A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments

Gabriele D’Orsoa, Marco Migliorea,*

a Dept. of Civil Environmental Aeronautics and Materials Engineering, University of Palermo, Transport Research Group, Viale delle Scienze Building 8, 90128 Palermo, Italy

ARTICLE INFO

Keywords:
Walkability
Pedestrian
GIS
Decision Support System
Active transportation

ABSTRACT

Despite the large investments made in the construction and modernisation of railway infrastructure, poor quality pedestrian routes may discourage users from using public transport. In fact, very little attention is generally paid to pedestrian mobility. Therefore, a method for evaluating the quality of pedestrian paths and the accessibility to railway stations has been developed. This method considers the main factors influencing the walkability of an urban area and makes it possible to establish the priorities for intervention, i.e. to identify the arcs of a pedestrian network that require prioritised action. The methodology is a decision support tool that can be used by policymakers and is developed in a GIS environment. Three railway stations in Palermo and its surrounding areas were chosen as a case study.

*Corresponding author.

E-Mail addresses: gabriele.dorso@unipa.it (G. D’Orso), marco.migliore@unipa.it (M. Migliore)
A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments

ARTICLE INFO

Keywords:
Walkability
Pedestrian
GIS
Decision support system
Active transportation

ABSTRACT

Despite the large investments made in the construction and modernisation of railway infrastructure, poor quality pedestrian routes may discourage users from using public transport. In fact, very little attention is generally paid to pedestrian mobility. Therefore, a method for evaluating the quality of pedestrian paths and the accessibility to railway stations has been developed. This method considers the main factors influencing the walkability of an urban area and makes it possible to establish the priorities for intervention, i.e. to identify the arcs of a pedestrian network that require prioritised action. The methodology is a decision support tool that can be used by policymakers and is developed in a GIS environment. Three railway stations in Palermo and its surrounding areas were chosen as a case study.

1. Introduction

Almost all trips between an origin and a destination require a walking section. Walking as a means of transport is commonly used for short trips or as a feeder for other modes of transport. People walk to shop or to reach a transport node, such as a bus stop, train station, car-sharing station, or bike-sharing docking station. Children walk to school, and senior citizens spend their free time going for walks. Therefore, in modern cities, the modal share of walking tends to be high, although it is often undercounted by statistics and travel surveys. However, poor pedestrian compatibility of certain environments may affect walking as a means of transport, thereby affecting the mobility of residents and tourists. For instance, the perception of personal insecurity or impassable sidewalks may affect one's walking ability and use of public transport, which today is considered non-efficient and unreliable, particularly in Italy. Current policies tend to promote a shift in the use of modes towards non-motorised and public transport (Pinna et al., 2017). A strengthening of the offering and an improvement in the efficiency of public transport are not unique strategies. Improvements in the public transport capillarity and accessibility to the required stations through an improved walkability are necessary. Impassable pedestrian paths (owing to the presence of obstacles, trash, pavement degradation, or steep slopes) make stations inaccessible and often cause users to prefer travelling by car over walking to a station. Moreover, the use of public transport as well as its service area, are determined based on the pedestrian distances to stops and stations from points of interest.

In a transit oriented developed neighbourhood, walkability is a key requirement. The building of new bus/tram stops or new railway/underground stations in an urban environment leads to a greater propensity for pedestrian mobility (Cervero et al., 2009). As an example, within 0.75 miles of light rail stations, care should be given to the quality of pedestrian routes to induce a modal shift towards public transport (Huang et al., 2017). Urban development with high housing densities and mixed land use, including a carefully planned pedestrian environment, is a means to increase the number of users and maximise the accessibility of public transport, counteracting the excessive use of cars in modern cities, which is associated with traffic congestion, noise and air pollution, accidents, land consumption, and extremely high social costs (Litman and Laube, 2002).

The aim of the present study is to establish a method that allows an evaluation of the walkability and quality of pedestrian routes in urban areas near railway stations through the creation of a database on the characteristics of the arcs of the pedestrian network. A quality index was determined for each arc, which considers several features that affect the walkability and quantifies how much a particular arc is walkable. Once the most critical places have been identified, the method developed in a Geographic Information System (GIS) environment makes it possible to establish priorities for intervention. The prioritisation is designed to allow economic resources to be invested under conditions in which pedestrian mobility is poorer and
highly requested. Therefore, the proposed method allows the identification of the arcs of a pedestrian network that requires priority actions and makes it possible to understand which interventions will improve the walking environment the most. Therefore, this method aims to be a decision-making tool for policymakers, who can take significant actions to promote pedestrian mobility. The method can be applied to other contexts and other cities, although different walkability indicators may come into play owing to the specific features of such contexts.

After an analysis of the scientific background provided in Section 2, the new method is described in Section 3 and compared with similar methodologies developed by other researchers, highlighting their strengths and weaknesses. In Section 4, because walkability affects the effective service area of public transport, pedestrian access to stations, and the number of users, a case study is presented in which the newly proposed methodology is applied to assess the pedestrian environment around three railway stations in Palermo that are currently undergoing construction.

2. Background

In the literature, several methods developed to assess the walkability of urban areas have been described. Walkability has been defined as a means of encouraging a shift from motorised to non-motorised transport modes (Bodeker et al., 2018); as an incentive for active mobility, helping prevent cardiovascular diseases (Su et al., 2017; Van Cauwenberg et al., 2016); or as a fundamental criterion for urban planning to counteract the phenomenon of urban sprawl by creating areas within different types of activities and services that are connected by short pedestrian distances (Papa and Bertolini, 2015). Other studies, such as those set out below, have looked at walkability in a wider sense and have focused on all factors that affect the walkability of an area and the perception of a pedestrian environment by users (Galanis and Eliou, 2011; Shumi et al., 2015; Christiansen et al., 2014; Leslie et al., 2005; Ruiz-Padillo et al., 2018). Several researchers have developed tools and methodologies that can reproduce the choices that pedestrians face during their travel from an origin to a destination (Kelly et al., 2011; Ariffin and Zahari, 2013; Moniruzzaman and Páez, 2016).

Schlossberg indicated that the access, connectivity, and number of potential walking routes are key elements to understand a pedestrian environment (Schlossberg and Brown, 2004). For this reason, the author identifies certain elements of a street network as walkability indicators. These indicators are the number of accessible paths, the number of impedance paths, the intersection density, the density of dead ends, pedestrian catchment areas (PCAs), and impedance pedestrian catchment areas (IPCAs). A PCA is the ratio between a network-defined pedestrian service area, which is determined by considering the network distance that pedestrians are willing to walk from a given point, e.g. from a station, and the theoretical pedestrian service area, which can be mapped as a circular area with a radius equal to the Euclidean distance from that point. The IPCA represents a re-calculated PCA, with high-speed, high-volume roads removed, which are a real barrier for pedestrians, particularly if there are no pedestrian underpasses or overpasses available.

Other researchers have assessed the walkability of an urban area using Walk Score™ (Carr et al., 2010), which is a website that allows a walkability score to be assigned to a location based on its access to different amenities (e.g. grocery stores, cafes, restaurants, bars, cinemas, schools, parks, bookshops, libraries, gyms, pharmacies, electronics stores, and clothing/music stores). Given an address, the online platform analyses the walking paths to nearby services, assigning scores to them based on their pedestrian distance. The same weight is attributed to each type of amenity, and the scores are added to obtain the Walk Score™ on a scale of 0–100. Therefore, the Walk Score™ measures the walkability by considering only the amenities at a walkable distance from a given point and the obstacles along the paths but does not assess other influencing factors, such as the quality of the pedestrian paths.

Several studies have focused on the close link between walkability and the built environment (Saelens and Handy, 2010). Galanis and Eliou (2011) argued that the basic features of a walkable urban road environment are accessibility, convenience, attractiveness, road safety, and personal safety. The researchers identified three types of walkability indicators through on-site surveys: road segment indicators, which describe the walkability features of the street, such as the sidewalk width or total area with street furniture; corner indicators, i.e. the features of sidewalk corners, such as the presence of ramps; and crosswalk indicators, which describe the features of pedestrian crossings, such as their length or width.

D’Alessandro et al. (2016) measured the walkability of the city of Rieti, Italy, using the Walking Suitability Index of the Territory, identifying twelve indicators, split into four categories: practicability (sidewalk surface, obstacles, and road slope), safety (protection from vehicles, road lighting, and crossing protection), urbanity (sidewalk width, road equipment, and land...
perceived walkability of different routes by female pedestrians in Dhaka, Bangladesh, by conducting walking interviews and creating a geo-referenced scoring system using GPS-enabled devices. The objective levels of walkability were mapped using GIS software, and the scores were classified into three categories (high, medium, and low walkability).

Finally, there have been numerous studies on maintenance optimisation models and the criteria used to prioritise infrastructure investments. In addition, a literature review was conducted by Van Horenbeek et al. (2010). The application of GIS in this field has also been widely investigated, particularly for road pavement management (Kiema and Mwangi, 2009; Ferrera et al., 2001). Lastly, GIS has also been applied for the planning of walkway maintenance projects (Avery et al., 1997).

3. Method

Taking into account the indicators identified in scientific studies, a method was developed for assessing the walkability and quality of pedestrian paths, overcoming the limitations of the PCA and Walk Score™ methodologies (the former only evaluates walkability in terms of the capillarity of a pedestrian network, whereas the latter evaluates it solely in terms of the presence of activities at a walkable distance). Not all walkability indicators identified in the literature have been included in the methodology, and only those elements that can be determined through objective and quantitative analyses have been considered. The methodology, which is essentially the same as that used by D’Orso and Migliore (2018) with certain adjustments, involves the following steps:

1. design of the pedestrian network;
2. inspection;
3. attribution of scores;
4. attribution of weights and calculation of the quality index;
5. realisation of a thematic map of the quality and identification of arcs with poor quality;
6. identification of a travel attractor and generator poles;
7. identification of arcs with greater pedestrian demand;
8. attribution of an index of importance to each arc;
9. calculation of the priority index; and
10. construction of a thematic map of intervention priorities.

In the first step, the pedestrian network is traced through GIS software and an ID number is assigned to each arc of the network. The tracing of a pedestrian network is a time-consuming phase because...
government administrations often do not hold such data in their databases and at most provide technicians with a road network shaped file. Using a road network rather than a pedestrian network is not possible because sidewalks, pedestrian crossings, and pedestrian zones must be accurately identified. It is also necessary to evaluate the pedestrian access to stations; in addition, the sections where the sidewalk is interrupted must be identified, along with wide streets with high traffic volumes and without traffic lights, which are barriers for pedestrians. Once the pedestrian network has been traced, the elements that influence the walkability for each segment of the network are assessed, and a score is assigned. This step is performed by a team of experts or previously trained volunteers. Weights are also attributed to the factors because they have a different impact on a pedestrian's perception of the quality of a pedestrian environment. Weights are derived from an analysis of the scientific literature (D'Alessandro et al., 2016; Ruiz-Padillo et al., 2018).

A higher weight is assigned to safety because it is the most important factor in the route choice decisions taken by pedestrians and strongly influences the walkability (Ruiz-Padillo et al., 2018).

To assess the practicability, the slope of the sidewalk is considered because it can constitute an obstacle, particularly for elderly people and wheelchair users. In particular, the slope must be less than 5% (Italian Ministry of Public Works Decree, 14 June 1989, No. 236) such that it does not become an architectural barrier. The pedestrian level of service (LOS) is also assessed and is strongly affected by the width of the sidewalk and the pedestrian flow (Fruin, 1971). The effective sidewalk width is considered herein; non-permanent obstacles, such as parked cars or motorbikes and stalls, or permanent obstacles, such as light poles, large trees, and kiosks, reduce the space for pedestrians and in some cases represent a real impediment, forcing pedestrians to get off the sidewalk and walk insecurely along the roadway. The presence of facilities for people with disabilities such as ramps, which are also useful for people with strollers, shopping carts, or luggage, is considered in the assessment of the pedestrian level of service. The absence of such facilities makes the sidewalks inaccessible to certain categories of pedestrians. Finally, the state of the sidewalk is assessed, verifying the presence of degradations such as depressions, often caused by the roots of trees, or holes, in which rainwater can pool, and the cleaning of the sidewalks.

Degradation and poor cleaning make pedestrian routes less secure (there have been numerous lawsuits regarding accidents caused by a poor state of sidewalk maintenance, and Italian municipalities have faced high costs), less attractive, and in some cases, impassable, particularly for certain categories of pedestrians (Amoroso et al., 2011). Litter on the sidewalks affects the route choices of pedestrians because the neighbourhood may be perceived as a run-down area (Amoroso et al., 2012).

The indicators related to safety are linked to pedestrian–vehicle conflicts and the sense of safety and/or security that the environment conveys. In fact, the presence of pedestrian-oriented street lighting is evaluated because it allows pedestrians to perceive an urban walking environment as being safe at night. The sense of security from crime (Ariiffin and Zahari, 2013) is linked to street lighting as well as to social factors.
such as familiarity with the neighbourhood, beliefs, and gender (Battista and Manaugh, 2018). Lighting is also essential for pedestrian crossings because pedestrians can safely cross the street only if adequate lighting is available (Moavedi et al., 2013). The current rules on public lighting designs (UNI 11248 in Italy) are used as a benchmark. As a safety indicator, the average traffic volume on the road is also identified: a high traffic volume (a flow of greater than 1,000 vph) causes a higher number of pedestrian–vehicle conflicts at pedestrian crossings, and increases the sense of insecurity in pedestrians walking on the sidewalks, as well as the air and noise pollution levels. The high speeds of the vehicles also affect the pedestrian’s perception of safety: in the methodology, roads with a commercial speed of below 30 km/h are considered safe for pedestrians, whereas those with a speed of over 50 km/h are considered dangerous.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weight</th>
<th>Indicators</th>
<th>Points</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practicability</td>
<td>0.3</td>
<td>Sidewalk slope</td>
<td>0</td>
<td>Steep slope for elderly people and wheelchair users (&gt; 5%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Manageable slope (&lt; 5%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrian LOS</td>
<td>0</td>
<td>High pedestrian flows, small pavement width, obstacles (LOS D, E, F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Low pedestrian flows, adequate sidewalk width or absence of obstacles (LOS A, B, C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface degradation</td>
<td>0</td>
<td>Presence of holes or dips, degraded sidewalk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Absence of holes or dips, pavement in a good state</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Street furniture</td>
<td>0</td>
<td>Absence of baskets, benches, and other elements of street furniture</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Presence of baskets, benches, and other elements of street furniture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shelter for rain and sun</td>
<td>0</td>
<td>No shelter from sun or rain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Presence of shelters from sun or rain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green spaces</td>
<td>0</td>
<td>Absence of flower beds or green areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Presence of flower beds or green areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shops</td>
<td>0</td>
<td>Absence of shops</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Presence of shop windows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building context, land use mix, and urban design</td>
<td>0</td>
<td>Degraded urban landscape (presence of damage to urban furniture, lack of cleanliness, presence of graffiti and abusive posters in buildings, presence of buildings with a degraded facade, presence of industrial buildings)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Nice urban landscape (perfect functionality of urban furniture, adequate cleaning, presence of well-maintained buildings)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Streetlights</td>
<td>0</td>
<td>Poor lighting according to the Uni standard (UNI 11248) or lack of streetlights</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Proper and efficient streetlights according to the Uni standard (UNI 11248)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic volume and vehicle speed</td>
<td>0</td>
<td>High traffic volumes (&gt; 1000 vph) or high speed (&gt; 50 km/h)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>In other cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Free flow (&lt; 300 vph) and low speed (&lt; 30 km/h)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barriers for pedestrian protection from vehicles</td>
<td>0</td>
<td>Absence of protection elements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Presence of barriers for pedestrian protection from vehicles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic control signal at intersections</td>
<td>0</td>
<td>Absence of traffic control signal at the intersection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Traffic control signal at the intersection but presence of conflicts between different traffic components</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Traffic control signal that eliminates conflict points between vehicles and pedestrians</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Driveways</td>
<td>0</td>
<td>Absence of driveways along the way</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Presence of one or more driveways</td>
</tr>
</tbody>
</table>

Therefore, the best situation for pedestrians is one in which a low traffic volume and low speed occur at the same time. Conversely, the presence of barriers for pedestrian protection from vehicles positively affects the level of safety (Landis et al., 2001). The presence of driveways is also evaluated. These represent a critical point in the walking experience: accidents can more likely occur under such presence because pedestrians tend to pay little attention to them. The presence of traffic lights is important for pedestrian crossings because they totally or partially eliminate conflicts between pedestrians and vehicles.

Finally, the indicators related to the pleasantness of the urban environment are illustrated. Street furniture accessories, such as benches and baskets and trees for shelter from the sun and rain, improve the attractiveness of the environment and make walking enjoyable (Galanis and Eliou, 2011). The environment
is made even more attractive by shops, shop windows, flower beds, green areas, and a nice urban landscape. Trees and flower beds are also natural barriers from vehicles, improve the air quality, and are a form of protection against the summer heat. A nice urban landscape, which depends on the cleaning, functionality of the equipment, integrity of the building facades, and the absence of graffiti, is also important because it affects the route choice, particularly during trips for shopping, leisure, and free time.

Once the inspections have been carried out and the factors evaluated, the quality index, in which a higher value indicates a higher quality of the arc, is calculated for each arc of the pedestrian network, and the quality map is then built in the GIS environment. With this map, it is possible to easily identify which pedestrian arcs have the lowest quality. Maps can also be created for individual macro-indicators to better understand which arcs are bad for a specific factor, or to understand which interventions are needed to improve the arcs that have the lowest quality.

To be used as a decision-support tool, the methodology must include an assessment of intervention priorities. The method must allow identifying those pedestrian arcs where an intervention is needed, not only because of their poor quality but also because of their importance. The importance of an arc is linked to how much that arc is used by the pedestrians. A potentially heavily trafficked road requires higher quality standards because poor walkability could affect more users. The real pedestrian flow in each arc of the network is extremely difficult to obtain.

To simplify the problem, trip generators and attractors can be identified. If, for example, the stations and the surrounding areas are considered, the attractiveness of the amenities (schools, hospitals, shopping malls, or offices) can be assessed by considering the number of employees or daily use, and the number of users of each station can be determined through ad hoc surveys. Such data provide an idea of the pedestrian flows between an origin and destination (stations and amenities). The potentially most important paths are determined based on an objective criterion, namely the user tries to minimise the walking distance and chooses pedestrian routes that correspond as closely as possible with the desired line; therefore, the most used arcs of a pedestrian network are identified as those that belong to the minimum cost paths (shortest paths). After the pedestrian flows are assessed, they are assigned to each arc of the network through an all-or-nothing assignment: the pedestrian flows are assigned only to those arcs that belong to the minimum cost routes between the origin–destination (O–D) pairs, and each arc has a flow that is the sum of the flows of the shortest paths to which the arc belongs. With the help of GIS software, the minimum-cost routes, where the cost is the distance, can be easily determined using Dijkstra's algorithm (Castelluccio et al., 2016), as demonstrated by Keshkamat et al. (2009) in the development of a versatile effect-based decision support system for transport route planning. Pedestrian flows can then be assigned, and arcs with the greatest flow can be identified. A score of 1 to 5 is then assigned to each arc with the aid of an Excel database when considering its importance in terms of the pedestrian flow: an arc with a score of 5 is considered extremely important, whereas an arc with an importance index of 1 is rarely travelled by pedestrians. It is also possible to create a map of the importance of the arcs in terms of the pedestrian flow using GIS software.

The quality index and the importance index must therefore be correlated when calculating the priority index through the following formula:

\[ \text{Priority} = \text{Importance} + 6 - \text{Quality} \quad (1) \]

Relation (1) ensures that the priority index of an arc is high if the need to intervene is also high. A map of the priorities for intervention can be created in a GIS environment. Through this map, it is possible to identify which arcs have an insufficient quality but a high number of users, and upon which arc policymakers should take priority action.

4. Case study

As a case study, three railway stations in Palermo, Italy, were considered: Francia, Belgio, and San Lorenzo. The stations are part of the railway line that connects the city to the airport of Punta Raisi and runs through the city for 13 km. The three stations are currently under construction (Belgio) or modernisation (Francia and San Lorenzo), according to a project of track doubling, which started in 2008. This research, therefore, refers to a future scenario in which the stations will be reopened to the public (D’Orso and Migliore, 2017).

The Francia and Belgio stations are located in residential and commercial areas, where there are numerous housing complexes, schools, and different shops and amenities, such as grocery stores, clothes shops, cinemas, restaurants, bars, bakeries, and gyms. These stations are near Viale Strasburgo, which is one of the most famous shopping streets of Palermo. Instead, the San Lorenzo station is located in an industrial area, where shopping malls and office buildings are present, along with a secondary school.
Three methods have been applied to determine the walkability of the areas around the stations: Walk Score™, the PCA method, and the newly developed method are described herein.

The online platform Walk Score™ provides extremely high scores for the three stations: 81 for San Lorenzo, 85 for France, and 94 for Belgium. These scores are derived from the fact that, in these areas, there are numerous shops and amenities within a short walking distance. However, this highlights a limitation of this method, namely it does not consider that the poor quality of the pedestrian paths can actually be an obstacle to pedestrian mobility, and can therefore decrease the walkability of the three areas.

The PCA is assessed by applying the second method. Thus, the pedestrian network is first drawn in QGIS, an open-source GIS software. In particular, this can be achieved using the QAD extension of QGIS, which allows using all typical features of a computer-aided drawing that are available in the program. A Google Earth map is imported through the QuickMapServices plugin and used as a background map. An arc is traced at each sidewalk or pedestrian crossing, and a node is placed at each intersection. The stations are accurately located in QGIS. The ideal service areas of the three stations are identified, tracing circular areas with a radius of 600 m, which is set as the acceptable walking distance. In this way, the service areas are calculated by considering the distances in a straight line. To calculate the PCA, the actual service area is also determined based on the network distances (Fig. 1).

The PCA score for each station, which is the ratio of the ideal and effective service areas, was determined as 0.29 for Belgio station, 0.18 for Francia, and 0.39 for San Lorenzo. Therefore, the actual service areas are reduced by more than 50% compared to the ideal areas, which indicates a lack of pedestrian accessibility to the stations. Viale della Regione Siciliana, a road with high-volume and high-speed traffic, is located near the stations and serves as an obstacle to pedestrian mobility.

Finally, the new method is applied. The research team assigns scores to each indicator based on surveys or with the help of Google Street View. The score for each of the three factors (practicability, pleasantness, and safety) is evaluated, and by applying the weights, the quality index of each arc is obtained. The scores of each indicator and the quality index are assigned in an Excel table, in which the identification numbers of each arc are reported. The data are then imported into the PostgreSQL database. Subsequently, through a union of tables in PostgreSQL, these data are joined to the geographical data of each arc and a thematic map concerning the quality of the arcs of the pedestrian network is built in QGIS (Fig. 2), in which the colour is associated with a range of quality index values:

- dark green = excellent (values between 4 and 5);
- light green = very good (values between 3.2 and 4);
- blue = good (values between 2.4 and 3.2);
- orange = barely acceptable (values between 1.6 and 2.4);
- red = poor (values between 0.8 and 1.6);
- amaranth = very poor (values between 0 and 0.8).

Once the quality of the arcs of the pedestrian network have been estimated, to establish the priorities
for intervention, it is necessary to evaluate the importance of each arc. Because there are no data on real pedestrian flows, the importance of each arc can be evaluated by considering the attractiveness of the trip attractors and generators, and the number of minimum cost paths to which the arc belongs.

Therefore, several O–D pairs are considered, and with the help of Dijkstra's algorithm, a routing algorithm implemented in PostgreSQL, the minimum cost paths are identified; in this case, the cost is the distance. Here, a string in SQL language can be used. The result is a table in which the minimum cost paths between the O–D pairs are identified and the cost in terms of walking distance needed to reach the different destinations is calculated.

Therefore, a score (from 1 to 5) is attributed to each arc, based on the importance of the same.

The priority index is calculated for each arc using formula (1). The map of the priorities is built in QGIS, as illustrated in Fig. 3.

5. Discussion

In Palermo, urban planners have not taken care of the needs of pedestrians, and there has been a poor control of the pedestrian environment as well as a lack of a method allowing the determination of proper priorities for intervention. Thus, the areas where the developed methodology has been applied are not properly walkable. The problems that make the pedestrian environment in these areas unattractive, unsafe, and impassable are as follows: a poor cleaning of the sidewalks, the presence of architectural barriers, the presence of obstacles such as cars parked on the sidewalk (unfortunately, a very common practice in Palermo), frequent interruptions of the pedestrian paths owing to the absence of sidewalks, poor drainage of rainwater, an abundance of depressions and holes owing to tree roots and poor sidewalk maintenance, poor lighting, and a lack of street furniture. To invest in public transport infrastructure, policymakers should understand that the poor quality of the pedestrian environment could lead users to prefer taking a private car rather than public transport, creating even more insecurity, a risk of accidents, noise, and atmospheric pollution. However, measures regarding pedestrian infrastructure, which can be identified by the proposed methodology, are relatively simple and inexpensive, but their impact on the quality of life of the citizens can be significant, particularly in Palermo, which is characterised by a fairly high demand for pedestrian mobility and a poor quality of its pedestrian environment.

The pedestrian arcs requiring priority interventions are those close to the railway stations because they link the stations with amenities and the pedestrian flow there is higher. Viale Francia, Via Ugo La Malfa, Via G. Tranchina, and Via Monti Iblei are streets where immediate action is needed. Along Viale Francia, there are no sidewalks, which makes the path unsafe, despite being the main access road to Francia station. The same situation exists in Via G. Tranchina, which connects the San Lorenzo station to all amenities in Via Ugo La Malfa. Students of a nearby school travel this road daily on foot; therefore, ensuring the safety of the station–school route should be a priority. Via Monti Iblei is characterised by overly narrow sidewalks, which creates an obstacle to the pedestrian flow at certain points. Finally, the sidewalks in Via Ugo La Malfa are extremely deteriorated owing to the parked vehicles and the tree roots (Fig. 4). The street is also marred by poor street lighting from an obstruction by trees, leading to a lack of safety, particularly at night and during the winter.

Only a few routes have sufficient quality and do not require measures for improvement, including the last section of Via Empedocle Restivo, where there are ramps for wheelchair users, elements of street furniture, wide sidewalks in a good state of maintenance, and a pleasant urban landscape (Fig. 5).
Viale Strasburgo, by contrast, can be split into three sections in which the quality progressively regresses. The first section, farther south, is characterised by large sidewalks, but the vehicle flow is intense and affects the level of safety. The second section, which starts from the intersection with Via Salvatore Aldisio, has a lower quality, the sidewalks are narrow and have various types of degradation. In addition, the quality index in the last section is lower because the lighting is poor, and the urban context is unattractive.

6. Conclusion

As stated in the introduction, the aim of this research is to develop a methodology for evaluating the walkability and quality of pedestrian paths when considering the attributes of the urban environment identified through previous research. Moreover, the proposed method allows identifying the arcs of a pedestrian network that require priority interventions. The methodology is therefore not only for assessing the state of a pedestrian network but also one of prioritisation, namely a decision support system allowing policymakers to use increasingly limited funds to improve the pedestrian mobility where required. Moreover, public transport feasibility studies often do not consider the fact that accessibility to a station depends not only on the network distance and the presence of impediments such as roads with high-volume and high-speed traffic, but also on the perceived quality of the pedestrian paths. Investments in public transport will be in vain if a lack of attention is paid to pedestrian mobility; therefore, this methodology is useful for improving pedestrian mobility before investments in public transport become simply a waste of resources. The method was developed using a GIS environment to produce thematic maps that are easily intelligible and have an immediate impact. The advantage of this method is helping policymakers identify areas where walkability needs to be improved and to understand where the most critical situations exist, which limit pedestrian accessibility. Furthermore, it is possible to foresee how the quality index changes with the realisation of possible interventions in a pedestrian network. In fact, it is possible to update the database each time an intervention improving or worsening the quality is carried out. One disadvantage, however, is the time-consuming nature of the data acquisition and scoring procedures applied. Another problem is that it may not be immediately evident what the quality index and priority index are indicating without conducting a further investigation: it is possible to understand in which areas the arc is lacking by simply checking the database of the scores assigned to the various pedestrian indicators. The need to design an entire pedestrian network makes the method effective for small areas, such as those surrounding railway stations. This indicates that the proposed methodology is suitable for evaluating the effectiveness of pedestrian accessibility to a station and the accessibility to the various amenities in the area, both of which are linked to the quality of the surrounding pedestrian arcs. It is therefore possible to understand whether the quality of the pedestrian paths around a station has such a detrimental impact that many users cannot use the urban railway system, preferring a private car instead to avoid unpleasant and unsafe pedestrian routes.

Future research should focus on improving the scoring system to allow the attribution of individual factors determining the overall quality of each arc. Interviews with a wider sample of citizens should also be carried out to improve the reliability of the method and better understand how each factor affects pedestrian mobility in the city of Palermo.

Competing interest statement

The authors have no competing interests.
References


Moayedi, F., Zakaria, R., Bigah, Y., Mushairry, M., Che Puan, O., Safitri Zin, I., Klufailah, M. A., 2013. Conceptualising the Indicators of Walkability for Sustainable Transportation. Journal Teknologi (Sciences & Engineering), 65:3.


