Development of an Intelligent System for the Recommendation of the Most Suitable Routes for Pedestrians

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Abstract

This study introduces an innovative approach to urban mobility through the development of an intelligent platform for smart cities. The platform leverages social media engagement to gather citizen insights about urban challenges, particularly focusing on pedestrian mobility and safety in District 6 of Tehran municipality. By encouraging users to discuss city problems, the system will collect valuable data on user preferences and experiences. The platform will utilize this crowdsourced information to provide personalized routing services that reflect the community's needs and concerns. Since the platform currently does not have active users, so a structured questionnaire was distributed to 100 participants to assess factors such as perceived safety, lighting conditions, and sidewalk width. This data was then integrated into a web-based public participation system, emphasizing the crucial role of citizen input in urban planning. Routing algorithms, including A* and Dijkstra's algorithms, were employed to identify optimized pedestrian routes based on the community feedback. Preliminary results suggest that these community-informed routes outperform conventional navigation systems, such as Google Maps, in addressing local conditions and user preferences. The platform not only enhances pedestrian experiences by prioritizing safety and accessibility but also demonstrates the potential of active citizen engagement in shaping urban environments. This approach represents a significant step towards creating more responsive and user-friendly smart cities, where citizen input directly influences urban services and planning decisions.

1. INTRODUCTION

Citizen participation in data creation is crucial for fostering a sense of ownership and empowerment within communities, particularly in the context of Public Participation GIS (PPGIS) (Rui & Othengrafen, 2023). When individuals actively contribute their knowledge and experiences, they help generate valuable, localized data that accurately reflects their needs and preferences (Lee, 2024). This participatory approach enhances the relevance and quality of the information used in spatial planning, promoting transparency and trust between citizens and decision-makers (Das Malakar & Roy, 2024). Within PPGIS, engaging citizens in data collection allows them to advocate for their interests, ensuring that urban planning and policy decisions are informed by real-life insights (Abas et al., 2023). By leveraging community-generated data, PPGIS facilitates the development of solutions that are not only effective but also responsive to the unique aspirations of residents, ultimately leading to more inclusive and sustainable urban environments (Aranda et al., 2023).

GIS serves as an essential tool for conducting a comprehensive analysis of proposed navigation routes (Albalawneh & Mohamed, 2024). By leveraging spatial data, GIS enables the systematic assessment of various factors influencing pedestrian pathways, such as proximity to amenities, traffic patterns, and environmental conditions (Angel & Plaut, 2024). This technology allows researchers to overlay multiple datasets, facilitating a holistic view of how different elements interact within the urban landscape (Yang et al., 2024). Through spatial modelling and visualization, GIS can identify optimal routes that enhance safety and convenience for pedestrians (Yang et al., 2024). Additionally, the platform allows for real-time updates and community feedback, ensuring that the analysis remains relevant and responsive to local needs (Kitchens et al., 2024). Ultimately, GIS empowers stakeholders to make informed decisions that improve navigation and promote walkable environments (Oloonabadi & Baran, 2023).

While Internet of Things (IoT) sensors provide valuable real-time data, PPGIS offers a more holistic approach to urban planning by emphasizing community engagement and local knowledge (Vahidnia, 2023). PPGIS empowers citizens to actively participate in the data collection process, ensuring that the information used in planning reflects the specific needs and preferences of the community (Das Malakar & Roy, 2024). This participatory approach fosters a sense of ownership and accountability among residents, leading to more relevant and context-sensitive solutions (Hofer et al., 2024). Moreover, PPGIS integrates qualitative insights and feedback that IoT sensors may overlook, such as personal experiences and perceptions of safety (Alsterskär, 2023). By combining spatial analysis with community input, PPGIS not only enhances the effectiveness of urban planning but also builds stronger connections between residents and their environments, making it a superior choice for addressing local challenges (Aranda et al., 2023).

Bagheri and Zarghami (2022) examined the physical, residential, and neighborhood features of housing within the context of Children’s Independent Mobility (CIM). The study utilized PPGIS to create behavioral maps. Conducted in Ilam, Iran, the research involved 360 children aged 12 to 14 and their

parents. Findings from correlation and linear regression analyses revealed a connection between housing characteristics and CIM. The most significant factors contributing to diminished CIM were the loss of open and safe spaces, as well as decreased attractiveness and playfulness in residential areas.
Hosseini et al. (2023) assessed rural infrastructure using the PPGIS tool in three phases: (1) identifying needs for PPGIS to address infrastructure issues, (2) designing the system based on these needs, and (3) evaluating its usability in villages. A questionnaire distributed in Shahriar County, Tehran, revealed that 24% of respondents cited water and sewage as major problems. While 92% reported issues using point features and 20% included photos, the evaluation indicated a need for training in map usage and improvements to the user interface to enhance participation in problem reporting.

Gavrilidis et al. (2022) explored interactions between urban residents and small public green spaces, assessing perceptions of ecosystem services. Using a comparative method, the study examined pocket parks in Hamedan (Iran) and Bucharest (Romania). Cluster analyses revealed similarities in green space usage but diverging preferences for future expansions.

One major challenge prevalent in contemporary urban centres is the issue of traffic congestion and air pollution (Auwalu & Bello, 2023). Residents frequently rely on private vehicles for transportation within the city, contributing to these problems. Various solutions exist to address this issue, such as enhancing public transportation infrastructure and promoting its use, as well as encouraging walking, cycling, and motorbike usage (Zecca et al., 2020; Gallo & Marinelli, 2020; Garus et al., 2024). Facilitating pedestrian movement can be vital in fostering a healthier city environment, and one effective approach entails tailoring routes to individuals' preferences (Rui & Othengrafen, 2023). Currently, a significant hurdle faced by pedestrians is the lack of pedestrian-friendly routing algorithms, with existing ones primarily designed for automobiles (Luxen & Vetter, 2011). This article aims to identify the key factors that influence pedestrian-friendly routes and subsequently apply this knowledge to a specific area for study.

In this study, a questionnaire was developed to gather data from 100 participants regarding factors such as safety, lighting, and obstacles affecting pedestrian routes. The responses were entered into a web-based public participation platform, where the results underwent a weighting process. Subsequently, optimized routes were selected using A and Dijkstra's algorithms*. This approach enhances pedestrian navigation by integrating community feedback into the route selection process.

2. Materials and Method

2.1 Experiment design and site selection:

District 6 in Tehran Municipality is a vibrant urban area characterized by its rich history and cultural diversity. Geographically situated at approximately 35.6939° N latitude and 51.3997° E longitude (Figure 1a), this district encompasses a blend of residential neighbourhoods, commercial centres, and recreational spaces. It features tree-lined streets and several parks, contributing to its aesthetic appeal. Notable landmarks, such as historic buildings and cultural institutions, enhance its significance as a central hub for both residents and visitors.

The area is well-connected by public transportation, making it accessible and lively. However, District 6 also faces challenges related to urban navigation, including safety concerns, varying sidewalk conditions, and the need for improved accessibility for individuals with disabilities. These aspects are crucial for understanding the dynamics of pedestrian movement within the district. As illustrated in Figure 1b, the geographical layout and key features of District 6 provide a comprehensive overview of the study area, highlighting its potential for enhanced navigation solutions.

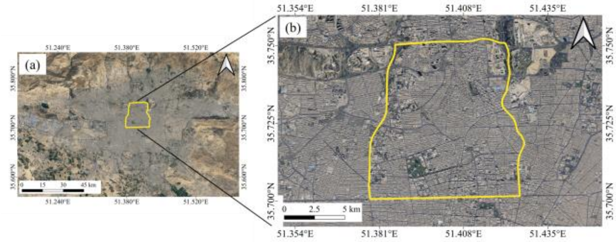

Figure1. Overview of the study area. (a) city of Tehran, (b) District 6.

2.2 Datasets

2.2.1 Suitability factors identification: To implement this study, several essential factors were identified to evaluate the suitability of each street for pedestrians in District 6 of Tehran. These factors include type of road, which encompasses classifications such as main street, boulevard, secondary street, highway, and alley. Road safety was assessed based on the level of perceived safety that citizens feel regarding personal safety concerning accidents while using these routes. The slope of the path was identified as a critical factor for pedestrian accessibility, while lighting conditions were deemed necessary for ensuring safety and comfort along the pathways. Additionally, sidewalk width was considered vital for accommodating pedestrian traffic. The type of road was already present in the dataset.

2.2.2 Crowed-Sourced Data: In the next step, after incorporating the slope and sidewalk width parameters for each street, qualitative factors related to each route, such as lighting levels and safety, will be examined. The proposal of this study involves developing a citizen-based social media platform. A key parameter in a smart city is citizen engagement, intending to enable users to generate data that can be utilized for urban services, including routing for pedestrians and, in the future, cyclists. By leveraging citizen-generated data, streets receiving negative feedback will have their scores reduced, thus decreasing their weight in the routing process.

Users within this platform can express their opinions in different categories such as safety and lighting conditions. An important aspect of this approach is that since the presence of obstacles can vary rapidly when the social media platform is operational, citizens can report issues such as ongoing street repairs or blocked pathways. In such cases, the affected route will receive a negative score, which will return to normal after one week unless further reports are made by citizens.

This collaborative approach aims to enhance data accuracy and improve the overall safety and usability of pedestrian pathways in the urban environment. However, due to the current unavailability of this platform to the public and the lack of active users, data were collected from citizens through questionnaires, with scores for all parameters ranging from 0 to 5.

Based on the field observations, most streets within a single category—such as highways or main streets—are perceived to be similar in terms of safety and lighting, except for those streets that received negative feedback in the survey, which had their scores reduced. Initially, users ranked each street category (highways, boulevards, main streets, secondary streets, and alleys) based on perceived safety and lighting. In the final stage of data collection, users ranked the importance of each parameter (safety, slope, pedestrian zone width, route length, and lighting) according to priority.

2.3 Suitable Rout Recommendation Algorithm for Pedestrians

2.3.1 Data Processing: In this study, a dataset obtained from mapping and surveying District 6 of Tehran municipality was utilized, which includes parameters such as sidewalk width and slope for each intersection. User feedback on factors like crossing safety, lighting levels, and the absence of obstacles were gathered through a structured questionnaire administered to 100 respondents. To facilitate comprehensive data collection, District 6 was clustered into ten areas based on proximity using the k-means clustering algorithm (Figure 2). From each cluster, eight streets of varying types were selected, with four oriented east-west and four oriented north-south. The slope for each street was calculated using an online tool (Ba Hesab[1]), and the average slope for streets of the same type and orientation was assigned to other streets within the same cluster. A similar approach was used to determine sidewalk widths. Although this method provides approximate values for parameters like slope and sidewalk width, it is acceptable for comparing streets, ensuring that data on all significant streets in the city were gathered for accuracy.

After assigning the parameters of slope and sidewalk width to each street and collecting user ratings for lighting and safety, all data were integrated into a unified dataset. User scores, along with other parameters, were normalized to a range of 0 to 1. A cost function was then defined, where the weight of each parameter—determined from user feedback—was multiplied by its normalized value. For parameters like safety, lighting conditions, and sidewalk width, where higher values are preferable, the normalized value was subtracted from one before applying the weight. This adjustment ensures that higher scores correspond to lower costs, reflecting the desirability of these parameters. The cost for each street was computed based on this methodology, allowing for a comprehensive evaluation of each route while considering user preferences and the relative importance of each parameter in determining pedestrian suitability.

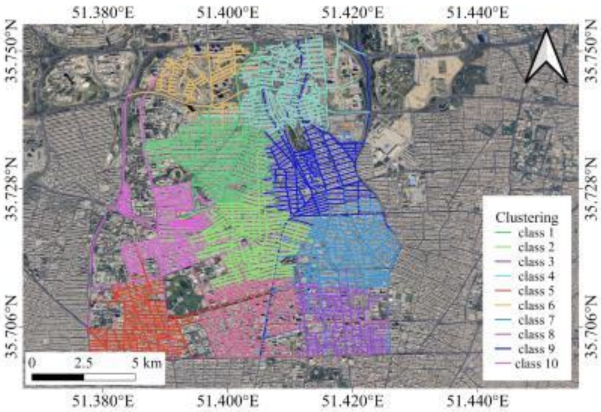

Figure 2. Clustering of streets in District 6 of Tehran based on geographical proximity.

2.3.2 Navigation Models: The street network analysis was conducted using the A and Dijkstra's algorithms* (Luxen & Vetter, 2011). These algorithms were employed to determine the optimal path based on the calculated costs for each route. The A algorithm*, known for its efficiency in finding the shortest path while considering various weights (Eppstein, 1998), was used alongside Dijkstra's algorithm, which is effective for identifying the shortest paths in graphs with non-negative weights (Moffat, 1985). By applying both algorithms, the most efficient routes were identified, taking into account the normalized parameters and user-defined weights. This approach allows for the selection of paths that minimize travel distance while optimizing for pedestrian safety, lighting, and other critical factors highlighted by user feedback. The results offer valuable insights for urban planning and pedestrian infrastructure development in District 6 of Tehran municipality.

2.3.2.1 **A* Algorithm:** The A* algorithm is renowned for its efficiency in finding the shortest path while considering various factors (Eppstein, 1998). It is a widely used pathfinding and graph traversal algorithm that efficiently plots the shortest walkable path between multiple nodes or points on a graph. This algorithm is particularly useful in scenarios with obstacles or constraints when determining the optimal path (Eppstein, 1998).

This study applies the A* algorithm to identify the most suitable pedestrian routes in District 6 of Tehran Municipality (Pasandi et al., 2021; Erke et al., 2020). The street network is represented as a weighted graph, where nodes denote intersections and edges represent street segments. The A* algorithm is utilized to determine the shortest path between two points while considering factors such as the slope, width, lighting, and safety of sidewalks (Verde et al., 2021; Herlawati et al., 2021).

By using a heuristic function that estimates the cost to the goal, the A* algorithm can efficiently explore the most promising paths first, leading to faster convergence compared to uninformed search algorithms like Dijkstra's algorithm.

By applying the A* algorithm to the pedestrian routing problem, the navigation system can efficiently find optimal paths that minimize overall costs while considering various factors affecting pedestrian accessibility and comfort. This information is valuable for urban planning and infrastructure development (Ghaffari, 2014; Khalid et al., 2020).

[1] https://www.bahesab.ir/map

2.3.2.2 **Dijkstra's Algorithm:** Dijkstra's algorithm is a well-established method for finding the shortest paths in graphs with non-negative weights (Moffat, 1985; Karczmarz et al., 2024). It effectively uses graph nodes in a weighted graph, making it particularly suitable for applications such as routing and navigation (Karczmarz et al., 2024). This algorithm can be applied to identify optimal pedestrian routes in District 6 of Tehran municipality by modeling the street network as a weighted graph, where nodes represent intersections and edges represent street segments with associated weights reflecting factors such as the slope, sidewalk width, lighting, and safety.

By utilizing Dijkstra's algorithm, this study contributes to developing safer and more efficient pedestrian networks in urban environments, ultimately enhancing the overall quality of life for residents in District 6 of Tehran Municipality (Fan & Shi, 2010; Sniedovich, 2006; Fuhao & Jiping, 2009; Chen, 2020).

3. Smart City Navigation and Web Application

This web application operates through two main services: a Routing Service and a Citizen-Oriented Social Network Service. Upon logging in, users are prompted to either sign up or sign in, leading them to a main page where they can access both services. If users select the social media option, they are directed to a platform that allows them to engage in discussions about various road-related categories, such as security and lighting (see Figure 3).

Figure 3. Overview of the Citizen-Based Social Media platform.

The proposed web GIS Smart City Navigation was developed based on an applicant-server architecture (Figure 4). The architecture of the platform leverages a variety of technologies to ensure an efficient and responsive user experience. The front-end interface is developed using the Bootstrap framework, which provides a responsive and visually appealing design. HTML is utilized to structure the content, ensuring compatibility across devices and browsers. The back-end is based on the MVT (Model-View-Template) pattern, implemented using the Django framework. This design separates the data model, user interface, and application logic, promoting maintainability and scalability. Data interactions are managed through Django's Object-Relational Mapping (ORM) system, allowing developers to interact with a PostgreSQL database using Python objects instead of SQL queries. User-generated content, such as messages and interactions, is stored in this robust database.

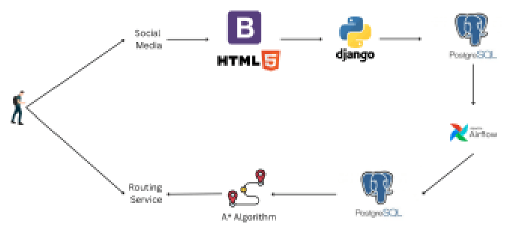

Figure 4. The architecture of Smart City Navigation.

To manage the dynamic nature of citizen-reported data and user messages within the social network, the platform utilizes Apache Airflow as a Workflow Management System (WMS). Each road segment is initially stored in a database with predefined Key Performance Indicators (KPIs), including safety, lighting, slope, and sidewalk width. When a citizen submits a report about a specific route, the data pipeline processes the input using Python and Apache Airflow.

Natural Language Processing (NLP) techniques are employed to analyse sentiments and extract relevant street names from user comments, determining whether they are positive or negative. This sentiment analysis is crucial for updating route-related information in the database, ensuring accurate and relevant routing data. The system uses a pre-trained BERT model for sentiment classification, correlating comments to the appropriate KPI(s) based on their category, such as safety concerns or poor lighting.

In addition, the platform employs the A* and Dijkstra algorithms for route optimization, allowing for a comparative analysis of their efficiency and effectiveness based on user inputs. The platform encourages citizen participation in urban management, fostering a culture of smart citizenship. Users are identified using their national IDs, linking account creation to real identities. This community-driven approach emphasizes factors like street obstacles, lighting conditions, and intersection security, enabling users to discuss and exchange opinions.

In this study, the results of a questionnaire from applicants were entered manually into the web application due to incomplete navigation processes. The collected data is systematically processed, and routes are selected using both the A* and Dijkstra algorithms. User feedback undergoes further processing to categorize comments and assess sentiment. The system measures consensus through likes and dislikes, incorporating significantly negative comments as negative scores for affected routes.

Although the system is not yet fully operational, initial efforts have focused on gathering user opinions through questionnaires to inform the ongoing development of the intelligent routing system. This structured workflow ensures that real-time citizen feedback is integrated into the platform, enhancing the accuracy and reliability of the pedestrian routing system.

4. Results

In this section, the output of a questionnaire that entered into the platform is considered and also the routes generated by the proposed algorithm are compared with Google Maps which is one of the most common navigation methods in Iran. The comparison focuses on various quantitative and qualitative characteristics to assess their suitability for pedestrians.

4.1.1 Questionnaire Results: This study presents the findings from a structured questionnaire administered to 100 respondents after they interacted with the smart city web application. Their experiences and processes are explained in the following sections.

Figure 5 illustrates the gender distribution among participants. It shows a significant majority of male participants (62) compared to female participants (37). This demographic insight helps us understand the gender balance within the study.

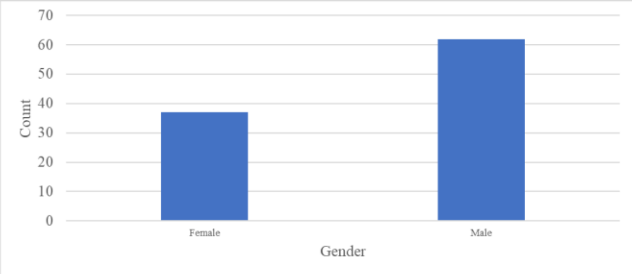

Figure 5. Distribution of Participator Gender.

Figure 6 displays the age distribution of participants, with notable peaks around ages 24 and 25. The data indicates varied participation across different age groups, highlighting trends in engagement among younger adults, particularly in their early twenties.

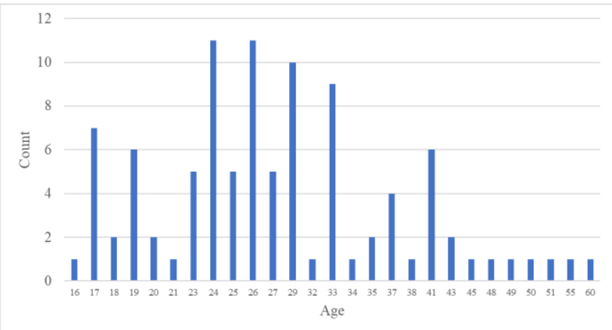

Figure 6. Distribution of Participant Ages.

Figure 7 categorizes participants by their occupations. The largest group consists of college students (41), followed by corporate employees (26). Other categories include high school students, shopkeepers, and taxi drivers. This information provides context on the participants' backgrounds and potential influences on their responses.

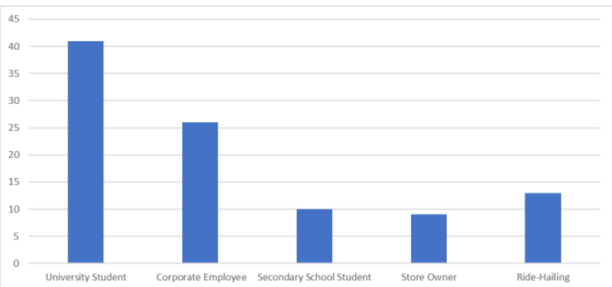

Figure 7. Distribution of Participant Occupation.

Initially assuming similar safety levels among streets of the same type, we refined our road safety evaluation by gathering participant ratings on perceived safety across different road categories. This process established an initial safety benchmark for each road type.

To capture localized safety variations, we segmented the study area into ten parts and asked participants to highlight crime-prone or unsafe areas within their segment. This information was recorded as citizen-reported posts on the platform. Streets frequently flagged as unsafe had their safety scores adjusted, ensuring a dataset that encompassed both general perceptions and localized risks.

Additionally, Figure 8 scrutinizes participants' safety perceptions across various road types. The combination of boulevards and main roads emerged as the most trusted option for safety, showcasing participants' preference for specific road types when assessing safety in their surroundings. This finding underscores the significance of individuals' road preferences in shaping their safety perceptions.

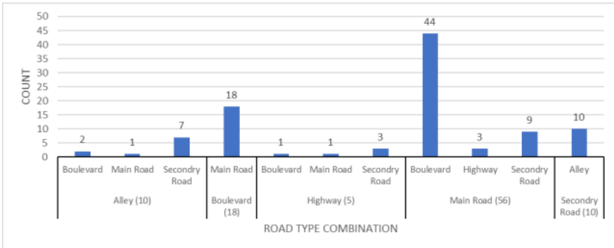

Figure 8. Safety Analysis.

Figure 9 evaluates participants' perceptions of lighting conditions across various road types. Combination of Main Road and Boulevards are identified as having the best lighting. This insight is crucial for understanding how lighting affects participants' feelings of safety and usability in their surroundings.

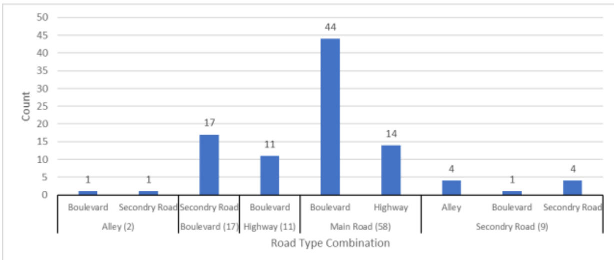

Figure 9. Lighting Analysis.

Figure 10 ranks various parameters based on their perceived importance to participants. Safety is prioritized significantly, suggesting these factors are critical in assessing road usability and safety. This analysis highlights the key considerations participants have when evaluating their environment.

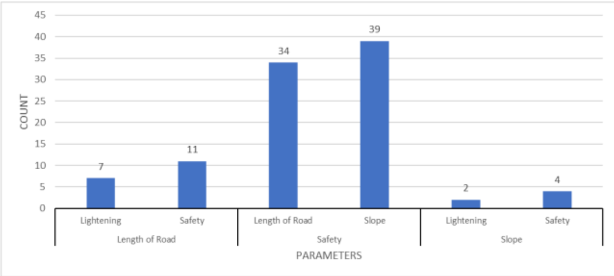

Figure 10. Parameter Weight Analysis

Implement the routing component of this study. These algorithms are widely recognized for their effectiveness in finding optimal routes. Applying both algorithms made it possible to compare the proposed routes and identify any discrepancies. Fortunately, after evaluating several routes, both algorithms suggested the same paths.
Additionally, the performance of these algorithms was assessed based on execution time. The A* algorithm outperformed Dijkstra's algorithm by approximately three seconds, which was anticipated given that A* is a heuristic algorithm known for its efficiency.

The proposed route in this study, begins at 55th Street, heading south toward Mohammad Ali Jahanara Street and then to Bagcheban Street. From Bagcheban, the road continues to Seyed Jamaluddin Asadabadi Square, followed by Seyed Jamaluddin Asadabadi Street to 27th Alley. From there, the path leads south along Chehelston Street to Fatemi Square. Next, it proceeds from Jihad Square to Joibar, then to Palestine, followed by Taleghani Street, Vasal Shirazi Street, and Shafi'i, ultimately reaching the destination which is shown in Figure 11a. The starting and ending coordinates are as follows:

- Starting Point: point1 = (5722204.129296306, 4265122.730411574)
- Ending Point: point2 = (5721504.4027697155, 4259945.990168185)

Since the platform designed in this article is specifically for users within Iran, the routes displayed on the map are written in Persian. However, in the output obtained from the suggested route in Google Maps, the street names are written in English.

Route 1: Start from 55th Street, heading toward Jahan Ara Street. Cross the Shahid Gomnam Highway, then proceed along West 2nd Street, Mehrdad Street, Mozaffari Khan Street, Rahi Moeiri Street, Dr. Fatemi Street, and Hijab Street, passing through Laleh Park to Quds Street. (Distance: 4.9 km, Duration: 1 hour and 18 minutes)

Route 2: Begin at 55th Street, proceed toward Jahan Ara Street, then continue along 36th Street, Biston Street, Fatemi Square, Joibar, Palestine, Taleghani, and finally to Quds Street.

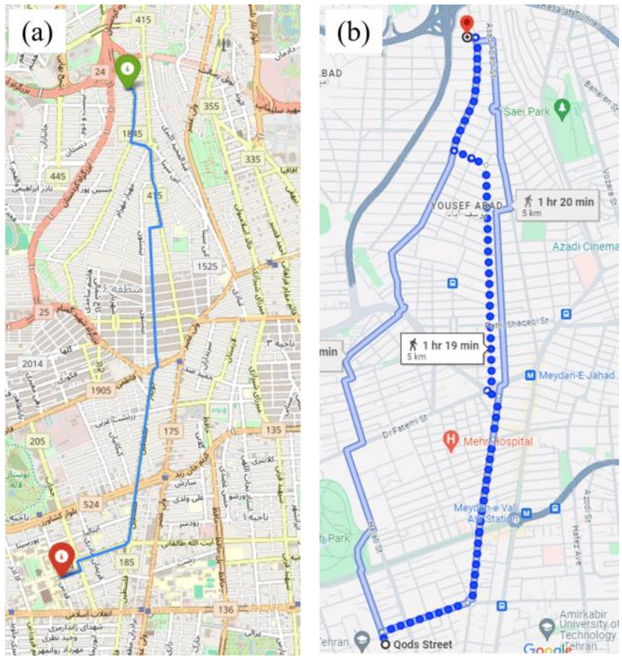

Figure 11. Proposed Routes: (a) Study Algorithm, (b) Google Maps.

The comparative analysis of routing algorithms revealed notable differences between the proposed method and Google Map suggestions, despite both identifying similar overall paths. While Google Maps directed users along Bisoton Street for a shorter route, the algorithm developed in this study recommended a slightly longer path via Seyyed Jamaluddin Asadabadi Street and Chel Seton Street, prioritizing user scores for critical factors such as safety and lighting conditions.

This alternative selection reflects a stronger emphasis on pedestrian preferences, particularly regarding safety and lighting, which were deemed the most important factors by citizens. Consequently, although the proposed route is marginally longer, it offers a potentially more comfortable and secure walking experience.

Based on Table 1, the length of our route measured 4.964 meters, whereas the Google Map route was only 4.8 meters long. This stark contrast can be attributed to our proposed route being significantly safer and more straightforward.

Name of the piece	lighting	security level	width of the sidewalk (m)	Slope %
Proposed Routes in this study				
55th St.	2	2	1	3.14
Jahan Ara St.	4	4	3	4
Baghcheban St.	3	3	1.5	1.14

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Seyyed Jamaluddin Asadabadi St.	5	5	3	4.5
28 St.	3	3	1.5	1
Chel Seton St.	5	5	3	4.5
Fatemi St.	5	5	5	0.04
Joibar St.	5	5	3	1.94
Palestine St.	5	5	3	2.9
Taleghani St.	5	5	3	0.15
Vasal Shirazi St.	5	5	3	3
Shafii St.	3	3	1.5	0.23
Total Length	4.96 Killo Meters			
Proposed Routes from Google Maps				
55th St.	2	2	1	3.14
Jahan Ara St.	4	4	3	4
36th St.	3	3	1.5	1
Bisoton St.	4	4	3	4.5
Fatemi St.	5	5	5	0.04
Joibar St.	5	5	3	1.94
Palestine St.	5	5	3	2.9
Taleghani St.	5	5	3	0.15
Vasal Shirazi St.	5	5	3	3
Shafii St.	3	3	1.5	0.23
Total Length	4.85 Killo Meters			

Table 1. Comparison of Factors Between Proposed Routes and Google Maps Routes

5. CONCLUSION

In this research, we aimed to address two key challenges in smart city management by proposing innovative solutions that prioritize citizen engagement and data-driven urban planning. The first solution focuses on the development of a comprehensive platform designed to encourage active citizen participation in city management. This platform would adopt a familiar, social media-like interface, allowing citizens to easily share their opinions, feedback, and concerns about urban infrastructure and navigation. By creating a space where citizens feel comfortable voicing their thoughts, this system ensures that their input becomes a valuable resource for city officials.

Through the use of Participatory Planning Geographic Information Systems (PPGIS), this platform will analyse citizen-generated data—such as comments on pedestrian safety, route preferences, or environmental conditions—and leverage Natural Language Processing (NLP) to extract sentiment and relevance from these messages. This citizen-sourced data will then be integrated into city management processes, providing valuable insights that can guide decisions on urban planning, public safety, and infrastructure improvements.

Beyond data collection, the platform will offer tangible services that directly benefit users, such as customized route suggestions for pedestrians.

The second major solution proposed in this research involves ensuring that the platform's services are built around citizen-driven data, creating a feedback loop where user input not only informs city management but also enhances the quality of services provided.

The platform is dedicated to enhancing active participation by offering tailored routing services that cater to the unique needs of various community segments. Our aim is to integrate these services into daily life, ensuring users consistently find value in their interactions with the platform.

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