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HYBRID PROGRESSIVE WEB APP (PWA) NAVIGATION SYSTEM FOR COLLEGE CAMPUS

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Abstract: Large college campuses are often difficult to navigate, especially for new students and visitors. GPS works well outdoors but is unreliable inside buildings. To address this, we developed a Hybrid Progressive Web App (PWA) that combines outdoor GPS navigation with indoor QR-based checkpoint tracking. GPS is used for campus-level guidance, while indoor navigation is performed by scanning QR codes placed at key locations or by manually selecting the current position. Each QR code represents a node in a pre-modeled indoor graph, enabling shortest-path routing using algorithms such as Dijkstra or A*. The system also detects route deviations and automatically recalculates the route when a new location is confirmed. The application supports start/stop navigation sessions and can function offline after initial installation, providing a reliable and scalable solution for campus navigation.
Keywords: *Hybrid Navigation, Campus Navigation, Progressive Web App, Indoor Localization, QR Navigation, Graph Algorithms, A* Algorithm, Dijkstra, Offline Navigation, Route Optimization, Geolocation, Smart Campus*

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I.INTRODUCTION:

Modern college campuses function like mini-cities with multiple buildings, hostels, laboratories and facilities spread across large areas. For freshers, visitors and even staff, navigating to the correct classroom or office can be confusing and time-consuming. Applications like Google Maps provide outdoor navigation but do not effectively support structured indoor navigation or campus-specific requirements.

To solve this problem, we propose a Hybrid PWA Navigation System that combines outdoor GPS guidance with indoor QR-based checkpoint navigation.

1.1 HYBRID LOCATION TRACKING MODEL

The system uses a hybrid tracking approach:

- Outdoor Navigation: GPS is used for campus-level guidance (e.g., parking to building entrance).
- Indoor Navigation: Location is confirmed through QR code scanning or manual user selection.

The UI displays the last confirmed location with a timestamp (e.g., “Updated 10s ago via QR”), ensuring transparency without continuous tracking.

1.2 QR-BASED INDOOR NAVIGATION

QR codes act as nodes in a pre-modeled indoor graph. When a user scans a QR, the system identifies the exact location and computes the shortest path using deterministic graph algorithms such as Dijkstra or A*. This ensures accurate and repeatable routing without relying on unstable indoor GPS signals.

1.3 ROUTE DEVIATION AND RE-ROUTING

Since continuous tracking is not used, deviation is detected when:

- The user does not reach the expected QR within a set time.
- The user scans a QR outside the planned route.

Upon new location confirmation (QR scan or “I’m here” manual input), the system automatically recalculates the best route.

1.4 ADDITIONAL FEATURES

- Multi-stop Routing: Supports limited chained routes (A→B→C).
- Start/Stop Session Control: Users can begin and end navigation sessions.
- Offline PWA Mode: After initial install, indoor maps, QR scanning and routing work offline. Data syncs when the internet is restored.

II LITERATURE SURVEY

2.1 EXISTING CAMPUS NAVIGATION APPROACHES

When we began analysing existing campus navigation systems, we observed that most research heavily focuses on continuous indoor positioning techniques such as Bluetooth Low Energy (BLE) beacons, WiFi fingerprinting, inertial sensor fusion, and camera-based localization. Systems like PEOPLEx: A BLE-based Indoor Localization Framework (2023) and BLE-PDR Integrated Floor Plan Navigation by Pan et al. (2025) report high positioning accuracy of nearly 1–2 meters. Similarly, Leitch (2023) – Ultra-Wideband Positioning Accuracy Analysis demonstrated 10–30 cm precision using UWB.

However, these systems rely on continuous tracking infrastructure, which increases cost, complexity, and energy consumption. Moreover, most of them are designed primarily for indoor-only environments and do not smoothly integrate outdoor campus-level navigation. In a college campus, users constantly move between parking areas, open spaces, and academic buildings. This transition between outdoor and indoor spaces remains poorly handled in many studies.

Another critical limitation is inclusivity and practical usability. Many technically advanced systems emphasize positioning accuracy but give limited attention to accessibility support, simplicity, or emergency responsiveness. For large academic campuses, a lightweight and user-confirmed approach may sometimes be more scalable and reliable than infrastructure-heavy continuous tracking.

To address these challenges, our system adopts a GPS + QR-based hybrid confirmation model instead of continuous sensor tracking. This approach reduces infrastructure dependency while maintaining reliable positioning through user-confirmed checkpoints.

2.2 PROGRESSIVE WEB APPLICATIONS IN NAVIGATION

Progressive Web Applications (PWAs) have emerged as a lightweight and efficient alternative to traditional mobile applications. Studies such as Blessing (2024) and Thomas & Kumar (2024) highlight that PWAs improve user adoption due to their cross-platform compatibility, low storage requirements, and install-free nature. Unlike native mobile applications, PWAs run directly in a web browser and can be added to the home screen without requiring large downloads. This makes them particularly suitable for student environments where users may have limited storage space or different types of devices.

PWAs also provide strong offline capabilities through caching and service workers, allowing applications to function even without continuous internet connectivity. While PWAs are widely used in education platforms and digital resource-sharing systems, their application in hybrid indoor-outdoor navigation remains limited. Very few studies explore how PWAs can support offline routing, QR-based checkpoint navigation, or emergency alerts in large campus settings. Therefore, integrating PWA technology with a hybrid GPS and QR-based navigation framework presents a scalable, accessible, and reliable solution for modern college campuses.

2.3 HYBRID INDOOR–OUTDOOR NAVIGATION TECHNOLOGIES

Hybrid navigation technologies aim to combine multiple positioning methods to improve accuracy and reliability. Existing research, such as Pan et al. (2025) on BLE-PDR integration and Leitch (2023) on Ultra-Wideband positioning, demonstrates that combining BLE, WiFi, IMU sensors, and UWB can significantly reduce localization errors. While UWB offers centimeter-level precision, it is expensive and energy-intensive, whereas BLE and WiFi are more affordable but typically provide only moderate accuracy. Most hybrid systems therefore rely on continuous sensor fusion to balance cost and performance.

However, these approaches are largely infrastructure-dependent and focus primarily on technical accuracy rather than scalability and practical deployment in college campuses. Continuous tracking also increases complexity and maintenance requirements. In contrast, our system adopts a lightweight hybrid model that integrates GPS for outdoor navigation with QR-based indoor checkpoint confirmation. Instead of continuous tracking, routing is performed on a pre-modeled indoor graph using deterministic shortest-path algorithms, enabling reliable, offline-capable, and scalable navigation without expensive infrastructure.

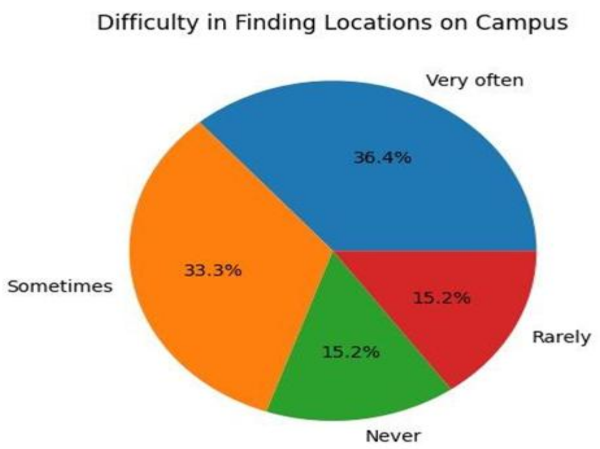
2.4 RESEARCH GAP

A review of existing studies such as PEOPLEx (2023), Pan et al. (2025), and Leitch (2023) shows that most navigation systems focus heavily on achieving high indoor positioning accuracy using continuous tracking technologies like BLE, WiFi, IMU, or UWB. Although these systems provide impressive precision, they often require costly infrastructure and complex maintenance, which limits their scalability in large college campuses. Moreover, many solutions treat indoor and outdoor navigation separately and do not ensure a smooth transition between GPS-based outdoor guidance and indoor positioning.

Additionally, limited research explores lightweight, infrastructure-free approaches such as QR-based checkpoint navigation combined with Progressive Web Applications (PWAs). Offline functionality, emergency responsiveness, and user-controlled session-based navigation are rarely considered core features. Therefore, there exists a gap in developing a unified, scalable, and user-friendly hybrid navigation system that integrates outdoor GPS with indoor QR-based confirmation tracking through an offline-first PWA framework.

2.5 CAMPUS-LEVEL LITERATURE SURVEY AND USER FEEDBACK

To better understand real-world navigation challenges within the campus environment, a structured survey was conducted among students, faculty members, and non-teaching staff. The objective of this survey was to identify common navigation difficulties, user expectations, and the practicality of implementing a hybrid navigation solution. Responses indicated that many students, especially first-year students and visitors, face confusion while locating classrooms, laboratories, administrative offices, and event venues. Participants also highlighted difficulties during crowded hours and examination periods when quick navigation becomes essential.



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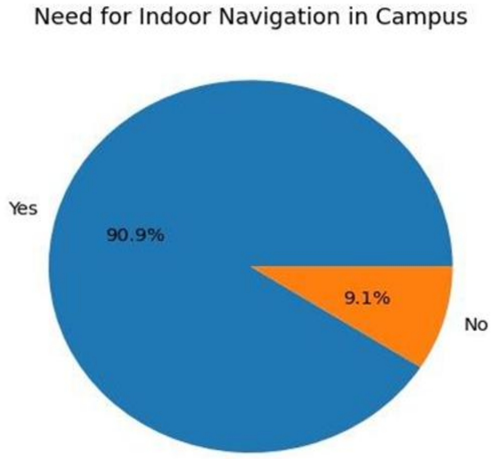
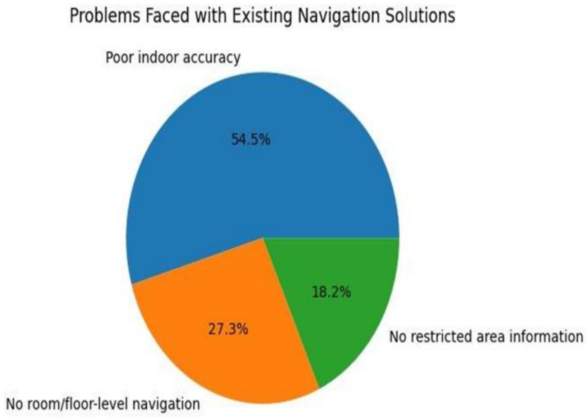




Above are the results we get after collecting all the data.

III METHODOLOGY

The proposed Hybrid PWA Navigation System follows a layered methodological architecture that integrates outdoor satellite-based positioning with deterministic indoor graph-based routing. The methodology is divided into five core components: spatial modeling, outdoor localization, indoor localization using QR nodes, shortest path computation, deviation detection and re-routing, and offline PWA deployment architecture. The system is designed specifically for structured environments such as college campuses where predictable movement corridors and defined building entry points exist.

3.1 Frontend Development and Progressive Web Application Framework

The user interface of the proposed campus navigation system is developed using React, a widely used JavaScript library for building interactive and component-based user interfaces. React enables efficient rendering of dynamic elements such as map markers, route paths, and navigation instructions through its virtual DOM architecture.

This improves the responsiveness and scalability of the application, especially when handling real-time navigation updates.The application is implemented as a Progressive Web Application (PWA) using modern web standards. A PWA allows the web application to behave similarly to a native mobile application while remaining accessible through a web browser. Service workers are used to cache application assets and map data locally, enabling offline functionality after the initial load. This feature is particularly useful in indoor campus environments where internet connectivity may be inconsistent.

3.2 Backend Framework

For designing the responsiveness across multiple device types, the system utilizes Tailwind CSS. Tailwind CSS is a utility-first CSS framework that allows developers to build responsive and modern user interfaces directly through predefined styling classes. The framework significantly reduces the need for custom CSS and accelerates development while maintaining design consistency throughout the application.The mapping functionality of the navigation system is implemented using Leaflet, an open-source JavaScript library designed for interactive map rendering. Leaflet enables the visualization of campus maps, navigation routes, and location markers with high performance and minimal resource consumption. The library provides essential map interaction features such as zooming, panning, route polyline drawing, and marker placement.The geographic data used in the system is sourced from OpenStreetMap (OSM). OpenStreetMap is a collaborative open-source mapping platform that provides detailed geographic data for roads, buildings, and pathways. The use of OSM allows the navigation system to integrate campus-level mapping data without relying on proprietary mapping services. Additionally, OSM data can be customized to include campus-specific pathways, building outlines, and entry points required for navigation within the Sandip Foundation campus.

3.3 Spatial Modeling of the Campus Environment

The first stage of the methodology involves converting the physical campus infrastructure into a computational graph model. The entire Sandip Foundation campus is divided into two spatial categories: outdoor navigable space and indoor structured space.

For outdoor navigation, major campus landmarks such as parking areas, academic blocks, hostels, cafeteria, and administrative buildings are modeled as geo-referenced nodes using latitude and longitude coordinates. Entry points to each building are marked as transition nodes between outdoor and indoor environments.

For indoor navigation, each building is modeled as a weighted graph G=(V,E)G = (V, E)G=(V,E), where:

VVV represents QR checkpoint nodes placed at corridors, staircases, junctions, elevators, and room clusters.

EEE represents navigable connections such as hallways, stair links, and floor connectors.

Edge weights represent actual walking distances between nodes.

Each QR code corresponds uniquely to a graph vertex. This ensures deterministic location confirmation rather than probabilistic estimation. Unlike Wi-Fi fingerprinting or BLE triangulation methods, this approach eliminates signal noise and drift, making the system computationally stable and infrastructure-light.

3.4 Outdoor Localization Using GPS

Outdoor navigation is implemented using the HTML5 Geolocation API embedded within the Progressive Web Application framework. When a navigation session begins, the system retrieves real-time GPS coordinates of the user device and maps them to the nearest outdoor graph node.

The outdoor navigation phase is restricted to guiding users from their current GPS location to the nearest entry node of the selected building. This design decision ensures that GPS inaccuracies (typically ±5–8 meters in campus environments) do not affect indoor navigation precision.

The path between the current location and building entry point is computed using the same shortest path algorithm framework applied indoors, ensuring architectural consistency across the system.

To optimize performance and reduce unnecessary sensor usage, GPS tracking is activated only during an active navigation session and deactivated once the user confirms entry into the building via QR scan.

3.5 Indoor Localization Using QR Checkpoint Confirmation

Indoor localization in the proposed system does not rely on continuous tracking sensors. Instead, it uses a checkpoint-based deterministic localization model.

When a user enters a building, they scan a QR code placed at a strategic location such as the entrance corridor. Each QR code contains a unique identifier mapped to a specific graph node. Upon scanning, the system:

- Confirms the exact indoor vertex location.
- Records timestamp of confirmation.
- Initiates shortest path computation from that node to the destination.
- This methodology ensures absolute indoor position accuracy at every confirmed checkpoint. Since the user explicitly validates their location through QR scanning, the system eliminates cumulative error common in dead-reckoning or inertial measurement systems.

Additionally, the system provides a manual location selection interface for cases where QR scanning is temporarily unavailable, ensuring robustness in real-world scenarios.

3.6 Graph-Based Shortest Path Computation

Figure 1: System Architecture of Hybrid PWA Navigation System For College Campuses

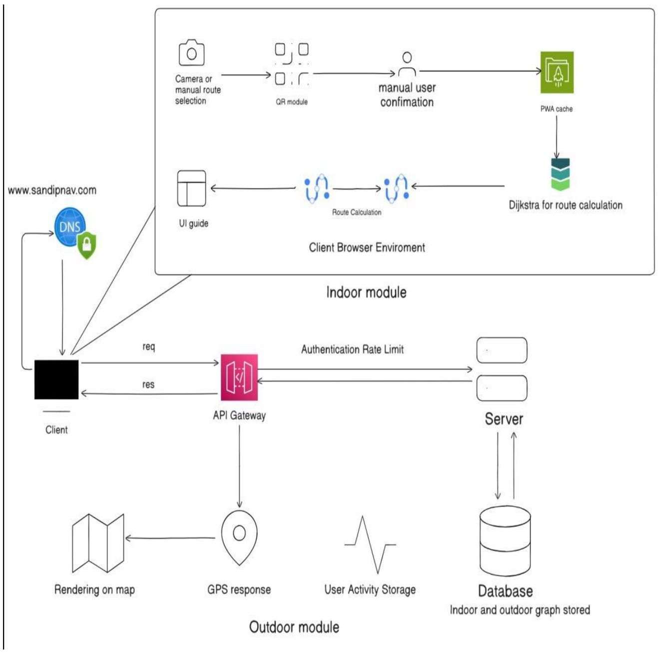


Figure 2: Landing Page of Hybrid PWA Navigation System For College Campuses

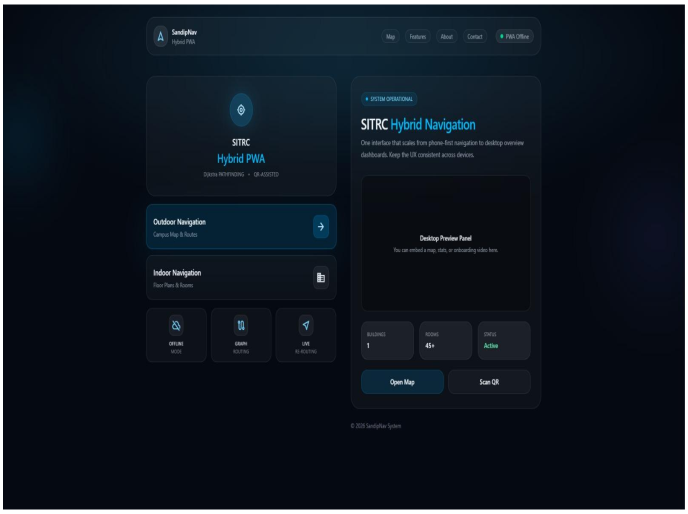


Figure 3: Map of Hybrid PWA Navigation System For College Campuses

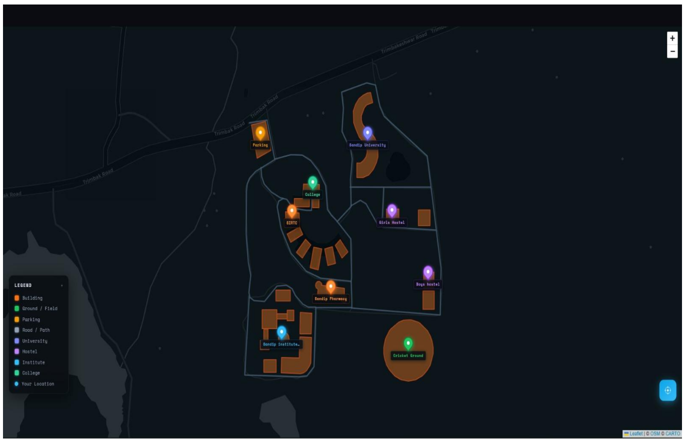


Figure 4: Features Page of Hybrid PWA Navigation System For College Campuses

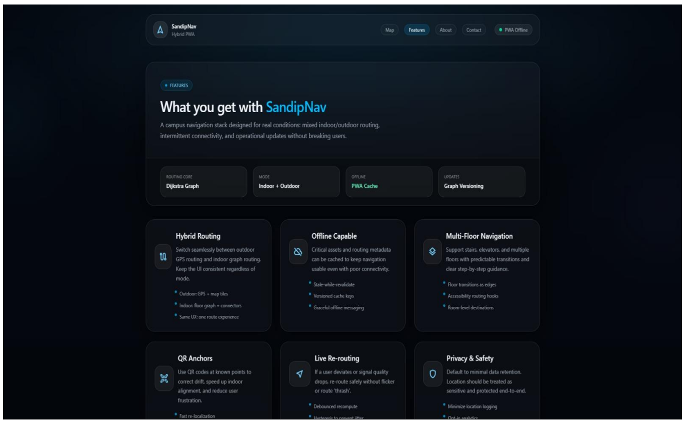
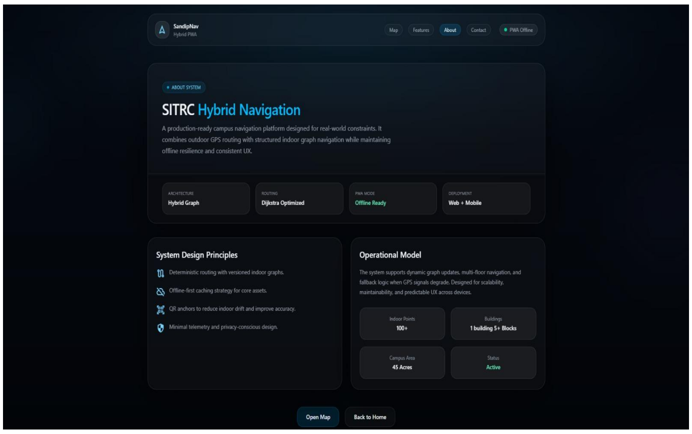


Figure 5: About Page of Hybrid PWA Navigation System For College Campuses



IV CONCLUSION

The proposed Hybrid PWA Campus Navigation System provides a scalable and cost-effective solution for large institutions such as Sandip Foundation. By combining outdoor GPS guidance with indoor QR-based checkpoint navigation, the system ensures accurate and reliable routing without relying on expensive continuous tracking technologies.The use of graph-based shortest path algorithms, deviation detection, and offline PWA functionality enhances system efficiency, usability, and accessibility. Overall, the solution successfully bridges the gap between indoor and outdoor navigation while remaining lightweight, practical, and suitable for real-world campus deployment.

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