*Wiz*RD: A Personalized Wayfinding Platform for Enhanced Urban Navigation

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Abstract. Wayfinding platforms help users navigate both indoor and outdoor environments in real-time. Many existing systems primarily optimize either distance or time, neglecting other important factors such as personal comfort, perception of safety, or emotional responses to the environment.

To overcome these limitations, we designed *Wiz*RD, a new wayfinding platform that allows users to express their preferences and obtain routes that optimize them. This is made possible by the fact that *Wiz*RD can automatically acquire and integrate new data sources, also enabling the definition of customized routing algorithms that take into account both data sources and user preferences. In addition, to support decision-making, *Wiz*RD includes a visualization dashboard that facilitates users' understanding of how different environmental factors affect the recommended routes. Finally, the platform supports multimodal navigation by integrating vehicle interchange stations called LUMIs.

A prototype implementation developed for the area around the University of Milano-Bicocca demonstrates the platform's ability to handle multimodal navigation and to address the specific needs of vulnerable people, such as the ones with impaired mobility, women, and children.

Keywords: Routing · Customized Wayfinding · Planning · Interactive Data Visualization

1 Introduction

Navigation in urban areas has become increasingly dependent on wayfinding solutions, which assist users in planning their trips and making more informed mobility decisions by providing directions for navigating indoor and outdoor environments in real time, reducing or eliminating printed maps.

Wayfinding platforms, however, often disregard human factors such as safety, comfort, or emotional response to the environment when calculating routes, optimizing for travel time or distance instead. Although incorporating such factors into routing algorithms is computationally feasible [3], the definition of effective metrics and cost functions that reflect user preferences, producing personalized and inclusive results, remains challenging.

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Several routing systems that rely on diverse data sources have been proposed. For instance, Balata et al. [1] proposed a navigation system for people with visual impairment that relies on existing landmarks to insert contextual information in directions given to users. Similarly, SearchPath [6] provides culturally relevant itineraries by combining known Points of Interest, such as museums and exhibitions, user preferences, and multimedia content. Both approaches succeed in producing personalized and contextually relevant routes. However, they have limited adaptability to changes in the environment or the application's requirements due to their use of static datasets. Integrating support for frequently updated datasets is essential, as highlighted by Taghipour et al. [7], who compared several models for travel time prediction. Their study showed a significant increase in the predictive capabilities of all models when presented with data from diverse, contextually relevant sources.

The importance of integrating dynamic datasets, such as public transport timetables, is shown by the study conducted by the authors of the FAVOUR algorithm [4]. FAVOUR calculates the route based on the current situation (e.g., traffic and weather) and the user's preferences, which are continuously updated while using the service. Multimodal transportation solutions, however, present their challenges: Bast et al. [2] discuss the efficiency of route planning algorithms in large transportation networks, particularly highlighting the complexities associated with multimodal route planning.

Many existing systems still cannot provide customized routing solutions or dynamically integrate environmental data. In response to those limitations, we present *Wiz*RD, a flexible and modular wayfinding platform designed to integrate multiple, diverse data sources that offers users extensive customization options. Unlike conventional routers that attempt to minimize travel time or distance, *Wiz*RD optimizes the calculated route according to user preferences while considering environmental factors expressed in the dataset and supports:

- the integration of heterogeneous data, including road network information, pre-calculated metrics, and real-time data from external providers;
- customizable cost functions that can be used to provide routes that respect users' preferences regarding safety, accessibility, or infrastructure quality;
- a data visualization system that helps users understand how the combination of the dataset and different preferences influence routing decisions;
- the combination of different transportation modes (e.g., walking, cycling, and shared vehicle services), properly following road regulations (e.g., bikes cannot travel on footways);
- the use of shared vehicle services via exchange points called LUMIs (Last-Mile User Mobility Interchanges).

Moreover, *Wiz*RD is particularly attentive to the needs of vulnerable groups, including individuals with mobility impairments, women, and children, by enabling the avoidance of barriers and the prioritization of safer or more comfortable paths.

We developed a prototype application for accessible wayfinding in the area surrounding the University of Milano-Bicocca, highlighting the capabilities of

*Wiz*RD. This real-world implementation demonstrates the platform's ability to compute personalized and context-aware routes based on user-defined preferences dynamically and to integrate new data sources, such as walkability [5] metrics, through dedicated procedures.

The rest of the paper is organized as follows: Sect. 2 provides an overview of *Wiz*RD and introduces its functionalities; Sect. 3 describes its architecture; Sect. 4 discusses the use case we developed; and Sect. 5 presents the conclusions and future research directions.

2 The *Wiz*RD Platform

This section provides an overview of the capabilities offered by the platform. Two main categories of users have been identified: *end users* and *knowledge integrators*. *End users* can interact with the system in two ways: they can request a route from one point to another, potentially using vehicles available at LUMIs, or they can view specific properties of the network, either in its entirety or limited to a specific subset, such as cycling paths. *Knowledge integrators*, on the other hand, are responsible for extending the system's functionalities by enriching the database with additional metrics that characterize road segments (such as walkability indexes).

2.1 Routing Support

The *Wiz*RD platform integrates multiple data sources to supplement each segment with diverse metrics, providing a more detailed road network representation. For example, a specific segment might have associated a walkability score of 10 (out of 100) from one source and a greenness score of 1 (out of 10) from another. The platform relies on a database to store and process heterogeneous data, using it to calculate routes optimized for a combination of metrics that differ from traditional distance- or time-based criteria. With this system, the *Wiz*RD platform can adapt to user preferences: for example, users may prioritize routes with lower pollution levels, paths characterized by greater walkability, or routes optimized for accessibility in cases of limited mobility.

*Wiz*RD also supports multimodal navigation, letting users combine walking and sustainable vehicles, such as bikes, e-bikes, and e-scooters. The platform also has built-in support for exchange points (LUMIs), where users may rent a vehicle or return it. When users select a shared vehicle, the system directs users to the nearest LUMI and then to the LUMI nearest to their destination. This only applies if a rental route takes less than just walking, in which case the system defaults to the latter. Ultimately, the router enforces regulatory constraints: for example, if a portion of the route (e.g., a crossing) requires the user to dismount from their bike, the system suggests a modal switch to ensure compliance with traffic regulations.

Figure 1 illustrates a multimodal route where users rent an e-scooter to travel from Building U9 to Building U6 of the Bicocca University campus. Another

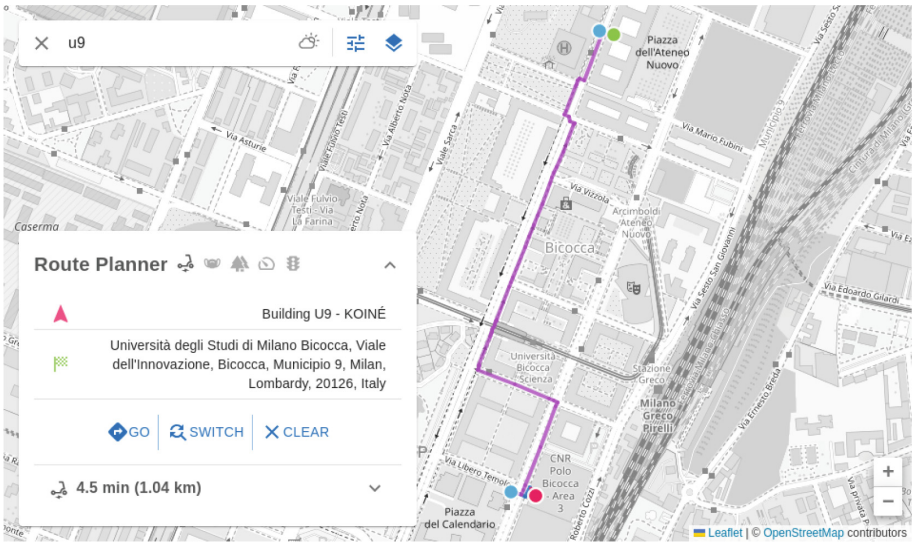

Fig. 1. Example of a multimodal route proposed to a user who wishes to rent an e-scooter to travel between university buildings, as presented by our prototype application.

example is shown in Fig. 2, where the system suggests a mode transition to comply with traffic regulations. In this scenario, we asked the router to provide a route to Building U14, traveling by e-bike. The system directs the user to the nearest cycleway (highlighted in orange), which terminates abruptly. At this point, the system instructs the user to dismount and walk along a connecting path (highlighted in blue) before resuming cycling on a service road. This example shows how the router adheres to legal constraints while respecting users' preferences.

2.2 Visualization Support

The *Wiz*RD platform provides a data visualization component that creates and displays *views* that represent selected attributes of specific portions of the road network. Views are overlaid on the interactive map, giving users a visual interpretation of the data stored in the platform's database, and are characterized by three key aspects:

1. They support **filtering** based on predefined criteria. Through filters, users can select specific subsets of the network, such as roads, footways, cycleways, or greenways, and analyze specific features: for example, a user may isolate pedestrian paths to examine walkability-related metrics.
2. They give a visual **representation of data sources**, which may include various attributes such as air quality, traffic conditions, infrastructure quality,



Fig. 2. Example of a multimodal route considering road network constraints; the highlighted pink area indicates the section pictured on the right. (Color figure online)

safety, accessibility, and walkability. Data can be displayed as individual metrics or synthesized through computational ***functions*** that combine multiple parameters to produce an aggregate value for each segment. These functions (see Fig. 3) enable users to personalize their navigation experience by creating specific criteria for route computation.

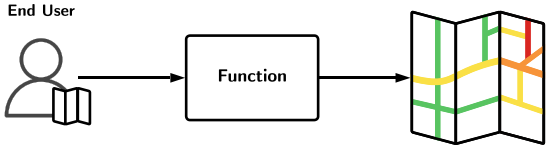

Fig. 3. Functions compute data for real-time visualization.

3. They can be **colored** according to specific attributes, giving a visual representation of variations in the dataset. Users can apply a uniform color to highlight specific segments (e.g., walkways or cycleways) or use a gradient scale to visualize differences in a selected metric (e.g., traffic colored by badness). Advanced customization options, including opacity and line width, can also be adjusted according to presented data. For instance, the default visualization strategy for air quality data uses wide, semi-transparent lines to simulate low granularity. An example of different visualization strategies is shown in Fig. 4.

In summary, *Wiz*RD's visualization component enables interactive data exploration and analysis, helping users gain deeper insights into the spatial distribution of critical infrastructure features.

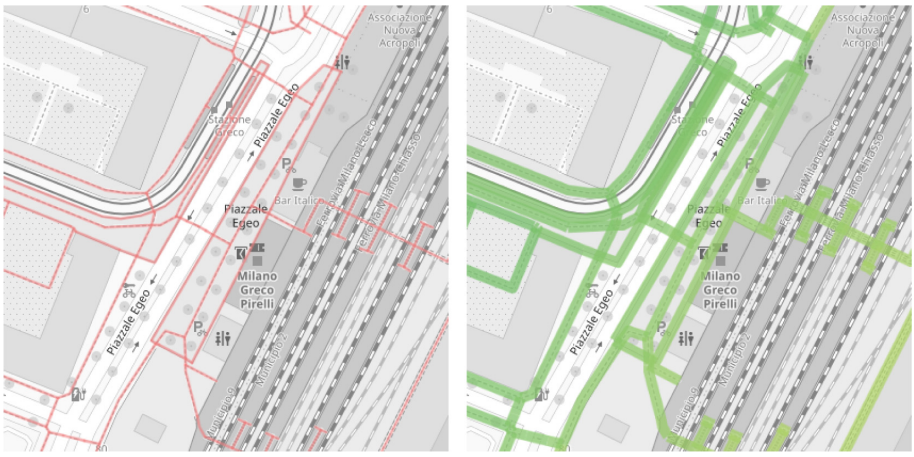

Fig. 4. Example of a preset view showing footways in coral (left) and a custom view visualizing air quality data in footways (right).

2.3 Knowledge Base Augmentation Support

The *Wiz*RD platform integrates various data sources, which contain values associated with specific segments of the road network. Each value corresponds to a distinct metric: pollution levels, traffic density, accessibility, or green space. Adding a new source associates more data to road segments and makes the network more capable of representing different aspects of the road infrastructure. When computing routes, these values provide weights for each road segment: by combining them and adjusting their relative importance, users can prioritize factors like safety, environmental impact, or accessibility and personalize their routes.

Knowledge integrators can also define ***procedures*** (see Fig. 5) to automatically perform complex operations on the dataset during the data preparation stage, ensuring that the results are readily available for later use.

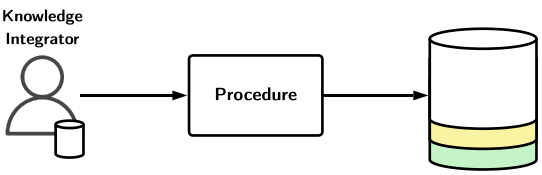

Fig. 5. Procedures handle data computation during the preparation stage and cache the results for future use.

3 *Wiz*RD Platform: Architecture

*Wiz*RD follows a traditional client-server architecture as depicted in Fig. 6. The *Data Provisioning* component is responsible for ingesting the map and related data, including data sources and processing procedures. The *Data Access* component manages data storage and ensures availability, while the *Data Consumption* component handles user interaction with the platform.

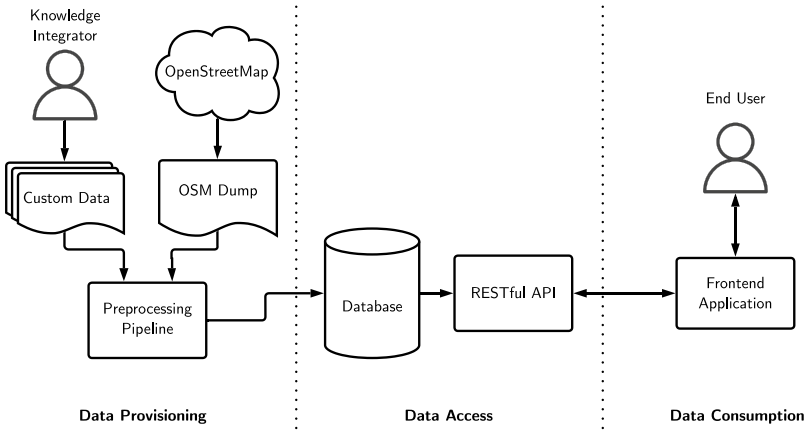

Fig. 6. Overview of *Wiz*RD's architecture.

3.1 Data Provisioning

*Wiz*RD uses the OpenStreetMap (OSM) dataset as a base layer for road network data and street classification. OSM has been chosen due to its comprehensive coverage and open data model.

The preprocessing pipeline is essential for obtaining raw data from OSM and transforming it into a format suitable for backend processing. The pipeline automates the conversion process through a set of scripts, ensuring that the system operates with up-to-date and accurate data. The pipeline consists of three main steps, as illustrated in Fig. 7.

- **Map Retrieval**: The first step retrieves OSM data for a specified area, storing it in a dump file. This process relies on `osmconvert`[1] to extract data within a defined bounding box.
- **Graph Building**: The second step transforms the OSM data into a graph structure that can be used for routing. The script ensures that the graph is optimized for routing. Indeed, the script: *i)* preserves road classifications (e.g., primary roads, bike lanes) and surface types (e.g., asphalt, gravel) to assign appropriate weights for routing; *ii)* identifies and handles one-way

[1] https://wiki.openstreetmap.org/wiki/Osmconvert.

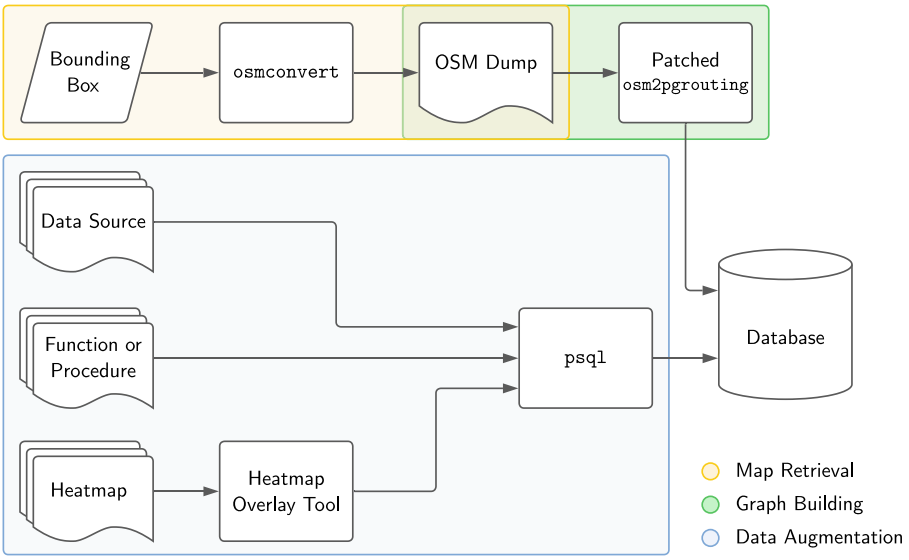

Fig. 7. Overview of *Wiz*RD's preprocessing pipeline.

roads, greenways, and pedestrian crossings, ensuring that the graph accurately reflects real-world conditions; *iii)* removes isolated graph components (e.g., non-walkable areas) that do not contribute to valid routes. The script uses a modified version of `osm2pgrouting`[2].

– **Data Augmentation**: The final step integrates data from external sources such as Points of Interest (POIs), traffic data, pollution, and Walkability Indexes (WIs) into the database. At this point, data from loosely coupled sources (i.e., heatmaps encoded as single-channel images) can be overlaid onto the graph. Different layers of the same data point can be stored concurrently in *profile* mode. This mode can be helpful in simulating real-world scenarios, such as traffic during different times of the day or pollution levels in different seasons. This step also loads user-defined functions (for online calculations) and procedures (for offline calculations) in the database.

3.2 Data Access

The backend uses the PostgreSQL database to store the road network and the data sources. In particular, the backend uses the PostGIS extension[3], which supports geospatial data types and operations. Table 1 presents a summary of the contents of the database.

[2] https://github.com/pgRouting/osm2pgrouting.
[3] https://postgis.net.

Table 1. Summary of tables used in the database.

Table	Description
`ways`	Data from the OSM dataset, including vertex pairs $\langle V_s, V_t \rangle$
`data`	Additional data that is not strictly required for building the network
`pois`	Data related to Points of Interest (POIs)
`modes`	Descriptions of supported modes of transportation, including their maximum speeds and the cost of rental
`ddesc`	Description of the columns in the `data` table
`fdesc`	Description of user-provided functions

To summarize the main datasets currently integrated into the platform, Table 2 provides an overview of their types, sources, and purposes.

Table 2. Data sources integrated into the *Wiz*RD platform.

Dataset	Source	Description
Road Network	OpenStreetMap[a]	Topology of the road network and accessory data including qualitative information such as street names, pavement surface type, and road classification, and quantitative information such as length
Points of Interest	Manually Generated	Points of Interest, including their names, coordinates, types, and accessory information
Walkability Indexes	Survey[b]	Quantitative indices that express the desirability of a route for pedestrians, such as infrastructure quality, accessibility, and safety
Traffic Data	TomTom Traffic[c]	Information regarding vehicular traffic such as its density, speed, and average travel time
Air Quality	Breezometer[d]	Mean European Air Quality Index (EAQI) value for each segment

[a] The dataset is gathered from OpenStreetMap (https://www.openstreetmap.org) using `osmconvert`

[b] The dataset was sourced from a survey conducted by the Department of Sociology and Social Research, University of Milano-Bicocca

[c] The dataset was sourced from TomTom (https://www.tomtom.com/products/traffic-stats/) on 22 September 2023

[d] The dataset was sourced from Breezometer (https://www.breezometer.com/air-quality-index/) on 22 September 2023

For route computation, the backend makes use of pgRouting[4], a PostgreSQL extension that supports several routing algorithms, including Dijkstra's, A*, and K-Shortest Paths (KSP). pgRouting requires a preprocessing step to build a graph representing the road network, on which routes are calculated by minimizing the route's cost.

User-defined cost functions can be supplied to the algorithm to optimize routing for specific scenarios and preferences. For example, a cost function that combines the type of vehicle, traffic conditions, and user preferences regarding air pollution can be used along with Dijkstra's algorithm to provide a personalized route. Users can pick their preferred algorithm from a list, select the desired cost function, and adjust related parameters. Additionally, multimodal routes can be requested, integrating LUMIs for users wanting to rent a vehicle.

The routing system's modular architecture offers a great degree of flexibility and allows knowledge integrators to tailor the platform for various use cases. Examples of target applications include personalizable navigation systems for end users and systems capable of estimating likely routes under various scenarios, such as the presence of green areas, commercial zones, traffic conditions, and the characteristics of different user groups.

Functions and procedures are written in the PostgreSQL dialect and are directly stored in the database during the Data Augmentation step. Recall that functions are used to perform real-time computations, such as calculating the cost of segments or generating data for visualization. In contrast, knowledge integrators typically define procedures and use them for offline computations during the data augmentation phase, as they allow for the pre-calculation and caching of the results of complex computations.

Finally, the backend exposes several RESTful API endpoints (some of them listed in Table 3) that facilitate communication with the frontend. These APIs support various operations, such as retrieving views, POIs, and calculating routes. Some endpoints are tailored explicitly for routing through LUMI stations.

3.3 Data Consumption

*Wiz*RD follows a client-server architecture, where the client is a frontend application responsible for user interaction and graphical representation of the data stored and processed by the backend server; communication between the two is handled via a RESTful API. Geospatial data is represented in GeoJSON[5] format, making it suitable for visualization with map rendering libraries such as Leaflet.js[6].

The frontend is a React-based Single-Page Application (SPA) running in a Node.js environment. It utilizes React-MUI[7] to draw UI elements. The following components provide user interaction:

[4] https://pgrouting.org.
[5] https://geojson.org/.
[6] https://leafletjs.com.
[7] https://mui.com.

Table 3. Summary of endpoints that are available through the API.

Endpoint	Method	Description
`/desc/data`	`GET`	Returns a specific Data Description
`/desc/func`	`GET`	Returns a specific Function Description
`/mode`	`GET`	Returns a specific transportation mode
`/mode/all`	`GET`	Returns all available transportation modes
`/poi/all`	`GET`	Returns all POIs of a given type
`/poi/nearest`	`GET`	Returns the POI of a given type closest to a set of coordinates
`/point/nearest`	`GET`	Returns the closest point to a set of coordinates
`/route`	`POST`	Calculates a Route
`/route/lumi`	`POST`	Calculates a Route that passes through LUMIs
`/view`	`GET`	Returns a view, given a filter and a data source

– **Map Component**: Built with Leaflet.js, this interactive map allows users to zoom, pan, and place markers for route planning. It integrates the OpenStreetMap Tile Server[8] for map tiles and the Nominatim API[9] for geocoding. Users can switch between different map themes (e.g., light or dark) and overlay geospatial data layers, such as traffic conditions or pollution levels, using Leaflet layers (see Fig. 8).

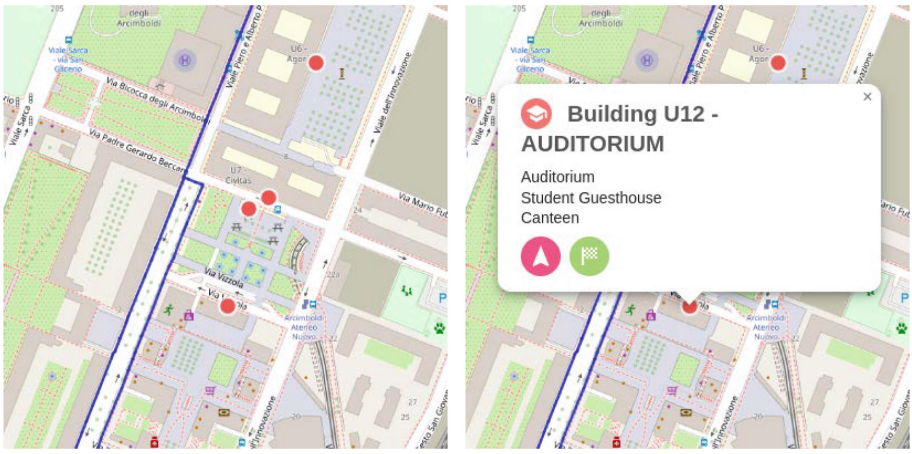

Fig. 8. A map showing cycleways, in blue, and campus buildings as red dots (left). The popup shown on the right gives information about the selected building. (Color figure online)

[8] https://wiki.openstreetmap.org/wiki/OpenStreetMap_Carto.
[9] https://nominatim.org.

– **Routing Options Component**: This module enables users to configure route preferences, including the selection of transportation modes (e.g., walking, biking, or driving) and additional constraints such as avoiding specific road types. Developed with React.js and Material-UI, it provides an intuitive interface for customizing routing parameters (see Fig. 9).

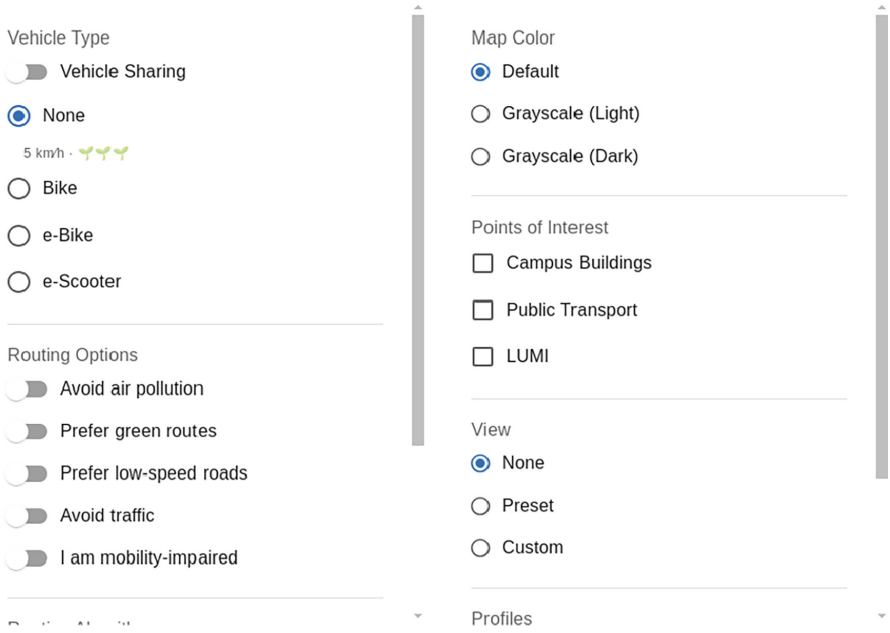

Fig. 9. The Routing Options panel (left) and the Visualization panel (right).

– **Route Planner Component**: This component allows users to calculate routes while displaying real-time updates on travel time, distance, and step-by-step directions. It dynamically retrieves routing data from the backend and renders the calculated route on the map with distinct markers and paths (see Fig. 10).
– **Visualization Component**: This component displays additional layers on the map that may be used for interactive operations, such as checking how many bikes are left at a LUMI or routing to a campus building. As shown in Fig. 11, the same system can also be used for static displays that allow users to explore datasets such as road network topology, traffic, or pollution levels. It also complements the routing system by providing a clear understanding of the influence of various factors on route selection based on user preferences and urban conditions. The visualization system has been built with React-MUI and Leaflet.js and is highly customizable, enabling users to tailor the displayed information to their specific needs. Figure 9 shows the Visualization panel, which can be used to turn layers on or off and change their appearance.

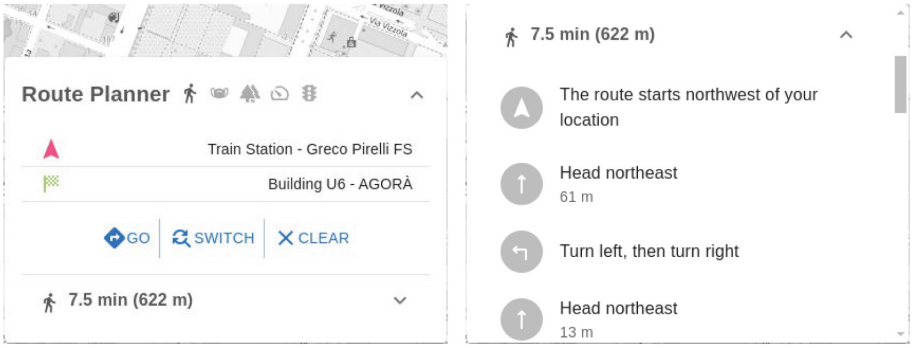

Fig. 10. The Route Planner (left) and the uncollapsed Directions section (right).

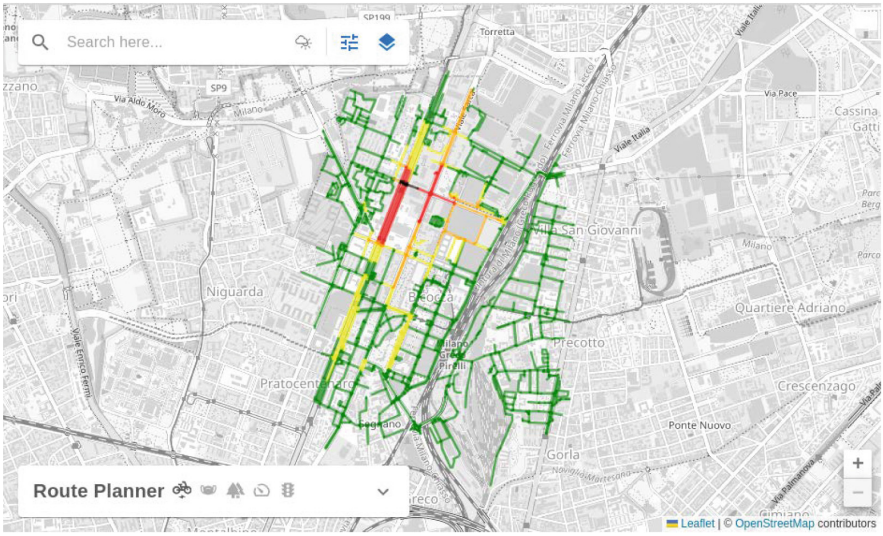

Fig. 11. Example of a data visualization overlay showing traffic data on the road network.

4 Use Case: Supporting Interactive Wayfinding for the MUSA Project

To validate our platform's feasibility and aid development, we created an application that caters to the needs of the MUSA project[10]. The prototype demonstrates the capabilities of the *Wiz*RD platform and aims at providing multimodal travel solutions for university students. As such, the application focuses on the area surrounding the main campus of the University of Milano-Bicocca, located in the Bicocca neighborhood of Milan.

[10] https://musascarl.it/.

4.1 The MUSA Project

This study was developed within the framework of the "Multi-layered Urban Sustainability Action (MUSA) – Spoke 1 – Urban Regeneration – Cities of the Future" project, funded by NextGenerationEU[11].

The MUSA framework involves a consortium of universities, research organizations, and companies under the leadership of the University of Milano-Bicocca. It aims to create a more sustainable, resilient, digital urban ecosystem by leveraging advanced research and public-private collaboration. In particular, Spoke 1 focuses on urban regeneration, seen from many different points of view. Among the objectives of Spoke 1 is the development of innovative strategies, practical methodologies, and intelligent tools for safe and sustainable intermodal mobility, supporting active mobility, and sustainable urban planning.

MUSA Spoke 1's research activities related to sustainable mobility focus on the university districts of Città Studi, Bicocca, and MIND in Milan and aim to develop innovative solutions for urban sustainability, including:

- Digitalization and green transition, to improve energy efficiency and reduce the environmental impact of cities.
- Sustainable mobility and intelligent infrastructure, focusing on low-impact transport and intelligent mobility.
- Urban regeneration and social inclusion to improve the quality of life in urban areas.

4.2 Usage Example

This section provides an example of how the MUSA Wayfinding application could be employed effectively for navigation on the Bicocca University campus.

Step 1 – Search: Students new to the campus must reach Building U7 for their class. Arriving at the campus by subway without a personal vehicle, they open the application and use the search bar to find the "Bicocca M5" subway station. The application returns several results, including the desired station. They select it, and a marker with a popup appears on the map. They tap the *Set as Starting Point* button from the popup, adding the metro station to the Route Planner.

Since they have a general idea of the location of building U7, they navigate to the Visualization panel and enable markers for all university buildings. They then tap on the marker closest to their estimated location of Building U7. When the popup appears, they set it as their destination using the appropriate button, adding the building to the Route Planner.

[11] https://musascarl.it/en/musa-urban-en/.

Step 2 – Route Preferences: Not feeling like walking, the students open the Routing Options menu and select the e-scooter rental option. Additionally, as they have asthma, they enable the *Avoid Pollution* preference to minimize exposure to pollutants that could trigger their condition. After closing the Routing Options menu, they observe that the icons in the Route Planner have updated: an e-scooter icon has appeared, and the face mask icon is now highlighted, indicating that their preferences have been applied.

Step 3 – Calculating the Route: The students tap the *Go!* button to initiate route calculation. The application then computes the most suitable course based on their preferences and proposes it to the students by visualizing it on the map. If the students are unsatisfied, they can modify one or more routing options to explore alternative paths.

5 Conclusions and Future Work

We presented *Wiz*RD, a wayfinding platform that integrates personalization and situational awareness, enabling users to define preferences and contextual needs through an intuitive interface. *Wiz*RD integrates diverse data sources and allows application administrators to enrich and customize the navigation graph. It also offers a visualization dashboard that helps users understand how personal preferences and environmental factors influence route selection.

An application developed within the MUSA project was designed to implement and validate the principles underlying *Wiz*RD, focusing on the area surrounding the University of Milano-Bicocca.

As future research avenues, integrating new data sources – including real-time data, such as traffic conditions or local event information – could improve the ability of *Wiz*RD to adapt to changing conditions dynamically and enhance the platform's ability to address increasingly diverse user needs. Moreover, the adoption of artificial intelligence and machine learning techniques could support more sophisticated route customization, enabling the platform to learn from user behavior and continuously refine its recommendations. However, while these technologies offer significant potential for personalization, they also introduce critical challenges related to bias, user privacy, and transparency. Thus, their integration should be handled with caution and with a clear understanding of these implications.

Collaboration with local authorities and mobility service providers could strengthen multimodal navigation (by having more and different vehicles available in LUMIs), improve data accuracy, and facilitate the platform's integration into broader urban mobility and sustainability initiatives. Ultimately, we believe that *Wiz*RD is also a valid tool for urban planners and policy-makers thanks to its powerful data processing and visualization systems. With the right combination of these components, the platform can assist in visualizing and identifying specific mobility patterns. As such, *Wiz*RD could be used to develop policies that promote safer, more inclusive, and more sustainable urban mobility practices.

Acknowledgement. This work has been developed within the MUSA – Multilayered Urban Sustainability Action – project, funded by the European Union – NextGenerationEU, under the National Recovery and Resilience Plan (NRRP) Mission 4 Component 2 Investment Line 1.5: Strengthening of research structures and creation of R&D "innovation ecosystems", set up of "territorial leaders in R&D".

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