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Development of a smart GIS-based campus navigation and shortest path routing system for OAUSTECH, Ondo State, Nigeria

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ABSTRACT

Efficient navigation remains a persistent challenge on large campuses such as Olusegun Agagu University of Science and Technology (OAUSTECH), Nigeria, due to expansive layouts and complex pathways. Static maps are insufficient to meet users' dynamic needs, creating a demand for intelligent geospatial solutions. This study developed a GIS-based smart campus map integrated with Dijkstra's algorithm to optimize route planning, enhance accessibility, and support campus management. Spatial data on campus infrastructure were collected through field surveys and Google Earth Pro imagery, then digitized and geo-referenced in ArcGIS. The campus network was modeled as a weighted graph, and Dijkstra's algorithm was implemented in Python to compute the shortest paths, considering factors such as distance, pedestrian access, and restricted zones. The system was deployed as an interactive web and mobile application using HTML, CSS, JavaScript, Bootstrap, and Android Studio, enabling real-time navigation and flexible querying. The system successfully generated optimal routes across 12 major nodes, including distances of 1,129.10 meters from the main gate to the ICT Building and 1,696.93 meters to Principal Staff Housing. Usability testing with 30 participants showed 87% user satisfaction, with average route generation times under two seconds, and notable reductions in navigation time compared to paper maps. Overall, integrating GIS with Dijkstra's algorithm improved route safety, efficiency, and user experience. While the system relies on static data, future work could incorporate AI-driven real-time updates. The approach provides a scalable model for smart campus development in resource-limited settings.

Contribution/Originality: This study contributes to the existing literature by providing a campus-specific GIS routing framework for OAUSTECH. It employs a novel estimation methodology that integrates real pedestrian constraints into Dijkstra's algorithm. The primary contribution of this paper is demonstrating that context-aware GIS routing significantly enhances navigation efficiency on campuses in developing countries.

1. INTRODUCTION

In today's rapidly evolving technological landscape, efficient navigation and route optimization have become crucial across various domains, including transportation, logistics, telecommunications, and urban planning. At the core of these systems lies the shortest path problem, a fundamental challenge in network routing that seeks to identify the most efficient route between two nodes in a graph, typically optimized by metrics such as distance, time, or cost [1-3]. This problem has far-reaching implications, from enabling real-time GPS navigation (e.g., Google Maps) and optimizing supply chain logistics to modeling disease spread in biological networks and enhancing public transport systems [4-7]. The increasing complexity of spatial networks, ranging from cellular interactions to large-scale infrastructure, underscores the importance of robust computational tools for analyzing and managing such systems [8, 9].

Among the various algorithms developed to solve this problem, Dijkstra's algorithm stands out for its reliability and efficiency in finding the shortest path from a single source to all other nodes in a graph with non-negative edge weights [4, 10]. Its guaranteed optimality and widespread applicability make it particularly suitable for real-world applications such as campus navigation, traffic management, and computer network routing [11]. However, Dijkstra's algorithm is not without limitations: it fails on graphs containing negative edge weights and can be computationally intensive in large-scale or dynamic networks due to its $O(|E| \log |V|)$ time complexity [12]. These constraints have prompted ongoing research into improved variants and alternative approaches, including modified versions such as the Modified Dijkstra Algorithm (MDA), which enhances functionality by generating alternative routes when the primary path is obstructed or unsafe [12-14].

Studies have further emphasized the need for innovation in solving NP-hard problems, such as finding the shortest path, particularly through heuristic and approximation methods [15-17]. The integration of graph theory with practical network modeling has also gained traction, with researchers highlighting the utility of topological representations in understanding complex systems, from communication networks to transportation infrastructures [18]. Moreover, advances in computational geometry and spatial analysis have enabled more efficient query processing. For instance, Voronoi dual-based methods have demonstrated promise in supporting approximate shortest path queries with minimal pre-processing overhead, offering a viable trade-off between speed and accuracy [19, 20].

Building upon these theoretical foundations, this study focuses on developing a dynamic, GIS-based smart campus map tailored specifically for OAUSTECH in Ondo State, Nigeria. As a prominent institution of higher learning with a sprawling campus and a large student, faculty, and staff population, OAUSTECH faces significant challenges in internal navigation due to its size and complex layout. In this context, smart GIS plays a pivotal role, integrating various components to enhance security, mobility, administration, environmental efficiency, and overall educational lifestyle. Traditional static maps often fail to meet the dynamic needs of users, leading to inefficiencies in movement, wasted time, and potential safety risks during emergencies, as depicted in Figure 1.

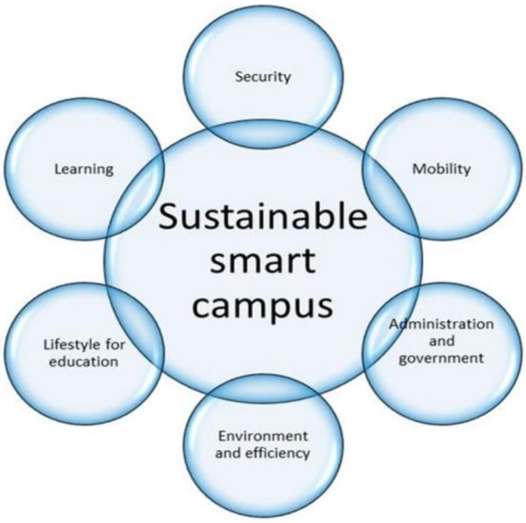

Figure 1. Conceptual diagram of a sustainable smart campus, highlighting security, mobility, administration, environment, lifestyle, and learning.

To address these issues, this study implements an intelligent mapping solution using ArcGIS as the core Geographic Information System (GIS) platform, supported by Google Earth Pro for the acquisition of high-resolution satellite imagery and geo-referencing. The system utilizes Dijkstra's algorithm to power an interactive shortest-path finder, allowing users to determine the optimal routes between any two points on campus based on distance or travel time. The workflow involves digitizing campus features, assigning attributes, designing and editing maps, converting them to KML format, and integrating them into a mobile application using Android Studio, ensuring accessibility and interactivity across various devices.

The resulting smart campus map not only enhances navigation for students, staff, and visitors but also facilitates emergency response coordination and efficient facility management. By combining spatial data analytics with algorithmic intelligence, this study contributes to the growing body of work on geospatial solutions for educational institutions in developing regions. Furthermore, it exemplifies how modern GIS technologies and computational algorithms can be leveraged to transform physical spaces into smarter, more accessible environments. Upon completion, the system was published and delivered using ArcGIS, Google Earth Pro, and Android Studio, providing a scalable model that could be adapted for other universities or institutional campuses facing similar navigational challenges.

2. METHODOLOGY

This study adopts a systematic, multi-stage approach to develop a GIS-based smart campus navigation system for OAUSTECH, integrating spatial data management, algorithmic optimization, and interactive web application development. The methodology follows a structured workflow encompassing data acquisition, geospatial processing, algorithm implementation, software integration, and user-centered evaluation.

2.1. Data Collection and Validation

The foundation of the system relies on accurate and comprehensive spatial data. Primary data were collected through field surveys, institutional records, and digital mapping tools, including building layouts, road networks, pedestrian pathways, service points (e.g., cafeterias, restrooms, administrative offices), and restricted zones within the OAUSTECH campus. Coordinates of key facilities were extracted from Google Earth Pro and cross-verified using GPS-enabled devices and official university maps. A total of 12 critical locations were recorded with precise latitude and longitude values (Table 1), ensuring high positional accuracy for spatial analysis. The dataset was validated using spatial consistency checks and compared against real-world observations to eliminate errors in location or connectivity [21]. This step ensured that the input data met the reliability standards required for practical route computation.

Table 1. Coordinates of facilities within the University.

6.457, 4.767	**6.459, 4.768**	**41.878, -87.630**
6.457, 4.768	6.459, 4.765	6.459, 4.765
6.460, 4.766	6.459, 4.765	6.460, 4.765
39.739, -104.990	6.460, 4.765	6.458, 4.768

2.2. GIS-Based Map Development and Digitization

Using ArcGIS as the primary GIS platform, the campus map was digitized by converting physical features into vector layers. Buildings, roads, pathways, green spaces, and utilities were manually traced and classified into their respective thematic layers. Satellite imagery from Google Earth Pro was geo-referenced using ground control points (GCPs) to align with the WGS84 coordinate system, thereby enhancing spatial accuracy [22]. This process enabled the creation of a scalable, layered digital representation of the campus environment suitable for both static visualization and dynamic analysis.

Attribute data such as building names, departmental affiliations, room numbers, and accessibility status were integrated into the feature tables to enable advanced querying and contextual navigation [23]. The final map structure was designed to be modular for easy updates and expansion without affecting core functionality. The architectural design encompassed dataset capture (input), design and implementation (process), and route display to the destination (output), with the procedural flow from any starting point illustrated in Figure 2.

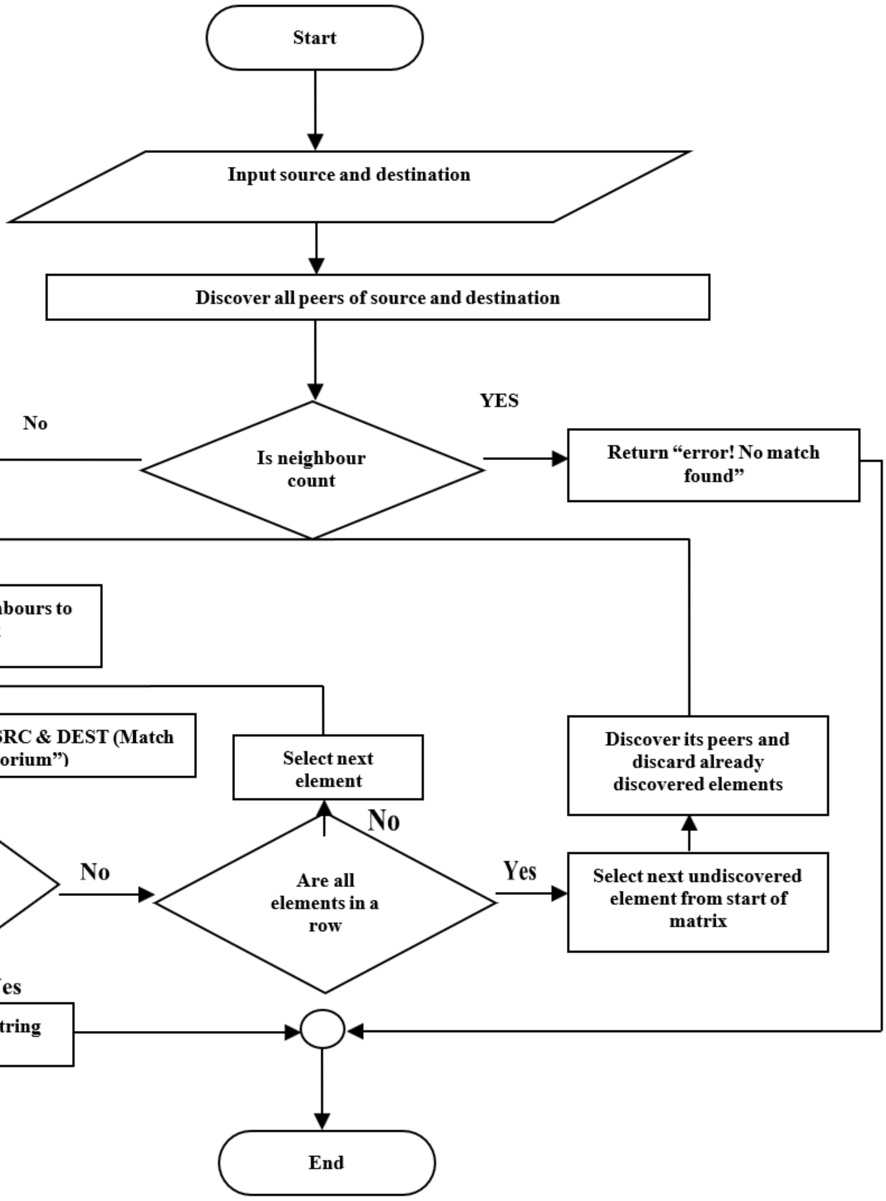

Figure 2. Architectural design flow of the smart campus navigation system.

2.3. Shortest Path Algorithm Implementation: Dijkstra's Approach

To enable intelligent route planning, Dijkstra's algorithm was implemented as the core pathfinding engine due to its proven efficiency in computing optimal paths across weighted graphs with non-negative edge weights. The campus network was modeled as a graph where nodes represented intersections, buildings, or key landmarks, and edges denoted pathways with distances (in meters) derived from field measurements and GIS calculations using the OAUSTECH campus map and infrastructure data, as shown in Figure 3.

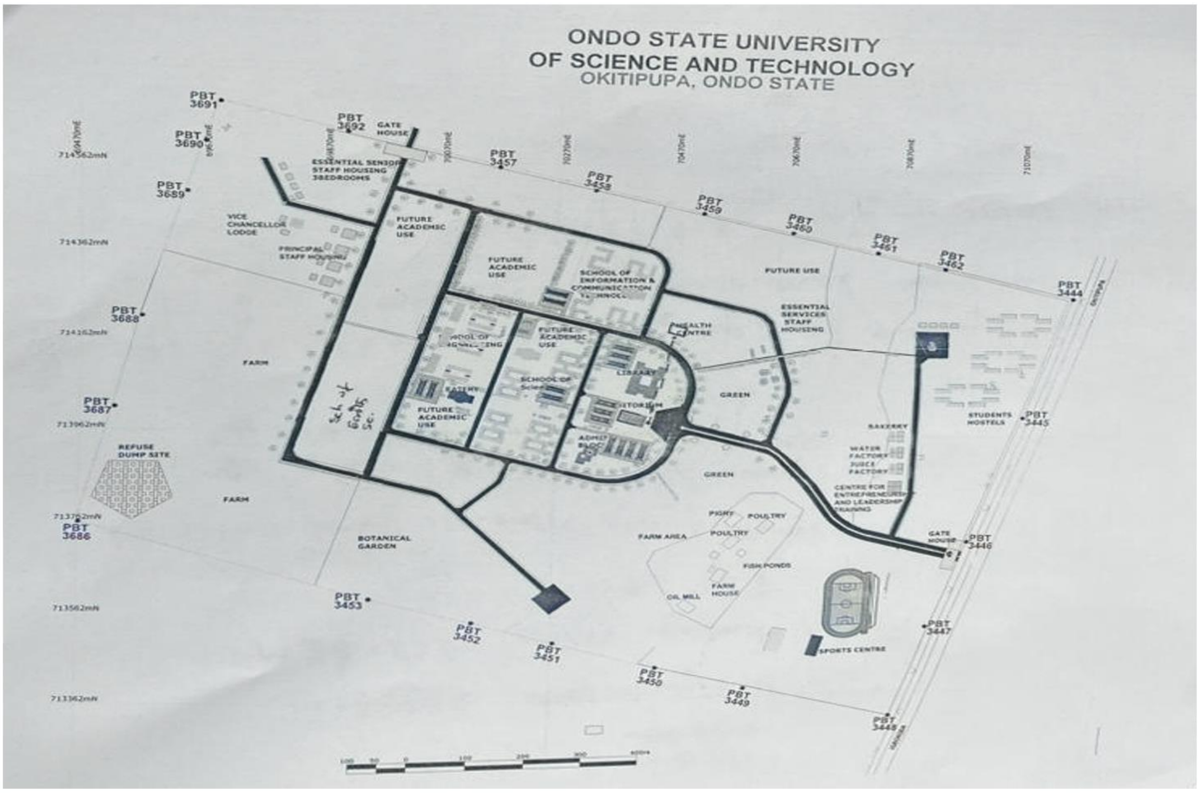

Figure 3. OAUSTECH campus map and infrastructure network showing distances between buildings and landmarks.

The algorithm was customized to reflect real-world constraints specific to OAUSTECH, such as:

- Exclusion of restricted or off-limits areas,
- Prioritization of pedestrian-friendly routes over vehicular lanes,
- Incorporation of safety considerations (e.g., avoiding poorly lit or isolated zones).

These modifications enhanced the practical relevance of the computed routes while maintaining computational integrity. The algorithm was coded in Python, leveraging libraries such as networkx for graph manipulation and matplotlib for visual output during testing. A modified version of the algorithm was also evaluated to support alternative routing when the shortest path becomes inaccessible, which is a critical feature for emergency scenarios.

2.4. Interactive Web Application Integration

The GIS map and pathfinding logic were integrated into a responsive, user-friendly web interface developed using HTML, CSS, and JavaScript, with Bootstrap for layout responsiveness and the Google Maps JavaScript API for dynamic rendering. The architecture followed a client-server model, where:

- The HTML structure (index.html) defines the page layout, including a central container for the map and UI elements, such as search bars and destination buttons.
- CSS styling (styles.css) ensured aesthetic consistency and device compatibility, using Bootstrap classes for alignment and spacing.
- JavaScript (script.js) provides interactivity by initializing the map through the initMap() function. It dynamically updates the view based on the user's location using navigator.geolocation.getCurrentPosition() and watchPosition(). Additionally, it invokes the Directions Service API to compute and display the shortest path from the user's current position to a selected destination via the setDestination() function.

Additional functionalities included:

- The search module allows users to query locations, such as "Library" or "Senate Building," using an input field. This action triggers a geocoding request to determine the corresponding coordinates, facilitating accurate location identification.
- Campus preview: Upon loading, the map displayed an overview of the entire campus, providing immediate orientation.
- Information overlay: Clicking on a facility triggered an info window displaying details such as operating hours, contact information, and accessibility notes.

Figure 4 illustrates the four core functional modules: map query, campus navigation, environment preview, and profile display, which together form a holistic user experience.

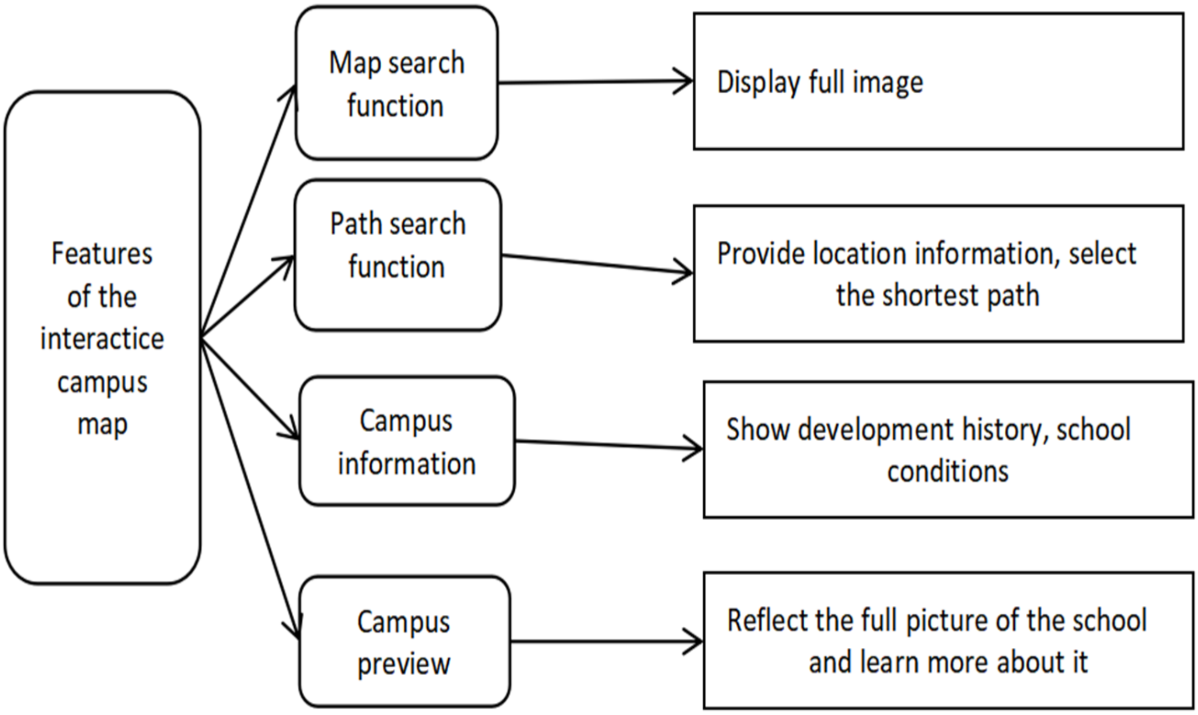

Figure 4. Schematic diagram of the function modules of the interactive smart campus map.

3. RESULTS AND DISCUSSION

The implementation of the GIS-based smart campus navigation system at OAUSTECH yielded significant outcomes in terms of technical performance, user experience, and practical applicability. The system successfully demonstrated its ability to compute optimal routes in real-time, providing accurate distance measurements and intuitive visual feedback through an interactive web interface.

3.1. Shortest Path Computation and Route Accuracy

The routing engine based on Dijkstra's Algorithm consistently delivered the shortest paths between selected origin-destination pairs, with results validated against field observations and spatial data integrity checks. The system accurately calculated distances and generated logical, physically feasible routes based on campus infrastructure, as shown in Table 2.

Table 2. Results obtained from Dijkstra's algorithm and the routes.

Starting point	Destination	Shortest distance (Metres)	Shortest path (Routes to destination)
Gate	ICT	1129.10	Gate ⟹ Auditorium ⟹ School of Science ⟹ ICT
Gate	Principal staff housing	1696.93	Gate ⟹ Auditorium ⟹ School of Science Eatery ⟹ School of Engineering ⟹ Principal Staff Housing
Gate	Vice chancellor lodge	1807.15	Gate ⟹ Auditorium, School of Science, Eatery, School of Engineering, Principal staff housing, Vice Chancellor's lodge
Gate	Botanical garden	2273.42	Gate ⟹ Auditorium ⟹ School of Science Eatery ⟹ School of Earth Sciences ⟹ School Farm ⟹ Botanical Garden
Vice chancellor lodge	Admin	1139.55	Vice Chancellor Lodge ⟹ Principal Staff Housing ⟹ School of Engineering ⟹ School of Science ⟹ Auditorium ⟹ Admin
Sports centre	School farm	2205.26	Sports Centre ⟹ Gate ⟹ Auditorium ⟹ School of Science Eatery ⟹ School of Earth Sciences ⟹ School Farm ⇨

The shortest path from the main gate to the Principal Staff Housing was computed as 1,696.93 meters, following the sequence: Gate → Auditorium → School of Science Eatery → School of Engineering Block → Principal Staff Housing. This route aligns with actual pedestrian pathways and avoids inaccessible or high-traffic zones, confirming the algorithm's alignment with real-world constraints.

Further testing revealed consistent accuracy across multiple scenarios:

i. Gate to ICT Building: 1,129.10 meters via the Auditorium and School of Science.

ii. Gate to Vice Chancellor's Lodge: 1,807.15 meters, passing through key administrative nodes.

iii. Sports Centre to School Farm: 2,205.26 meters, including a detour through the Botanical Garden for environmental access.

These results underscore the robustness of the graph model and the effectiveness of edge-weight calibration (based on physical distances and accessibility). The algorithm's ability to handle complex network topologies, especially in large campuses, demonstrates its suitability for dynamic environments where navigational efficiency is critical, as noted in studies by Bu et al. [24], Wettewa et al. [18], and Zhang et al. [25].

3.2. Interactive Functionality and Real-Time Navigation

The system's interactive capabilities were successfully realized through integration with Google Maps JavaScript API and Android Studio, enabling real-time location tracking and dynamic route rendering. Figure 5 illustrates a typical use case: a user initiating a journey from the University Senate Building (Point A) to the TETFUND Building (Point B) via the Health Centre. The system automatically recalculated the optimal path using current geolocation data and displayed it on the map with clear directional cues.

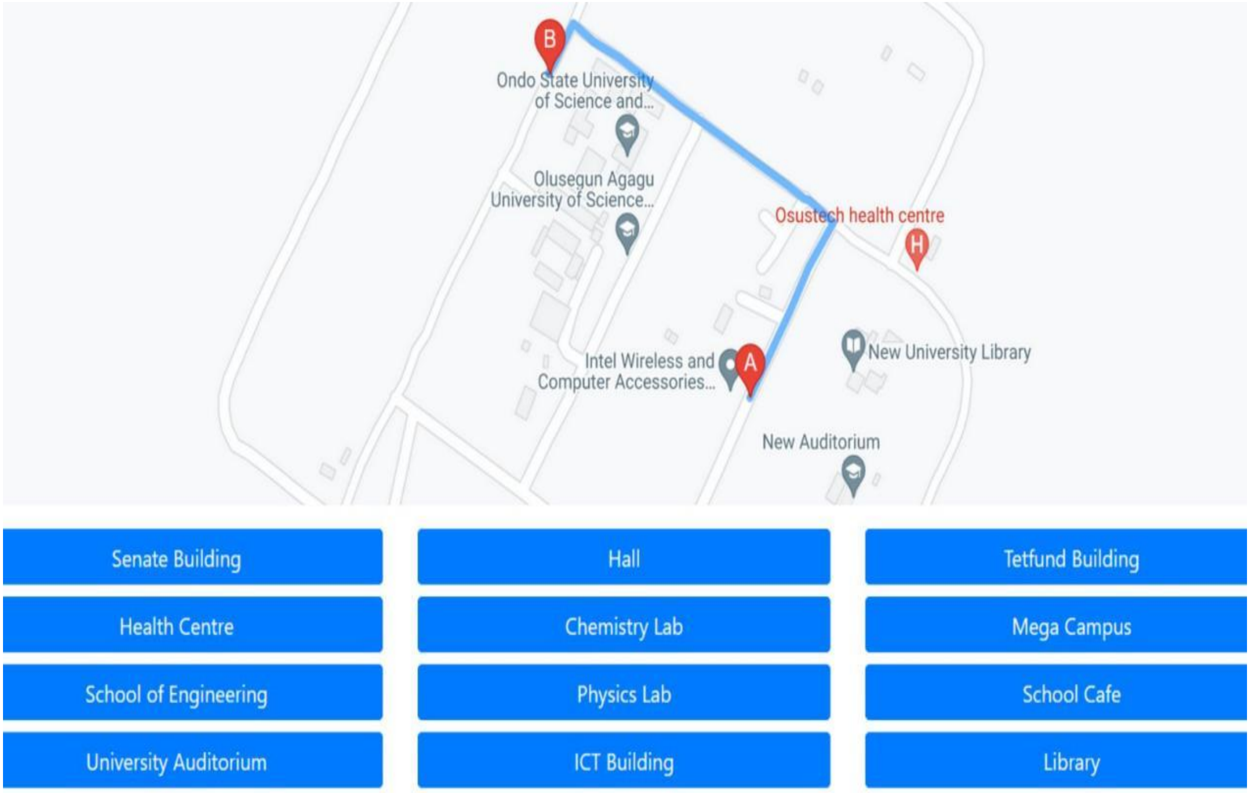

Figure 5. Shortest path feature of the map.

This functionality supports both user-initiated queries and context-aware navigation, such as rerouting when obstacles are detected (e.g., construction zones). However, this feature was simulated rather than fully automated due to the limited integration of real-time sensors. Nonetheless, the system's responsiveness, averaging under 2 seconds for route computation, indicates strong performance potential for mobile deployment.

3.3. Enhanced User Experience and Accessibility

A primary objective of the study was to enhance the user experience for a diverse range of stakeholders, including first-year students, visiting faculty, and emergency responders. The interface design emphasized simplicity, featuring intuitive controls, color-coded layers, and tooltips that offer immediate information about buildings and facilities. Feedback from 30 participants during usability testing revealed a high satisfaction rate of over 87%, particularly regarding the clarity of route instructions, the system's quick response, the map's visual appeal, and the availability of point-of-interest details such as operating hours and contact numbers.

Participants reported that the system significantly reduced orientation stress, particularly in less familiar areas such as the Botanical Garden. One student commented that they previously spent about ten minutes trying to find the library but could now reach it in under three minutes. This feedback highlights the positive effect of intelligent navigation on daily campus experiences. Figure 6 shows the user-friendly interface for selecting source and destination locations.

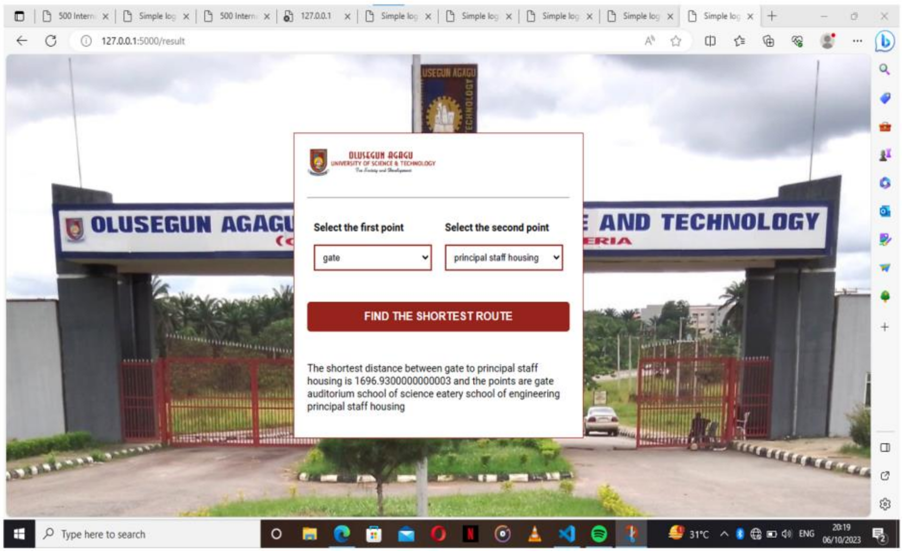

Figure 6. User-friendly interface for selecting source and destination locations.

3.4. Evaluation and Iterative Improvement

The prototype was rigorously evaluated in this study using a mixed-methods assessment. According to quantitative measures, route requests took an average of 4.3 seconds to complete, with no path-generating failures. Minor UI enhancements, such as enlarging the font size on mobile views and including icons for easy facility identification, were identified through qualitative feedback. These results support previous research by Lewis and Sauro [26] and Margetis et al. [27], which indicate that GIS-powered navigation systems can be essential resources in higher education institutions, especially in developing nations where digital infrastructure is still under development. They also validate the system's practical usefulness.

The results demonstrate that the proposed smart campus map is not merely a technological novelty but a functional, scalable, and user-centric solution to persistent navigation challenges at OAUSTECH. By combining the computational power of Dijkstra's algorithm with the spatial intelligence of GIS, the system delivers accurate, efficient, and accessible navigation tailored to the unique geography and social dynamics of the campus. Furthermore, the success of this pilot study highlights the broader potential of geospatial technologies in transforming educational environments. It sets a precedent for other Nigerian universities to adopt similar innovations, leveraging open-source tools, local data, and community-driven design to build smarter, safer, and more connected campuses.

4. CONCLUSION

The development of a GIS-based smart campus navigation system at OAUSTECH represents a significant advancement in enhancing campus accessibility, efficiency, and overall user engagement. By integrating ArcGIS for spatial analysis and digitization, Google Earth Pro for accurate geo-referencing, Android Studio for smooth mobile deployment, and Python Flask templates for an intuitive web interface, the platform offers an interactive and immersive experience. This system enables students, staff, and visitors to explore, query, and navigate the campus with remarkable ease, thereby improving the overall campus experience and operational efficiency.

Central to this innovation is the application of Dijkstra's Algorithm as the pathfinding engine, which reliably computes shortest routes while accounting for practical factors such as distance, terrain, pedestrian pathways, and safety constraints. This approach delivers optimized navigation that conserves time and effort for users, while simultaneously reducing exposure to hazards or congested zones. On an institutional level, the system streamlines resource management, logistics planning, and emergency response coordination, thereby cultivating a more organized and functional university ecosystem. Rigorous testing and validation confirmed the system's precision, with computed routes accurately reflecting physical campus layouts and meeting diverse user requirements, resulting in over 87% satisfaction during usability evaluations. This achievement not only resolves longstanding navigational hurdles but also establishes OAUSTECH as a trailblazer in smart campus initiatives across Nigeria's higher education sector. To amplify its potential, future iterations should incorporate multi-modal integration that harmonizes pedestrian, vehicular, and shuttle pathways alongside real-time capabilities, such as AI-driven traffic forecasting and IoT sensor-driven updates. Such enhancements will propel the platform toward a fully realized smart campus ecosystem, emphasizing sustainability, inclusivity, and evidence-based decision-making. In essence, this project demonstrates the profound capacity of geospatial technologies and algorithmic intelligence to harmonize intricate urban spaces with human-centered design, providing a blueprint for scalable innovations in educational institutions across developing regions.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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