **MIT-WPU**.	Device-dependent; not optimized for offline or secure use.
2021	Nikoohemet et al. [7]	Smart campus map using **OpenStreetMap + CAD integration** for digital twins.	Mapping-focused; lacked AR navigation and adaptive routing.
2025	Zhang et al. [8]	Security analysis of **QR-based login systems (QRLoginChecker)**.	Identified vulnerabilities; did not propose AR navigation integration.

Table I: Literature Review Summary

III. Proposed System

The proposed system, NavMate, is an Augmented Reality (AR) 3D Smart Campus Navigation Application that combines AR, 3D modeling, QR-based secure authentication, and graph-based shortest path algorithms in order to provide seamless navigation to students, employees, and visitors. In contrast to current AR-alone or kiosk-based systems, NavMate prioritizes portability, offline use, and data security such that users are provided with continuous guidance through both indoor and outdoor campus spaces.

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By integrating engaging AR overlays with interactive 3D maps and safe authentication mechanisms, NavMate helps users find classrooms, laboratories, offices, and event halls and also makes digital campus management better. The system has scalability incorporated into it for further expansion to become an extensive smart campus ecosystem that includes IoT-based information, analytics, and real-time services.

A. Objectives:

The key aims of the proposed system are as follows:

AR-Based Navigation: To create an AR-powered mobile app that can place visual navigation guidance arrows, labels, and direction indicators over the user's real-time camera feed for instant, intuitive, and immersive navigation.

Indoor and Outdoor Integration: To combine GPS outdoors with markerless AR indoor navigation with optional QR landmarks to recalibrate. This mixed method provides accuracy in varied environments.

Graph-Based Pathfinding: To deploy effective graph algorithms like Dijkstra's or A* for shortest path calculation with optimal paths between buildings, rooms, and event spaces, even in the case of multi - floor layouts.

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3D Interactive Campus Map:

To create a 3D interactive campus map with pan, zoom, and rotate functionality. This visualization helps in pre-navigation orientation and augmenting spatial knowledge.

To provide QR-based login for secure and controlled access. Students log in through institutional ID QR codes, whereas visitors are issued temporary access credentials, thus protecting data and ensuring authorized use of the system.

Event and Exam Hall Locator:

To facilitate easy identification and navigation to particular venues, e.g., examination halls or seminar rooms, eliminating confusion at academic or administrative events.

Offline-First Design:

To provide consistent performance using local mapping and navigation caching, to allow seamless functionality even in low or no-connectivity areas.

B. System Architecture

The system utilizes a modular architecture, where every component has a specific function but is used in collaboration with the other components to offer real-time

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navigation and protection. The architecture consists of five primary modules.

User Interface (UI) Module:

Provides a user-friendly interface for user interaction, such as destination choice, faculty search, and AR overlay visualization. Presents directional guidance, text labels, and building information through an interactive 3D map. Accessibility features are enabled to include every user.

Pathfinding Engine:

The SmartARPath Engine decides the shortest and optimal path between the user and destination based on a combination of Dijkstra's and A* algorithms. The campus is mapped as a graph, with nodes indicating important locations and edges indicating walkable routes. The engine monitors continuous user movement and dynamically recalculates routes in the event of deviation or obstruction of paths, providing adaptive and precise navigation.

Database Module:

Stores important datasets such as 3D building models, node– edge information, user profiles, event calendars, and QR authentication logs. Supported with SQLite, this module offers offline caching to provide continuity in navigation independent of the internet.

AR Visualization Module:

Created with Unity AR Foundation and ARCore (Android) and ARKit (iOS), this module manages real-time rendering of AR overlays.

It employs Simultaneous Localization and Mapping (SLAM) to synchronize virtual markers (arrows, labels, and direction pointers) with the environment as perceived by the mobile camera.

Secure Access Module:

Utilizes QR-based authentication to limit system access to approved users such as students, lecturers, and authenticated visitors. Indoor checkpoints for location recalculation are also made using QR codes to improve positional accuracy in AR navigation.

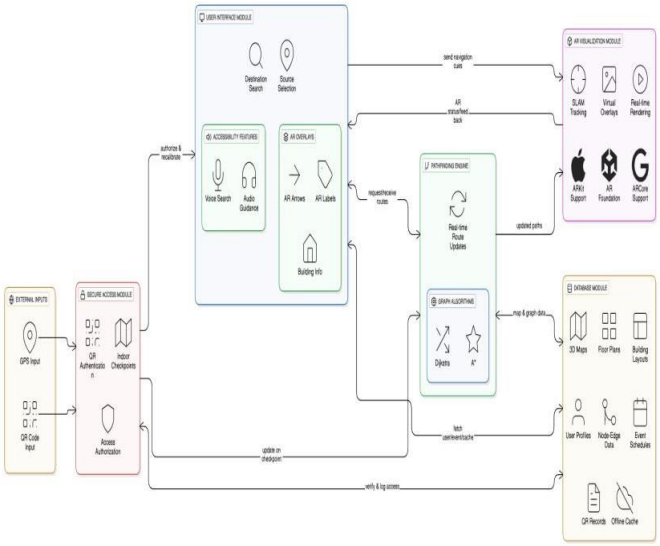

Fig. 1. System Architecture of NavMate

C. System Workflow:

The system workflow of NavMate is intended to provide smooth interaction between the user interface, database, pathfinding engine, and AR visualization

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module. The process is technologically sound and user-friendly as well, coping with typical navigation issues including indoor drift, low connectivity, and route deviation. Sequential system workflow is as follows.

App Initialization and Authentication:

The user initiates the NavMate mobile application. At start- up, the Secure Access Module requests authentication. Students authenticate by scanning their institutional ID QR code, while visitors sign up for temporary access through a visitor QR pass. This step secures that only legitimate users have access to the navigation system, ensuring institutional data integrity.

Destination Selection:

Upon successful authentication, users are offered an interactive 3D campus map with a search and filter interface. They can navigate manually, utilize text search queries (e.g., "Room 203"), or choose from a set of predefined categories like classrooms, labs, offices, or event spaces to facilitate quick and natural navigation configuration.

Database Retrieval:

Once the destination has been chosen, the Database Module loads corresponding datasets such as building plans, 3D map models, and node–edge graph structures. If the user is working offline, pre-cached data is loaded automatically to provide seamless functionality and maintain consistent performance irrespective of connectivity.

Pathfinding and Route Optimization:

The SmartARPath Engine determines the optimal route between the current location and destination through hybrid graph-based algorithms (A* and Dijkstra's). QR checkpoints positioned strategically indoors serve as recalibration nodes to reduce AR positional drift and enhance location accuracy. The calculated path is then enriched with contextual information like floor changes, directional arrows, and proximal landmarks, for a more intuitive and context-rich navigation experience.

AR Visualization and Navigation:

The AR Visualization Module turns on the smartphone camera and superimposes virtual navigation components— such as arrows, labels, and markers—onto the live stream directly. For example, an arrow can point in the direction of a hallway or a label can say "Library – 50 m ahead." The system updates AR overlays dynamically in real time as the user navigates the campus, providing correct and immersive directions.

Deviation Management and Recalculation:

When the user strays from the route, the system automatically perceives positional shifts using Simultaneous Localization and Mapping (SLAM) technology integrated with GPS and IMU sensor inputs. The pathfinding engine computes a new optimal route and the AR module immediately adjusts on- screen overlays to route the user back on track without human intervention.

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Error Handling and Offline Mode:

When GPS precision degrades outdoors, the system switches to cached AR placement or prompts for a QR checkpoint rescan to realign.

In case of AR drift indoors, users are asked to rescan an immediate QR marker to regain spatial accuracy.

When offline mode is in place, navigation still takes place smoothly from precached maps and graph data until internet connection returns.

User Feedback and Learning:

When the destination is reached, the user is prompted to provide instant feedback for accuracy and general experience. This is retained in the system database and used in incremental updates to optimize pathfinding effectiveness, AR alignment, and user satisfaction in later versions.

IV. Expected Results and Discussion:

The designed NavMate system is expected to revolutionize navigation on university campuses via the combination of AR-based overlays, secure QR authentication, and offline map capability. These aspects are expected to collectively enhance navigation accuracy, efficiency of performance, user satisfaction, and security of the system. The anticipated results are presented below:

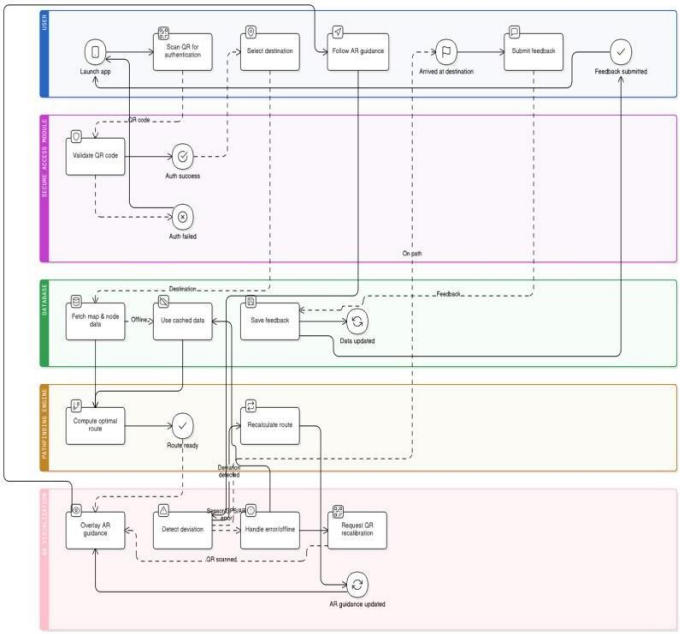

Fig. 2. Workflow of NavMate

A. Navigation Accuracy:

Outdoor Navigation:

With GPS technology, NavMate should provide 1.5–2.0 meters of positioning accuracy, which should be sufficient for differentiating buildings, walkways, and outdoor event spaces on the campus. Although this fits within the typical accuracy range of contemporary smartphones, NavMate improves accuracy with graph-based route optimization to minimize GPS drift errors.

Indoor Navigation:

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By incorporating QR checkpoint recalibration and markerless AR tracking, the system seeks to minimize positional drift errors to less than 1 meter. This addresses a typical shortcoming of ARCore-only systems, where tracking drift grows over time. Carefully placed QR markers on key junctions provide real-time accurate localization even in multi-floor and intricate indoor areas.

B. User Experience:

Immersive AR Guidance:

With AR overlays, users will have intuitive direction arrows, floating labels, and contextual cues directly displayed on the camera view to provide an immersive and seamless wayfinding experience. For instance, a user looking for "Exam Hall 204" will have virtual direction arrows leading them along the corridor with real-time labels like "Exam Hall – 50 m Ahead".

Interactive 3D Maps:

The addition of an interactive 3D campus map enables users to pan, zoom, and rotate to visually navigate their environment. It provides added spatial awareness, especially for new students or guests, and serves as a planning tool prior to starting navigation.

Convenience and Utility:

Other functionalities like event and exam hall finders, faculty finder, and visitor registration further improve usability. These features reduce disorientation and time during peak hour times like orientation programs, university fests, and exams.

C. System Performance:

Pathfinding Efficiency:

The SmartARPath Engine, which is driven by Dijkstra's and A* algorithms, will be able to calculate optimized routes within less than three seconds, even for multi-building or multi-floor routes. This provides minimum waiting time between the selection of destinations and initiation of navigation.

AR Rendering Stability:

Built with Unity's AR Foundation and ARCore/ARKit integration, the system is supposed to run at a frame rate of over 25 FPS on current-day smartphones. The performance ensures AR overlays render with minimal lag and without hiccups in real-time navigation.

Offline Functionality:

NavMate has an offline-first architecture, allowing seamless usage even in regions with poor or no connectivity—like basements, auditoriums, or off-campus sites. All the necessary information, such as building floor plans, 3D models, and graph topology, are stored locally, overcoming one of the biggest weaknesses of current AR-based navigation systems, which are too internet-live dependent.

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D. Security and Accessibility:

Secure QR-Based Login:

The QR authentication process distinguishes between students, staff, and visitors. Students have full functionality through institutional QR codes, whereas visitors get limited tokens. This grants access to navigation data under control and bars unauthorized use of campus information.

Safety from QR Exploits:

Unlike insecure QR implementations found in previous research, NavMate includes session verification, encrypted tokens, and time-limited authentication, which prevents session hijacking, phishing, and malicious QR tampering.

Accessibility and Inclusivity:

Subsequent versions of NavMate will focus on universal accessibility, such as voice guidance, haptic output, and multi-lingual functionality. These will render the system accessible to non-English speakers and differently-abled individuals, which is in sync with the values of smart, inclusive campus planning.

V. Future Work:

While the envisioned NavMate system is anticipated to offer secure and engaging campus wayfinding, there are a number of areas left to exploit in future development and research. As technology evolves, NavMate may become a more scalable, intelligent, and accessible platform that goes beyond mere wayfinding to be an integral part of smart campus infrastructure.

A. Scalability:

The prototype as of now is intended to navigate a few buildings on campus. Future development will revolve around optimizing 3D models and bringing cloud rendering and streaming into play to service the visualization of large campuses with hundreds of buildings. By outsourcing heavy processing to cloud servers, the system can take the processing load off smartphones and maintain smooth performance even on mid-end devices. This scalability will enable NavMate to be deployed within multi-campus universites or city-scale edu-hubs".

B. Advanced Indoor Positioning:

Though QR checkpoints allow cheaper indoor accuracy improvement, sole reliance on QR codes can restrict seamless navigation. Subsequent implementations are likely to incorporate next-generation technologies like:

- Visual-Inertial Odometry (VIO): To enable indoor tracking continuously by leveraging camera data and motion sensors.
- Bluetooth Low Energy (BLE) Beacons: To enable indoor positioning via signal triangulation with 1–3 meters accuracy.
- Ultra-Wideband (UWB): Providing centimeter-order accuracy indoors, appropriate for navigation within labs, libraries, or big exam rooms.

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A combination of AR tracking, QR markers, and wireless signals in a hybrid method can greatly minimize errors and enhance robustness in complicated indoor spaces.

C. Real-Time Adaptability:

The existing system delivers static optimized paths. Future implementations can integrate Internet of Things (IoT) sensors and crowd-monitoring systems to allow real-time adjustability. For example, on campus events or exam days, NavMate would be able to sense congested hallways or obstructed passages and reroute users to alternative pathways. Likewise, IoT-capable fire alarms or security notifications can reconfigure navigation routes automatically during emergencies, improving safety and efficiency.

D. Accessibility and Inclusivity

Subsequent releases of NavMate will focus on inclusivity by adding multimodal navigation interfaces, including:

- Voice navigation for blind passengers.
- Haptic feedback (vibrations) for turn-by-turn directions without having to glance at the phone.
- Multilingual interface support for foreign students or tourists.

By making maps accessible to everyone, NavMate can be used by a greater population base, upholding the cause of inclusive education and digital equity.

E. Cross-Platform Deployment

The first deployment will focus on Android phones with ARCore support, while long-term development will also support iOS phones through ARKit. Apart from smartphones, NavMate would also find applications in wearable technologies like smart glasses, AR headsets, or smartwatches, allowing for hands-free navigation. Faculty members, security personnel, and event planners would especially benefit from hands-free options in time-critical environments.

F. Integration with Smart Campus Ecosystems:

Long-term enhancement will place NavMate in more than a navigation role by extending it to the overall smart campus infrastructure. Extended possibilities are:

- Digital Twin Platforms: Developing an active digital twin of the campus to be monitored and planned.
- Smart Attendance Systems: Marking attendance automatically as students enter classrooms through QR- based or location-based authentication
- Event Notifications: Giving real-time notice of campus events, exam timetables, or room allocations.
- Campus Security Services: Aid in emergency management by leading students to safety areas or exits

With these integrations integrated into it, NavMate can potentially shift from an

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independent navigation app to be the central platform for smart campus activities.

VI. Conclusion:

This paper introduced NavMate, a Smart 3D Campus Navigation System that combines Augmented Reality (AR), secure QR-based authentication, offline usage, and graph-based pathfinding to transform campus navigation. The system closes the indoor-outdoor navigation gap, delivering an intelligent, user-focused experience for students, teachers, and guests within university settings.

Taking advantage of immersive AR overlays and interactive 3D mapping, NavMate provides natural and precise real-time navigation, allowing users to easily find classrooms, laboratories, administrative offices, and event facilities. Integrating features like event and exam hall locators, faculty directory access, and offline map functionality makes navigation more convenient, dependable, and usable in various use contexts. Secure QR-based authentication provides safe access, authenticating users while protecting institutional data.

The suggested architecture showcases the possibility of integrating AR technology, smart algorithms, and 3D visualization to develop an interactive and effective navigation system. NavMate not just enhances the user experience but also facilitates campus digitalization efforts by encouraging intelligent infrastructure management and green mobility habits.

In addition, this work provides the foundation for future integration with IoT-based real-time monitoring, digital twin spaces, and AI-powered personalization, making NavMate a cornerstone of the smart campus ecosystem.

In summary, NavMate represents the next wave of campus navigation—smart, inclusive, safe, and scalable. It makes daily navigation more engaging while supporting the overall vision of creating interconnected, tech-enabled educational institutions for the future.

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