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A Walkability Index including Pedestrians' Perception of Built Environment: The Case Study of Milano Rogoredo Station

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Abstract: Active modes can play a key role in the transition toward sustainable urban mobility, and transport systems should be designed to support and incentivize them. For instance, walking accessibility to main urban centralities is a factor to pay attention to, as well as the way in which pedestrians perceive the characteristics of the infrastructure and the surrounding environment should also be considered. This study proposes a method for computing a walkability index of the paths for accessing transport nodes (e.g., railway station). The index is based on individuals' perception of walkable infrastructure features (e.g., kerbside width, presence of urban furniture, greenery, etc.). It allows having a more realistic view of the catchment area of the node and to identify policies for improving pedestrian accessibility. The method has been validated using an ad-hoc survey in the area of the Milano Rogoredo railway station (Italy). The map of the estimated walkability indexes is consistent with the real conditions of the Milano Rogoredo neighbourhood and allows for identifying those areas where walkability can be improved.

Keywords: built environment; pedestrian perception; accessibility; catchment area; railway station

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1. Introduction

In recent years, investments have been directed at improving the network, the quality, and the technologies of public transport services as well as supporting the transition toward a more sustainable mobility with minimized greenhouse gas emissions [1]. Particularly, in urban areas, the focus is posed towards how to promote active mobility (cycling and walking) and how cities could be re-designed to improve pedestrians' and cyclists' accessibility. In this perspective, accessibility can be considered as a framework to design integrated transport and land use policies [2]. As argued by [3,4], the characteristics of urban environment (e.g., proximity to public transport, density, and socio-psychological factors) influence the way in which people move. Moreover, high-density urban areas cannot be only served by low-capacity transport modes (i.e., private cars), leading therefore to the conclusion that in these contexts it is necessary to promote the shift towards public transport.

Transit-Oriented Development (TOD) [5,6] and the "15-minutes city" concept [7,8] are relevant examples of urban design principles promoting walking and cycling modes [9,10]. European policies are focusing more and more on the development of walkable urban areas [11], since walking has many benefits on citizens' quality of life [12,13], on the shift toward a more sustainable and healthier lifestyle [14–16], and on improving social inclusion [17,18] and safety [19,20].

However, more attention ought to be put into investigating how the quality of walkable infrastructures influences the willingness to walk, and therefore into analysing the perception that pedestrians have on walkable paths, neighbourhoods, and urban spaces [21]. This would allow to better understand the real catchment area of urban nodes, and consequently, to support the development of policies and the allocation of resources in effective interventions. New methodologies to assess the quality of walkable paths in the catchment area of transport nodes have to be developed by taking into account not only the technical characteristics of the walkable infrastructure (e.g., sidewalk width, number and type of crossings, pavement quality, traffic segregation, etc.), but also of pedestrians' perception of the surrounding space.

This paper proposes a data-driven methodology for the computation of a walkability index and presents its application to the case study of the Milano Rogoredo railway station. The walkability index relies on individuals' perception, estimated via in situ surveys, on walkable infrastructure features extracted from GIS databases (e.g., kerbside width, presence of urban furniture, greenery, etc.). The Milano Rogoredo railway station was selected as a case study. Transport infrastructures usually generate spatial impacts [22], and railway stations can indirectly create spatial discontinuity in the urban texture: this is the reason why they are receiving increasing attention and are objective of investments aimed at revamping station buildings, regenerating at the same time surrounding spaces that are often degraded [23–26]. These investments should be guided by new assessment frameworks (see for instance [27]), that also consider the impacts of redesigned urban spaces on the walkability of areas themselves [28]. This study contributes to the existing literature by presenting a peculiar case study, discussing the results obtained from the application of the proposed methodology. The Milano Rogoredo railway station, in fact, represents a critical node for the transport network of the municipality of Milan and, at the same time, a boundary between two neighbourhoods of the city facing deep differences in the quality of urban environment. The results from the application allow for identifying potential areas of intervention within the Milano Rogoredo urban environment, guiding policymakers in developing effective policies and investments for a more walkable city.

The remainder of the paper is organised as follows: in Section 2, a review of the literature related to the indexes used for the assessment of walking accessibility around urban centralities is presented; in Section 3, the proposed methodology to estimate walkability indexes is described; in Section 4, the proposed method is applied to the case study of the Milano Rogoredo railway station; and in Section 5, the results are analysed and discussed.

2. Literature Review

The role of railway stations as a node of the transport network and as a centre for daily activities has been widely investigated in the literature. Particularly, the two dimensions of railway stations—a transport node and a place for activities—have been combined in a model (the "node-place model") and used as classifying criteria [29]. The node-place model had been further improved to consider pedestrian accessibility as an additional indicator for the identification of well-balanced node-place stations [30]. Studies highlight the necessity of improving the overall on-foot accessibility of railway stations [31,32] by also considering that people seem to be prone to walk more to get access to long haul services (especially railway services), instead of short haul ones such as bus services [33]. Additionally, a higher accessibility increases the probability of using active modes (i.e., walking and cycling) [34], sustaining the shift towards a more sustainable mobility. Time and distance are however variables that cannot sufficiently describe the walkable catchment area of railway stations [34], since they lack information about the quality of the infrastructure and about the users' perceptions; additionally, a gap between the accessibility maximization and travel time minimization exists and has been investigated [35]. Graphical approaches to map walkable areas and advanced measures for active accessibility have been developed [36,37]. For instance, walk index-type measures aim at overcoming the limitations of time-based measures by accounting for the quality of urban streets [38]. The quality of urban streets can be derived by estimating some characteristics of the infrastructure, aggregated in attributes and indicators, and also with the support of computer-based techniques [16,39]. These indicators (Table 1), which are mostly objective and related to the type, connectivity, and quality of both the infrastructure and neighbourhood, have been demonstrated to impact the perceived walkability of areas, and consequently, the citizens' likelihood to walk [39–45].

Table 1. Indicators used in the literature for the assessment of walkable infrastructure.

Indicator	Amoroso et al. [40]	Moniruzzaman et al. [41]	Yencha et al. [39]	Schlossberg et al. [42]	Galanis et al. [43]	Ruiz-Padillo et al. [44]	D'Alessandro et al. [45]
Crosswalks	•	•			•		
Signal	•	•			•		
Crossing speed	•						
Crosswalk scramble	•						
No turn on red	•						
Traffic calming features	•	•				•	•
Signs for pedestrians	•						
Sidewalk width	•				•	•	•
Impediments/obstructions	•	•		•	•		•
Kerb	•	•	•		•		
Trees and green areas	•	•	•		•	•	•
Seatings	•	•			•		
Graffiti	•						
Litter	•				•		
Lighting	•	•	•		•		•
Construction/abandoned sites	•	•				•	
Street lanes	•	•					
Vehicle speed	•					•	
Traffic volume	•					•	•
Points of interest	•	•	•		•	•	•
Art/historic sites	•	•	•				
Intersection type		•					
Sidewalk slope		•				•	•
Public transport stop		•			•		
Cleanliness		•					
Vertical mix in building		•				•	
Building height		•					
Activities for seniors		•					
Sidewalk completeness		•					
Building characteristics			•			•	•
Intersection density				•			
Dead-end density				•			
Sidewalk area					•		•
Permanent street furniture					•		•
Pavement quality						•	
Visual attractiveness						•	
Crossing protection							•

The abovementioned measures can be combined to obtain a preliminary walkable index. Walk Score® is a computer-based index that estimates the walkability around centralities of the city based on the shortest distance to a group of preselected destinations (e.g., commerce/services, public transport, restaurants, shopping, parks/green spaces, schools, etc.), the density of traffic intersections around the origin, and other geometrical features [46]. This tool has been further developed by considering other features of the pedestrian path [47] and it has been also critically reviewed: future research should take into account also for other aspects that influence walkability, such as crime, aesthetics, topography, weather, and trip purpose [48,49]. Other walkable attributes (Table 2) were therefore identified to classify streets accounting also for additional characteristics that are more related to the user's needs and perceptions, such as security, traffic safety, and practicability [50–53].

These characteristics are strongly related to the personal perception of the users and therefore could require the development of a specific survey campaign. This survey would be aimed at assessing the relation between these characteristics and the willingness to walk for people, and consequently, to weigh the objective features of the infrastructure.

Table 2. Indicators used in the literature for the assessment of walkable urban environment.

Indicator	Leslie et al. [50]	Saelens et al. [51]	Frank et al. [52]	Bahrainy et al. [53]
Residential density	•	•	•	
Land-use mix	•		•	
Street connectivity	•	•	•	
Walking path	•	•		•
Aesthetics	•	•		
Traffic safety	•	•		•
Crime	•	•		•
Population density		•		
Distance to non-residential locations		•		•
Open spaces		•		
Physical activity facility		•		
Interaction/presence of others		•		•
Visual information				•
Climatic factors				•
Street furniture				•

3. Methodological Approach

To overcome the limitations of objective measures and to integrate the personal perceptions of users, here is presented a methodology for the computation of a walkability index that can be applied to estimate the walkability of streets in the surroundings of urban centralities, such as railway stations.

3.1. Variables Specification

A selection of previously identified features related to the walkability of urban infrastructure and areas, as for the literature, has been considered. Features have been selected based on the availability of open-access data and with the scope of proposing a methodology that is easy to be transferred to other contexts, overcoming the diffused limitations in the data availability. Features that have been considered for the analysis are reported in Table 3, clustered into five main groups: infrastructure, attractions, vehicular conflicts, urban environment, and urban furniture.

Table 3. Variables considered in this study.

Group	Variable
Infrastructure	• Sidewalk width
Attractions	• Points of interest
Vehicular conflicts	• Intersections • Crosswalks • Car lanes
Urban environment	• Population • Green areas and greenery • Buildings elevation • Lighting • Benches • Fountains

3.2. Questionnaire Design and Data Collection

Some features of the walkable paths refer both to the physical characteristics of the infrastructure and to the land use. To complement this information with personal perceptions about the walkable environment, a Revealed Preference (RP) questionnaire has been developed. The survey consisted of four sections to collect information about:

i. socio-economic and demographic data of the interviewee—age, gender, working position, income, and educational level;

ii. attendance habits at the station—type of railway service used (regional or high-speed), time spans of the day in which station areas are mostly frequented (early morning, morning, afternoon, evening, and night), frequency of attendance (often, sometimes, rarely, only during working days, etc.), mostly frequented places for waiting the train arrival or reasons for which the person uses the station places (e.g., cross them to reach other places, go to a shop/bar, etc.), and the average waiting time at the station or average amount of time spent in station places;
iii. the journey—origin and destination of the undertaken trip, series of modes of transport used to reach the station, travel time to reach the station and the destination, and the presence of luggage;
iv. habits and perceptions related to walking—assessment on how some characteristics of the urban environment impact the interviewee's walking path choice. Namely, these characteristics were the presence of clear signs and indications at intersections and crosswalks, presence of lighting, largeness of spaces (that has been reconducted to the building elevation data), presence of greenery and green areas as well as commercial activities and other services (i.e., points of interests), crowding of areas and sidewalks (that have been reconducted to the number of people living nearby the walkable path), sidewalk width, presence of urban furniture (namely, benches and fountains), presence of traffic and vehicles in the surroundings and along the sidewalk (estimated considering the number of car lanes in the near proximity of the walkable path), presence of safety cameras, and the hour of the day. The presence of safety cameras and the hour of the day information were collected for other research that fall outside the scope of this paper and therefore are not considered in the proposed methodology.

Information of questionnaire sections (i.), (ii.), and (iii.) were collected through multiple choice questions, except for the demand related to the origin–destination trip. To assess interviewees' opinions about the perception of walkable paths in questionnaire part (iv.), Likert scales and open questions were used. Particularly, interviewees were asked to weigh the features of the walkable path by assigning a score between "very negatively" and "very positively". Collected values were then processed as a score ranging between −2 and +2, giving the possibility of understanding which are the most impacting elements. Open questions instead were used to give interviewees freedom of judgment and opinion, acquiring therefore a deeper knowledge about how the walkable spaces around the Milano Rogoredo railway station are really perceived.

3.3. Walkability Index Specification

The walkability index WI_j associated to the walkable link j of the analysed network is calculated as a weighted average of link attributes $X_{i,j}$ according to Equation (1).

$$WI_j = \sum_i \beta_i X_{i,j} \tag{1}$$

Weights β_i account for subjective perceptions that users have of the walkable paths and are estimated using the analysis of the collected survey data. Here below are presented the link attributes X_i that have been considered in the computation of the walkability index. They refer to:

- Infrastructure—Index considering the sidewalk width (SW).
- Attractions—It accounts for the number of activities and points of interest (POI).
- Vehicular conflicts—The number of signalized intersections and crosswalks (INT) as well as the number of car lanes (CL) in the streets are considered.
- Urban environment—Urban environment accounts for the population living in the nearby areas (POP), the square meters of green areas and greenery (GA), the buildings elevation (BE), and the presence of lighting (L), benches, and fountains (BF).

All the attributes X_i have been min–max normalized, according to Equation (2):

$$X_i{}^* = \frac{X_i - \min\left(\vec{X}\right)}{\max\left(\vec{X}\right) - \min\left(\vec{X}\right)} \quad (2)$$

where $\vec{X}$ is the vector of all the values assumed by the attribute X_i in the analysed network.

4. Application and Results

4.1. Milano Rogoredo Case Study

Milan is a city in Northern Italy that counts 1.36 million inhabitants in its municipality and more than 3 million inhabitants in its metropolitan area, being one of the most populated in Europe. The Milano Rogoredo railway station is one of the main stations of the city since represents its access door for those coming from the South. It is a complete intermodal hub: it is connected to the underground network and to both urban and extra-urban bus services; moreover, the position of the station is strategic for vehicular traffic given the presence of a motorway junction in the near proximity. The railway station is served by several suburban lines that connect to the metropolitan area, by some regional lines that connect the city to other Italian regions, and by some inter-city and long-haul high-speed services that provide connections with Southern Italy. The station is in a peripheral area, and therefore its neighbourhood is a suburban district characterized by a combination of residential buildings, industrial areas, and green areas. On the southern side of the station—the red point in Figure 1—there is a park, the above-mentioned motorway junction, and an industrial zone; on the eastern and western sides, there are residential districts, with some commercial activities and offices. Despite the presence of some overpasses, rails constitute a barrier for pedestrians, representing a boundary between two neighbourhoods facing significant differences in the quality of the urban environment. On the eastern side, in fact, the residential district has been recently built and renewed; on the western side, the quality of infrastructures and buildings is poorer. This imbalance in the urban structure, the presence of an important node of the transport network, and the consequently high presence of users make this context an optimal field of application of the proposed methodology.

Figure 1. Overview of the Milano Rogoredo railway station area (source for background map: Google Earth).

All link attributes X_i were collected from opensource GIS databases and from other sources (i.e., queries of OpenStreetMap, Regione Lombardia databases, AMAT). Data were then visualized and processed in QGIS (Figure 2).

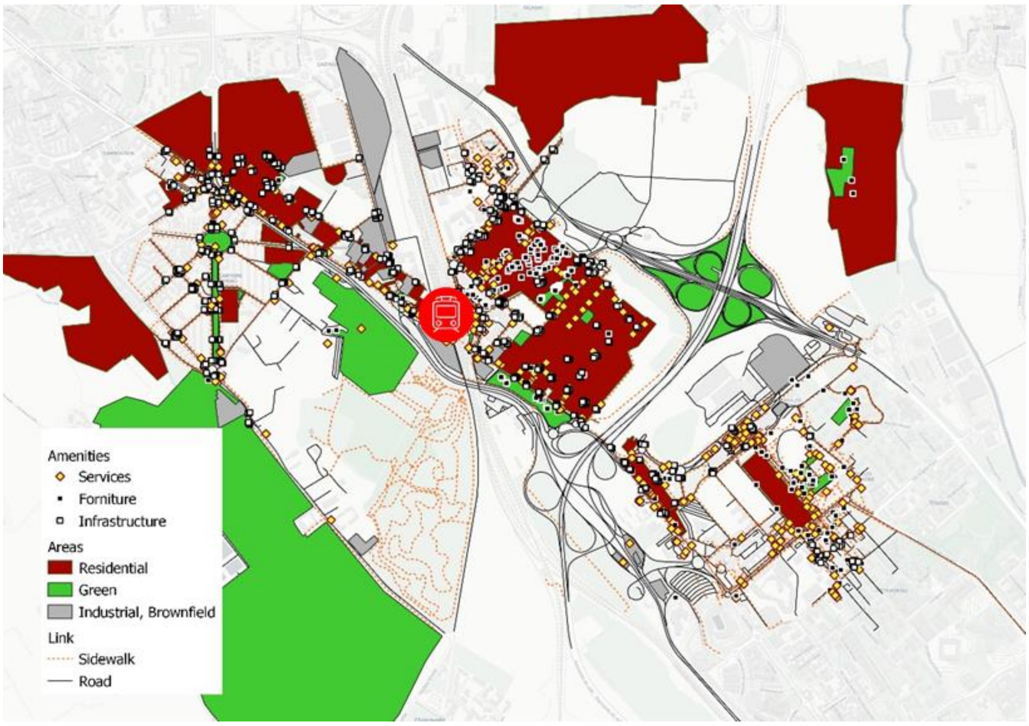

Figure 2. Extraction of collected data: amenities and land use (source for background map: OpenStreetMap).

4.2. Sample Description

The data collection process was carried out in November 2022 and lasted approximately four weeks. The data were acquired via an in situ survey campaign and with face-to-face interviews that were conducted during weekdays between 7 a.m. and 7 p.m. The spaces used for the interviews were the railway platforms, the station hall, and the squares located at the two exits of the station. Respondents were randomly chosen among railway station attendants and 300 answers were collected. Responses for gender were fairly balanced with male respondents around 53% and female respondents around 47%. The sample is evenly distributed among the age segments, with the exceptions of over-50 and under-16 age groups, where there was a smaller number of responses—they overall accounted for less than 20% of answers. A total of 65% of interviewees were employed and 30% were students. The Milano Rogoredo railway station has been found to be mostly attended by commuters (60%), but also with a considerable share of users (40%) that were occasional. Most of the travellers waited for regional and suburban trains, but there was also a large portion of users attending the station to catch long-haul train services. A total of 67% of the interviewed users carried light luggage (backpack/bags), while about 20% carried a heavy luggage such as a trolley or suitcase. The remainders carried nothing with them. Respondents declared they mostly wait at the station for a short period of time (about 45% between 5 and 15 min, 37% between 16 and 30 min), while only 12% waits for more than half an hour, as it can be expected by commuting workers and students.

4.3. Walkability Index Estimation

From the results of the survey campaign, the walkability weights β_i for the different network characteristics were calculated. Table 4 reports these values: these have been obtained by averaging the sample scores related to the different variables.

Table 4. Estimated β parameters included in the walkability index formulation.

	Walkability Parameters β_i	Value
β_{SW}	Sidewalk width	+0.60
β_{POI}	Number of activities and points of interest	+0.25
β_{INT}	Number of signalized intersections	−0.08
β_{CL}	Number of car lanes in the near proximity	−0.17
β_{POP}	Population living in the near proximity	+0.12
β_{GA}	Surface of greenery/green areas in the near proximity	+0.07
β_{BE}	Building elevation	−0.05
β_{L}	Lighting	+0.17
β_{BF}	Number of benches and fountains	+0.09

Sidewalk width, activities, and points of interest, as well as street furniture (i.e., benches and fountains), lighting, population living in the near proximity, and the presence of greenery positively impact the walkability of the path. On the other hand, intersections (i.e., interactions with the traffic and discontinuities in the infrastructure), car lanes, and higher buildings are features that negatively impact the perceived walkability, reducing the value of the walkability index.

For each link, the data were combined with the weights β_i reported in Table 4 to compute the walkability index. Figure 3 shows a graduated map of the obtained walkability indexes WS. This map allows visualizing how the distribution of the walkability index is variegated among pedestrian links of the study area and how strong differences exist between the eastern and western sides of the railway station building due to the presence of rails.

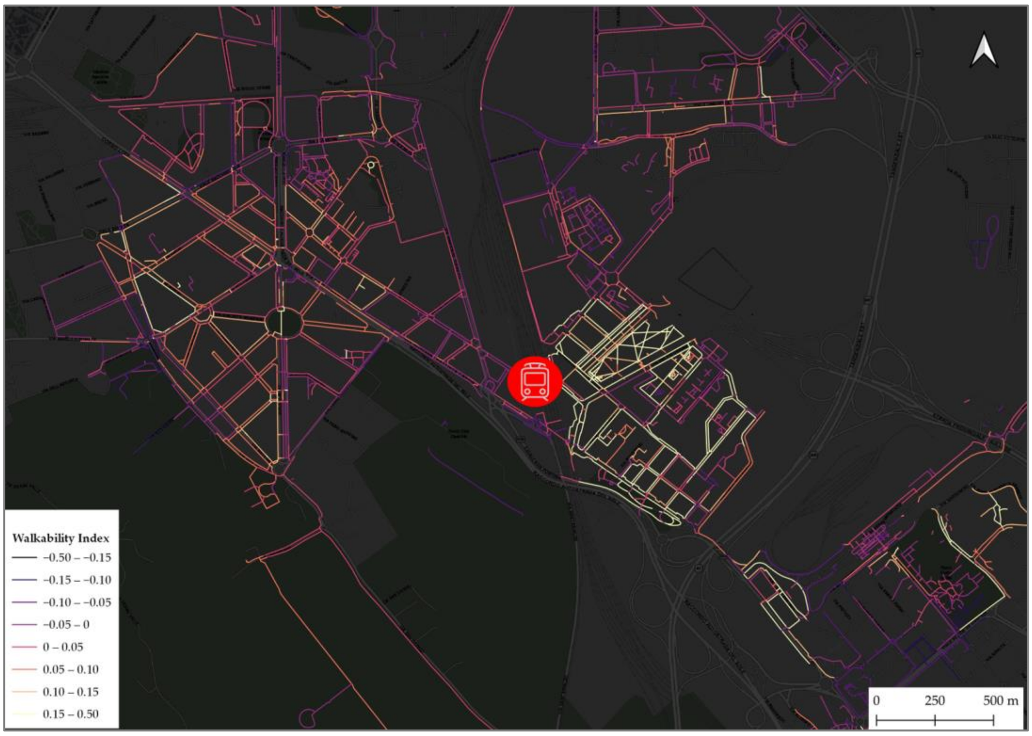

Figure 3. Walkability index map (source for background map: OpenStreetMap).

The value of the walkability index ranges between −0.175 and +0.578 and is distributed according to the bar chart in Figure 4. Nearly 60% of walkable paths has been associated with an index between −0.05 and +0.05; more than half of the links resulted has been found to have a slightly positive walkable index ($0 < WI < +0.15$).

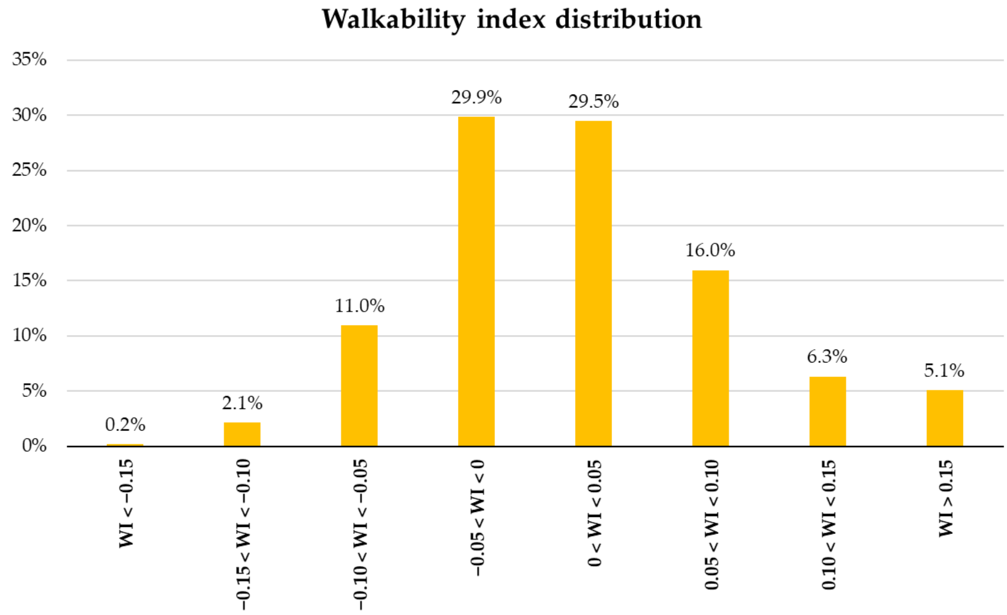

Figure 4. Walkability index distribution among the links of the network.

5. Discussion

The Milano Rogoredo railway station is an important interchange node of the city. Due to its strategic role in the transport network, the station and its neighbourhood have been the object of several projects and studies aimed at improving their aesthetics and accessibility. The neighbourhood, in fact, is in the peripheral area of the city and therefore suffers for degraded conditions and poor quality of the infrastructure in some specific areas. The presence of rails creates a boundary for pedestrians that does not allow an easy transfer from one side of the neighbourhood to the other: apart from the station, there are few more points where people can cross rails and this condition creates issues for the population as well as splits the urban environment into two different and autonomous areas. Recent interventions have been conducted to requalify a portion of the neighbourhood, in particular the eastern side of the station, and new financial resources have been allocated for further improving the quality of the area [54]. On the eastern side of the neighbourhood new sidewalks, squares, buildings, and offices were realised, improving the perceived quality of the urban environment (Figure 5); the western side instead still presents some criticalities: poor quality sidewalks, constructions areas, poor lighting, and more vehicular traffic, as well as green areas that are not well finished and are associated with crime and a state of abandon (Figure 6).

Figure 5. Eastern side of Milano Rogoredo railway station (source: Google Earth).

Figure 6. Western side of Milano Rogoredo railway station (source: Google Earth).

This gap between the two portions of the neighbourhood leads to an unbalanced perception that pedestrians have about the urban environment, as emerged by discussing with interviewees during the face-to-face in situ surveys. In particular, the western side of the station has been found to have a poor perception of quality, and therefore, pedestrians were less willing to walk along those sidewalks instead of the ones of the eastern side. This gap in the urban environment quality has been caught via the computation of the walking index and is visible in Figure 3: here, an area characterized by a positive walkability index on the eastern side of the station is present, while there is a wide area of negative index (associated to low walkability) on the western side. Some slightly positive walkability indexes can be observed in the far-western part of the map of Figure 3 since there are an important square and a boulevard of the city that is rich in residential buildings and services. The results therefore confirm that the proposed methodology well captures the differences in the urban environment and can transfer its characteristics and features in a quantitative measure—the walkability index—that is also coherent with the perceptions of pedestrians. This method can be used as a supportive tool for the definition and implementation of policies aimed at increasing the walkability of urban areas, since it accounts for the real perceptions of users. Walkability indicators, in fact, can be used to classify urban centralities based on their walkable accessibility and therefore to assess their potentialities for investments. The case study of the Milano Rogoredo railway station represents an application of the walkability index as a tool for the comparison and evaluation of TOD projects [42,55]. Based on the obtained results, it is possible to suggest some interventions that can be implemented to improve the overall walkability of the railway station western side, which is the most critical area, as shown below:

- Developing a wider and more connected walkable network in parallel with a reduction in traffic and a better segregation of pedestrian and car flows;
- Increasing the sidewalk width to make walking more comfortable;
- Providing a more pleasant walking environment by installing a more diffused lighting and more well-finished greenery.

The formulation suggested for the walkability index—similar to the one adopted by the EPA (United States Environmental Protection Agency) in its guideline [56]—allows for the transferability of the methodological approach to other contexts. However, it could be further expanded to consider perceptions of different target users differing from socio-demographic or socio-economics attributes, as pointed out in [48]. The proposed data-driven methodology could be easily embedded in the evaluative framework of urban policies, as proposed by Boulange et al. in their research [57]. This would also support designers and policymakers to develop policies, simulate impacts, and identify the most effective strategies to be implemented for more walkable neighbourhoods.

6. Conclusions

This paper presents an easy-to-be-transferred data-driven methodology for the calculation of a quantitative walkability index that results from the combination of objective features of the infrastructure and subjective perceptions of users. The use of data related to objective features of the infrastructure (i.e., number of intersections, signals, lanes, benches, urban furniture, etc.) and of the urban environment (i.e., activities, points of interest, land-use mix, etc.) has been widely discussed in the literature and is associated with the computation of walkability indexes. This information, however, lacks in the subjective perceptions that pedestrians may have of the surrounding environment. The proposed methodology has been developed with the scope of using subjective users' perceptions to weigh objective characteristics of the walkable infrastructure, estimating a walkability index: the higher the index, the more walkable the facility is. This methodology allows for mapping the indexes for the walkable links around the urban centralities, identifying which areas of the neighbourhood lack walkability. The outcomes of the proposed methodology allow to put into the spotlight those zones of the neighbourhood that may need to be requalified, and consequently, to support policymakers in defining and designing ad hoc interventions: the tool also allows for quickly assessing the effects of the designed interventions on the perceived walkability, identifying the most effective and optimal measures. Moreover, its mathematical formulation allows to easily transfer the proposed methodology to other case studies involving urban centralities different from railway stations (e.g., metro terminals, hospitals, malls, etc.), or to other small, medium, and large urban areas. The Milano Rogoredo railway station case study has been presented as a supportive example of the potentialities of the methodology. The tool, however, presents some limitations that can be a field of further research and developments. One aspect is related to the availability of data concerning urban furniture and lighting, which are not always accessible or detailed and that could therefore be estimated using computer-based techniques. Another aspect that has not been considered into the model is the impact of climate conditions, especially for those contexts where extreme weather is present (e.g., cities in the extreme north or in the desert). Moreover, future developments could focus on the application of a path choice model considering the walkability level as the input variable to estimate "perceived" catchment areas of urban nodes or centralities. In addition, the impact of users' psychosocial characteristics on the perception of urban environments, and consequently their path choices, is worth investigating. People, in fact, might perceive different levels of walkability, depending on their profile (e.g., gender, age, attendance at the station and therefore the knowledge of the place) or on other factors; for instance, those influencing their perceived level of safety (e.g., presence of safety cameras or the hour of the day). Additional investigations can be performed in this sense by segmenting and analysing the collected data for different groups of users: this would provide a deeper understanding of the impacts of these socio-demographic characteristics on the perception of walkable paths.

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