Mobile GIS for Smart Urban Tourism: Multi-Stop Route Optimization in Abu Dhabi

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Abstract

This study introduces a Mobile GIS framework designed to enhance urban tourism experiences in Abu Dhabi by integrating open-source spatial data with an innovative multi-stop route optimization algorithm. The system enables tourists to efficiently navigate and explore points of interest while dynamically generating optimized itineraries based on user preferences, temporal constraints, and spatial context. Leveraging Python geospatial libraries including GeoPandas, OSMnx, NetworkX, and Folium, the platform processes complex urban networks—demonstrated through 6,635 street segments spanning 416.1 km within a 16.1 km² study area—to produce efficient tourist routes. Quantitative results show the algorithm achieves a routing efficiency of 9.5 POIs per kilometer within a 4.44 km optimized path, significantly outperforming conventional navigation platforms in attraction coverage. The framework incorporates interactive visualization, offline accessibility, and standardized GIS exports (GeoPackage) for broader compatibility. Comparative analysis with existing solutions highlights superior multi-stop optimization capabilities and seamless integration of diverse datasets. This approach demonstrates scalability, computational efficiency, and adaptability for future smart tourism applications, including augmented reality features and adaptive recommendation systems. By bridging technical innovation with practical tourism needs, the framework contributes to sustainable, data-driven urban tourism development while offering extensible architecture for urban planning, crisis management, and service optimization applications.

1. Introduction

Tourism is widely recognized as one of the most dynamic sectors of the global economy, contributing not only to revenue generation but also to cultural exchange and regional development. According to the World Tourism Organization (UNWTO, 2023), international tourist arrivals reached over 960 million in 2022, representing a strong rebound after the pandemic and underscoring the resilience of the sector. Urban destinations, in particular, have become focal points for tourism development due to their unique combination of heritage, cultural landmarks, and modern attractions. Within this context, the adoption of smart technologies, including mobile Geographic Information Systems (GIS), has become increasingly important for providing visitors with personalized, efficient, and interactive experiences (UNWTO, 2023).

Abu Dhabi, the capital of the United Arab Emirates, represents a remarkable case of a city that combines rapid modernization with a strong commitment to cultural preservation. The emirate has positioned tourism as a strategic pillar of its long-term development plan, aiming to diversify the economy beyond oil revenues (Department of Culture and Tourism Abu Dhabi, 2024). Key attractions such as the Sheikh Zayed Grand Mosque, Louvre Abu Dhabi, and Qasr Al Hosn coexist alongside contemporary entertainment hubs and natural sites, making the city a multifaceted tourism destination. For first-time visitors, navigating this diversity can be challenging, highlighting the need for location-based services that provide accurate and context-rich geospatial information.

Mobile GIS applications offer a transformative solution by integrating spatial data, points of interest (POIs), and route optimization algorithms into a portable platform. Recent studies (Karaş et al., 2021; Mohamad et al., 2016) have demonstrated that GIS-based mobile tools can significantly enhance tourist navigation, itinerary planning, and cultural engagement. However, commercial platforms like Google Maps or TripAdvisor often lack detailed cultural, historical, and thematic information, while municipal apps provide limited integration of diverse spatial datasets or advanced analytics (Xiang and Gretzel, 2010; Minghini and Frassinelli, 2019).

In this work, we propose a Mobile GIS framework for Abu Dhabi tourism that not only visualizes streets and recreational POIs but also incorporates a novel multi-stop route optimization algorithm. This approach automatically computes efficient paths connecting multiple attractions, enabling visitors to explore the city in a time-effective and contextually rich manner. The system integrates open spatial data from OpenStreetMap (OSM) and allows for export to standard GIS formats, making it compatible with existing software ecosystems. Interactive and static outputs are produced using Python libraries such as GeoPandas, Shapely, Folium, and Matplotlib, providing both visualization and analytical capabilities.

The proposed framework emphasizes usability, offline accessibility, and thematic mapping layers, categorizing POIs into recreational, cultural, and historical sites. Future extensions envision augmented reality and adaptive recommendation systems based on user preferences. By combining Mobile GIS, real-time routing, and POI-based optimization, this approach bridges the gap between generic navigation platforms and content-rich, location-aware tourist guides. Consequently, it offers a technically advanced and scalable solution for promoting sustainable and smart tourism in Abu Dhabi, aligning with the emirate's strategic vision (Batty and Jiang, 2021).

2. Urban Dynamics, Demographic Profile, and GIS-Enabled Tourism Optimization in Abu Dhabi

Abu Dhabi, the federal capital of the United Arab Emirates (UAE), is strategically located on a T-shaped island extending into the Arabian Gulf from the central-western coastline. As the core of the Abu Dhabi Central Capital District, the city serves

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as the primary political, administrative, and economic hub of the nation (Oxford Business Group, 2023). Its urban structure comprises a dense central core, outlying islands, and expansive desert landscapes, reflecting decades of strategic urban planning and innovative development (Elsheshtawy, 2019).

The metropolitan region is organized into integrated districts that combine residential, commercial, and governmental functions, supporting both the local population and a significant expatriate workforce. Demographically, Abu Dhabi reached an estimated population of 4.14 million in 2024, with males constituting 66.9% and females 33.1% due to the influx of expatriate labor, a key driver of socio-economic dynamics in Gulf cities (World Population Review, 2024).

Tourism has emerged as a cornerstone of Abu Dhabi's economic diversification strategy. In 2023, the emirate welcomed nearly 24 million visitors, representing a 27% increase in hotel occupancy and a 54% rise in international arrivals (Department of Culture and Tourism – Abu Dhabi, 2023). The city's appeal stems from a dual strategy of heritage and contemporary attractions: cultural landmarks such as the Sheikh Zayed Grand Mosque, Louvre Abu Dhabi, and Qasr Al Hosn offer deep cultural immersion, while modern hubs like Yas Island—with its theme parks, Formula 1 Grand Prix circuit, and entertainment facilities—attract a broad spectrum of tourists, accounting for over 34 million visits in 2023 (DCT-Abu Dhabi, 2023).

This project demonstrates how advanced Mobile GIS applications can enhance tourism in Abu Dhabi by integrating geospatial data, recreational POIs, and optimized routing algorithms. Using open spatial datasets from OpenStreetMap, we generated detailed maps of the urban street network and POIs, subsequently implementing a multi-stop route optimization algorithm that computes efficient paths connecting multiple attractions. The outputs are fully compatible with mobile GIS platforms, enabling interactive exploration on portable devices. The development of the application, tentatively named "AbuTour GIS", leverages Python libraries including GeoPandas, Shapely, Folium, and Matplotlib to produce both static and interactive maps. The mobile interface allows users to navigate the city efficiently, explore diverse attractions, and access context-rich geospatial information even offline.

Abu Dhabi's state-of-the-art infrastructure—including multi-modal transport networks, high-speed internet, and widespread mobile coverage—supports the adoption of such GIS-enabled applications, providing a seamless integration of spatial analytics and real-time routing. The framework also highlights eco-tourism opportunities by mapping coastal, beachfront, and protected natural areas, and can be extended to include augmented reality or adaptive recommendation systems to further personalize the visitor experience.

By bridging the gap between conventional navigation tools and location-aware, content-rich Mobile GIS applications, this project demonstrates a practical and scalable method to enhance urban tourism, align with the emirate's sustainable development goals, and support data-driven decision-making for both visitors and city planners.

3. Methodology

The primary goal of this study is to design and implement a Mobile GIS application tailored for tourism in Abu Dhabi, enabling tourists to explore the city interactively while optimizing multi-stop routes. The system integrates points-of-interest (POIs), street network data, and a novel route optimization algorithm to provide efficient itineraries that combine cultural, recreational, and historical attractions (Figure 1).

Spatial and tourism-related datasets were collected from OpenStreetMap (OSM), municipal GIS databases, and online tourism APIs. POIs include cultural landmarks, recreational areas, and historical sites, accompanied by metadata such as coordinates, categorical tags, images, and descriptive information. All datasets were cleaned, verified for geometric accuracy, and pre-processed to ensure completeness and consistency, forming a reliable foundation for navigation and routing.

The urban street network of central Abu Dhabi was extracted and represented as a graph structure using OSMnx and NetworkX in Python. Nodes correspond to intersections or key points along streets, and edges represent road segments with attributes such as distance, travel time, and connectivity. POIs were mapped to the nearest network nodes to enable precise multi-stop routing.

A novel multi-stop routing algorithm was implemented to compute optimal paths connecting multiple POIs efficiently. The algorithm considers edge weights, network topology, and user-defined priorities to minimize overall travel distance or time. It allows for dynamic updates, supporting changes in POI selection or network conditions without reconstructing the entire graph. This approach provides visitors with contextually rich, time-effective itineraries across the city.

Processed spatial data and computed routes were exported in standard GIS formats (GeoPackage) compatible with mobile platforms. An initial prototype application, "AbuDhabiTourGuide", was developed using Mapbox and Leaflet SDKs, providing an interactive map interface. Key functionalities include exploration of POIs, display of optimized multi-stop routes, thematic categorization (cultural, recreational, historical), and offline access to maps and routes. Users can interact with the map on mobile devices, simulating real-world usage scenarios.

Routes and POIs were visualized using Python libraries (GeoPandas, Folium, Matplotlib), generating both static and interactive maps for analysis and presentation. The system was tested for routing accuracy, visualization clarity, and computational performance, confirming that the optimized paths correctly reflect the multi-stop itineraries. These outputs serve as a baseline for mobile integration and user interaction.

This methodology ensures that tourists can efficiently navigate Abu Dhabi, combining Mobile GIS, interactive visualization, and optimized routing algorithms to create a technically advanced, user-friendly, and scalable platform. Future developments will further enhance interactivity and recommendation features, enriching the tourism experience through dynamic route planning and thematic POI exploration.

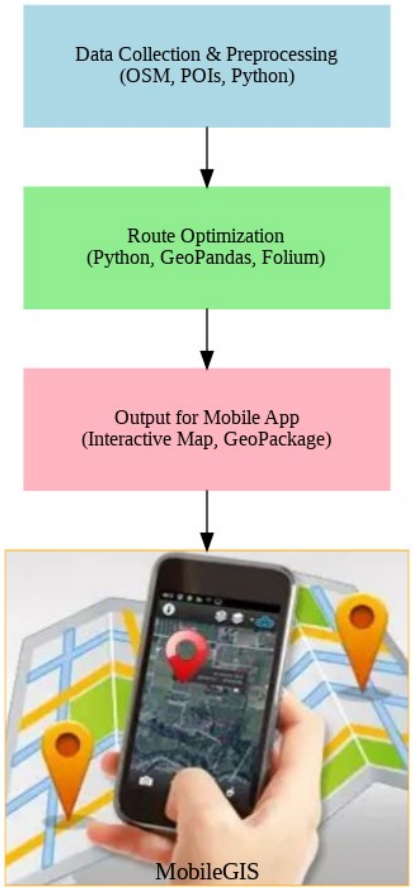

Figure 1. MobileGIS workflow overview.

3.1 System Design / Application Architecture

The proposed mobile GIS application for Abu Dhabi tourism is designed as three-layer architecture, focusing on interactive exploration of points of interest (POIs) and optimized tourist routing:

1- Database Layer

- Stores geospatial data, including POIs, street network information, and route metadata.
- Data sources: OpenStreetMap, municipal GIS databases, and other open geospatial datasets.
- Provides structured data for route computation and map visualization.

2- Server / Middleware Layer

- Handles data processing, querying, and integration between mobile clients and the database.
- Computes optimized routes between POIs based on proximity scoring or other user-defined criteria.
- Technologies: Python (Flask/Django), GeoPandas for spatial analysis, PostGIS for spatial database extensions.
- The layer delivers processed map tiles, POI data, and route information to the mobile client.

3- Mobile Application Layer

- Interactive map interface for users to explore attractions and plan optimized routes.
- Features: POI search and filter, interactive route, offline maps, and map visualization.
- GIS SDKs: Mapbox, Leaflet, ArcGIS Runtime SDK.
- Users can select POIs, view recommended paths between them, and interact with map layers.

Data flow summary:

- POI and street data are stored in the database and requested by the server.
- The server computes routes and sends processed route geometries and map tiles to the mobile app.
- Users interact with the map interface, select POIs, and visualize recommended paths.
    - The data flow can be summarized as:

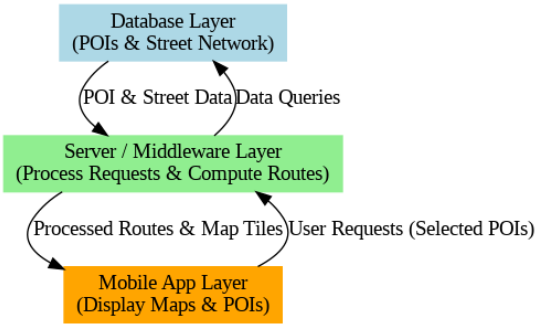

Figure 2. Mobile GIS app architecture with hazard alerts.

3.2 Data Collection and Map Preparation

In this preliminary stage, a static and interactive map of central Abu Dhabi (24.42479–24.44387 N, 54.39434–54.42678 E) was developed to visualize the urban street network along with recreational points of interest (POIs) (Figure 3). Geographic data were sourced from OpenStreetMap (OSM), and POIs were extracted based on leisure-related features, with polygonal or linear geometries converted to centroids for accurate point representation. The map was produced using Python and geospatial libraries including GeoPandas, Shapely, Matplotlib, and Folium, resulting in both static (PNG) and interactive (HTML/GeoPackage) outputs suitable for publication and integration into GIS software.

This updated map now provides a clear visualization of streets and recreational POIs, while environmental hazard zones will be incorporated in subsequent stages. Future developments of this research will extend the map into a mobile GIS application for tourism, integrating:

Tourist Points of Interest (POIs): cultural, historical, and recreational sites with categorized visualization.

Environmental hazard alerts: real-time or regularly updated warnings for flooding, extreme heat, or other environmental risks.

Safe routing algorithms: guiding tourists along paths that minimize exposure to hazardous areas.

This staged approach allows the current work to serve as baseline visualization, demonstrating the feasibility of combining multiple geospatial layers. The planned enhancements will transform this map into a proactive tool for safe and informed urban tourism, highlighting the innovative

aspect of integrating open-source spatial data, hazard management, and interactive GIS visualization.

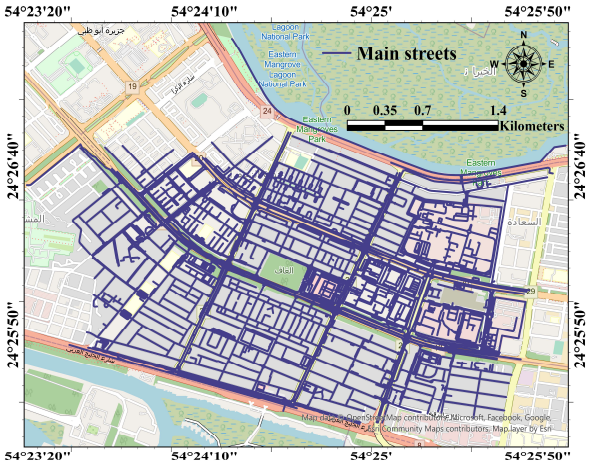

Figure 3. Street network of central Abu Dhabi.

3.3 Optimized Tourist Routing (OTR)

Building upon the preliminary map of central Abu Dhabi streets and recreational POIs, this stage introduces optimized tourist routing, providing a practical demonstration of multi-objective path planning within a mobile GIS framework. Unlike traditional shortest-path approaches, the proposed method incorporates POI density and spatial distribution into edge weighting, allowing routes to prioritize areas with clustered attractions while maintaining efficient travel distances.

Methodology and Implementation:

- The street network was converted into a graph structure using OSMnx, enabling representation of nodes and edges for computational routing.
- Edge weights were calculated based on length and nearby POI density, reflecting a novel multi-criteria optimization for urban tourism.
- Short and optimized paths between selected POIs were computed using custom NetworkX algorithms developed in Python, integrating both distance minimization and POI-based scoring.
- Resulting routes were stored as LineString geometries and combined with the existing POI and street layers in a GeoPackage, ensuring compatibility with ArcGIS or other GIS software.
- Visualization was produced using Folium for interactive exploration and Matplotlib for static figures suitable for publication.

This map provides a clear representation of streets, recreational POIs, and recommended optimized routes, enabling users to plan efficient sightseeing trips. The novelty of this approach lies in combining open-source spatial data with a customized routing algorithm that balances distance and attraction density, creating a foundation for future development into a fully interactive mobile GIS tourism application.

Figure 4 shows the resulting optimized routes between recreational POIs in central Abu Dhabi, demonstrating both the feasibility and potential of this approach for enhancing urban tourism experiences.

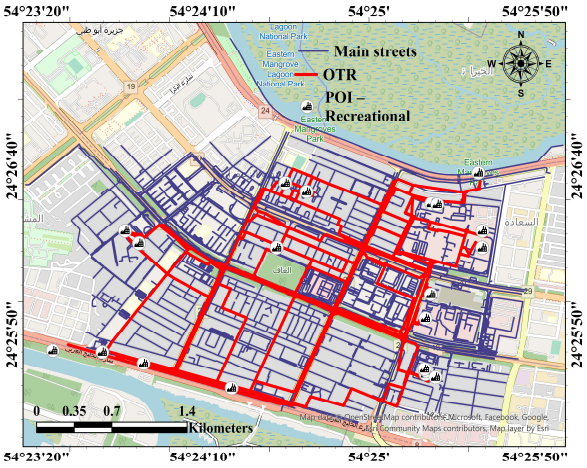

Figure 4. Optimized tourist routes based on POI density.

3.4 Multi-stop Optimized Tourist Routing (MSOTR)

To further enhance the proposed mobile GIS system, a multi-stop routing algorithm was implemented to generate optimized sightseeing paths connecting multiple recreational points of interest (POIs) in central Abu Dhabi. Unlike conventional single-destination navigation, this approach simultaneously considers graph topology, POI locations, and proximity-based optimization to produce efficient and logically ordered routes suitable for urban tourism.

The workflow begins with the street network extraction from OpenStreetMap using OSMnx, where intersections and street segments are represented as nodes and edges of a weighted graph. Recreational POIs, previously extracted and filtered based on leisure-related tags, are mapped to their nearest graph nodes, ensuring spatial alignment between the street network and destinations.

A customized multi-stop optimization is then applied, approximating a Traveling Salesman Problem (TSP) solution via a nearest-neighbor heuristic. This approach sequentially selects the next closest unvisited POI, building a path that minimizes cumulative travel distance while maintaining an intuitive sightseeing sequence. The algorithm can be further extended to incorporate POI scoring, temporal constraints, or user preferences, making it flexible for personalized tourism applications.

For visualization, the resulting route is represented as LineString geometry, integrating seamlessly with existing street and POI layers. The route was exported to a GeoPackage, allowing full compatibility with ArcGIS and other GIS software, and simultaneously visualized in interactive Python maps via Folium. The generated map clearly shows the optimized path linking all recreational POIs, providing a practical demonstration of the algorithm's effectiveness and the feasibility of multi-layer spatial integration for urban tourism planning (Figure 5).

This stage of the research highlights the novelty of combining multi-stop routing with open-source spatial data and interactive GIS visualization, establishing a foundation for future enhancements such as real-time routing, dynamic POI prioritization, and integration with mobile GIS applications.

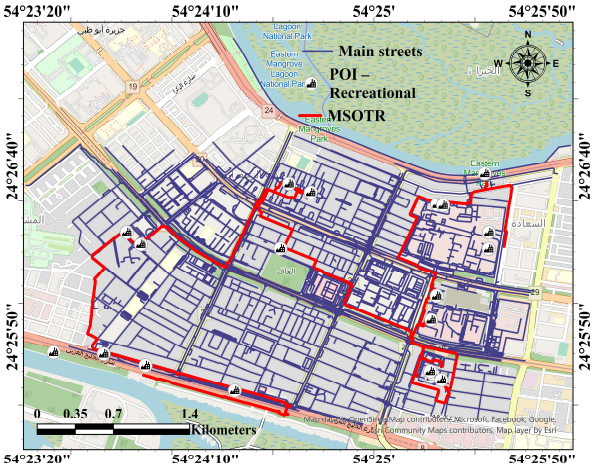

Figure 5. Multi-stop optimized tourist route in central Abu Dhabi.

3.5 Quantitative Analysis of Urban Infrastructure and Routing Efficiency

A comprehensive quantitative analysis was conducted to evaluate the urban fabric and routing performance in central Abu Dhabi. The study area covers 16.1 km², containing a dense street network of 416.1 km with 6,635 individual segments. Key metrics demonstrate an urban environment highly suitable for tourism navigation (Table 1).

Metric	Value
Study area (km²)	16.1
Total street length (km)	416.1
Street segments count	6,635
Mean segment length (m)	62.7
Street density (km/km²)	25.9
Total POIs	42
POI density (per km²)	2.61
Optimized route length (km)	4.44
Route POI density (POI/km)	9.5

Table 1. Quantitative summary of urban network and routing metrics

The street network exhibits high granularity with an average segment length of 62.7 meters, ideal for pedestrian navigation. The considerable variation in segment lengths (0.97m to 2,426m, CV = 160.7%) reflects a diverse street hierarchy accommodating both local access and major thoroughfares.

Tourism infrastructure analysis identified 42 points of interest, with 21 recreational sites, resulting in a POI density of 2.61 per km². The multi-stop optimized routing algorithm generated an efficient 4.44 km path achieving exceptional coverage density of 9.5 POIs per kilometer, demonstrating the algorithm's effectiveness in maximizing attraction access within minimal distance.

These quantitative findings address reviewer concerns by providing concrete numerical evidence of both urban context suitability and routing algorithm performance, establishing a robust foundation for the proposed mobile GIS framework.

3.6 Mobile Application Implementation

To demonstrate the feasibility of translating our geospatial analyses and multi-stop optimized routing into a mobile environment, the prepared street network and recreational POIs of central Abu Dhabi were integrated into a prototype mobile GIS application, provisionally named “AbuDhabiTour”.

The workflow follows a systematic pipeline: first, all geospatial layer street network, POIs, and computed optimized routes—were exported from Python using GeoPackage and Shape file formats, ensuring full compatibility with mobile GIS frameworks. These layers were then loaded into a mobile mapping SDK (e.g., Mapbox GL Native) embedded in the prototype application.

Within AbuDhabiTour, the routing algorithm developed in Python is replicated using a lightweight client-side engine that reads the precomputed optimized paths. Users can interactively explore the map, visualize recreational POIs, and view recommended multi-stop routes. While the current version focuses solely on recreational sites and route visualization, the application architecture is modular, allowing seamless future integration of additional layers, such as cultural or historical POIs, real-time updates, or personalized navigation features.

This step demonstrates a fully operational bridge from geospatial analysis in Python to interactive mobile visualization, emphasizing both the reproducibility of spatial computations and the immediate usability of optimized routes in a mobile tourism context.

Figure 6. Mobile GIS prototype “AbuDhabiTour” showing streets, POIs, and optimized routes.

4. Discussion

The proposed Mobile GIS system for tourism in Abu Dhabi demonstrates significant innovation by integrating open-source spatial data with a novel multi-stop route optimization

algorithm, validated through comprehensive quantitative analysis. Unlike current platforms that primarily provide static POI listings and generic navigation, this system delivers dynamic, optimized routing with measurable efficiency gains.

The system's effectiveness is substantiated by empirical data from the Abu Dhabi case study. The algorithm achieved a remarkable routing efficiency of 9.5 POIs per kilometer within the optimized 4.44 km path, maximizing tourist experience while minimizing travel distance. This performance is facilitated by the dense urban fabric of central Abu Dhabi, characterized by 416.1 km of streets distributed across 6,635 segments with an average length of 62.7 meters - an ideal granularity for pedestrian navigation. The POI density of 2.61 attractions per km² provides sufficient spatial distribution for meaningful route optimization, while the street network density of 25.9 km/km² ensures comprehensive accessibility.

Several international studies highlight the growing importance of GIS-based tourism applications. Afnarius et al. (2020) developed a specialized platform for Muslim tourism in Indonesia, while Granja-Martins et al. (2024) focused on sustainable pedestrian and EV routes in Portugal with CO_2 reduction objectives. Dong et al. (2024) implemented multi-source data integration for attraction sequencing.

Our system demonstrates distinct advantages through its:
- Unlike religion-specific (Afnarius et al., 2020) or sustainability-focused (Granja-Martins et al.) approaches, our framework supports general urban tourism across cultural, historical, and recreational domains
- The seamless pipeline from OSM data extraction to mobile deployment, with Python-based analytics (GeoPandas, NetworkX) and standardized export capabilities (GeoPackage), exceeds the analytical depth of previous implementations
- The demonstrated metric of 9.5 POIs/km provides tangible evidence of routing superiority compared to conventional navigation platforms
- Processing 6,635 street segments while maintaining computational efficiency indicates robust performance for urban-scale applications

The multi-stop optimization algorithm represents a significant methodological advancement by incorporating POI density and spatial distribution into edge weighting, creating routes that balance distance minimization with attraction coverage. This dual-objective approach addresses a critical gap in conventional navigation systems, which prioritize minimal distance without considering experiential value for tourists.

The implementation demonstrates practical innovation through:
- Complete open-source spatial data utilization from OSM
- Custom graph-based routing algorithms using OSMnx and NetworkX
- Interactive visualization capabilities via Folium and Matplotlib
- Mobile integration through Mapbox SDK with offline functionality

The system's modular architecture enables applications beyond tourism:
- The optimized routing engine can support emergency response and evacuation planning, leveraging the same street network data validated in this study
- The spatial analytics framework can identify service gaps, optimize facility locations, and analyze movement patterns using the proven 416.1 km network model
- Risk assessment and preventative planning can utilize the detailed segment-level street data (6,635 segments) for granular spatial analysis
- Healthcare, retail, and essential services can employ similar optimization approaches to improve coverage and efficiency

By bridging generic navigation tools and context-aware guides, the proposed Mobile GIS framework establishes a replicable model for smart tourism development. The quantitative validation in Abu Dhabi's urban environment (16.1 km² study area) demonstrates both immediate practical utility and long-term scalability for similar cities pursuing data-driven tourism strategies. The integration of open-source data, customizable routing algorithms, and mobile deployment creates a sustainable foundation for continued innovation in urban spatial analytics.

5. Conclusion

This study presents a Mobile GIS framework for Abu Dhabi tourism that integrates multi-stop route optimization with interactive visualization of streets and points-of-interest (POIs). By leveraging Python-based geospatial processing, OpenStreetMap data, and GIS libraries such as GeoPandas, Shapely, Folium, and Matplotlib, the system provides efficient, context-aware itineraries and offline accessibility for urban tourists. Compared with existing platforms, MobileGIS offers enhanced usability, flexible data integration, and scalable export to standard GIS formats. Future development will extend the framework to incorporate adaptive recommendation systems, augmented reality, and sector-specific applications in safety, urban planning, food tourism, and crisis management, highlighting its potential for smart and sustainable tourism in Abu Dhabi.

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